National Seminar on

ROLE OF MINERAL INDUSTRY in ECONOMIC DEVELOPMENT

Exploring the critical link between mineral resources & India's growth story

11th & 12th October 2025 Nagpur

:: ORGANIZED BY ::

INDIAN MINE MANGERS' ASSOCIATION, NAGPUR BRANCH

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NATIONAL SEMINAR
ROLE OF MINERAL INDUSTRY IN ECONOMIC DEVELOPMENT

11th & 12th October 2025 Nagpur

:: ORGANIZED BY ::

INDIAN MINE MANAGERS' ASSOCIATION, NAGPUR BRANCH

PROCEEDING EDITED BY

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पी० एम० प्रसाद
अध्यक्ष-सह-प्रबंध निदेशक

P. M. Prasad
Chairman-Cum-Managing Director

5 DECADES OF UNEARTHING ENERGY
(एक महारत्न कंपनी)

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(An ISO 9001:2015, ISO 14001 : 2015 & ISO 50001:2011 Certified Company)

MESSAGE

India is endowed with sizeable resources of minerals like iron ore, bauxite which is a primary source for aluminium, mica where the country is a top global producer, chromite and others like zinc, manganese. Apart from these India has abundant-coal reserves as well. India is also second largest producer of aluminium and crude steel. Minerals play a crucial role in the economic development of the country by providing essential raw materials that drive up manufacturing and industrial growth. In FY 2022-23 India's mineral and mining sector accounted for 2% of GDP. Though in percentage terms it sound minimal in actual gross value addition it translates over Rs. 3 Lakh Crores.
India's government has been bringing about major policy reforms in the mining sector like transparent auction processes the ease of doing business attracting private investment that boosts overall economic development. India is also focusing on exploring and harnessing critical minerals that are vital the economic and environmental future. The mining sector is also a major employment oriented sector, directly and indirectly, sustaining the livelihoods of millions of people and promotes rural development through initiatives funded by mining revenues.

I am pleased to know that Indian Mine Managers Association (IMMA), Nagpur chapter is organizing a National Conference on "Economic Development - Role of Mineral Industry" (EDMI-2025) on 11 and 12 October 2025 at Nagpur. The theme is topical at a time when India's Mines Ministry is extending major policy support to develop competitive advantages under Atmanirbhar mission of the Nation.

The conference which aims to deliberate on critical issues of the mineral sector, with participation from professionals, industry leaders, experts, and corporate representatives will be of the intense interest to the mining sector and its professionals.

I congratulate IMMA, Nagpur Chapter for their efforts and endeavour in organizing this Conference and offer my Best Wishes for its success

(P M Prasad) 04/10

Ph. : (033) 2324 6611/2324 6622 ▪ Email : chairman.cil@coalindia.in ▪ Website : www.coalindia.in

Message from the Managing Director

Mr. B. Prabhakaran, Managing Director, Lloyds Metals & Energy Ltd for the souvenir:

It gives me immense pleasure to extend my greetings to the Indian Mine Manager Association (Nagpur Chapter) on the Fifth National Conference on *"Economic Development – Role of Mineral Industry" (EDMI-2025).* As the oldest professional body of mining engineers in India, the Association plays a vital role in advancing discourse on mining, steel, and resource management.

The mining and steel sectors contribute significantly to employment and account for nearly 2.5% of India's GDP. These industries have long been the backbone of our nation's progress, driving industrial growth, enabling infrastructure development, and creating livelihoods across communities.

At Lloyds Metals & Energy, our operations in Gadchiroli exemplify a transformative green revolution. Once a remote and underdeveloped district, Gadchiroli is now being reshaped through investments such as our Rs 5,000 crore Pellet Plant and Slurry Pipeline Project, which alone reduces carbon emissions by 74,000 tonnes annually. Our flagship Surjagarh Iron Ore Mine is set to become India's first certified green mine, having already reduced Green House gases by 36,000 tonnes annually through pioneering electric mining technologies, renewable energy integration, and green logistics initiatives.

Beyond industrial growth, the region has witnessed social upliftment, including new roads, educational institutions such as Lloyds Raj Vidya Niketan School, improved healthcare access, and sustainable employment opportunities for local communities.

This holistic green transformation reflects our commitment to balancing economic growth with environmental stewardship and inclusive social development. As Gadchiroli advances towards becoming Maharashtra's steel hub, I take pride in reaffirming Lloyds Metals & Energy's commitment to pioneering sustainable mining practices, driving India's industrial progress while safeguarding nature for future generations.

I sincerely thank the Indian Mine Manager Association (Nagpur Chapter) for organizing EDMI-2025 and providing a valuable platform for dialogue and exchange. I am confident that the insights and discussions shared during this conference will help strengthen the mineral industry while promoting sustainable and inclusive growth.

Warm regards,
B. Prabhakaran
Managing Director
Lloyds Metals & Energy Ltd.

पंकज कुलश्रेष्ठ
महानियंत्रक
Pankaj Kulshrestha
Controller General

भारत सरकार
GOVERNMENT OF INDIA
खान मंत्रालय
MINISTRY OF MINES
भारतीय खान ब्यूरो
INDIAN BUREAU OF MINES

Dated 08th October, 2025

MESSAGE

I am delighted to know that the Indian Mine Managers' Association, Nagpur Branch, is organizing a *National Conference on "Economic Development: Role of Mineral Industry (EDMI:2025)"* on 11–12 October, 2025, at Nagpur, with the objective of deliberating on the vital role of the mineral industry in driving India's economic growth and industrial development.

The mining and mineral sector forms the backbone of our nation's economy by supplying critical raw materials to core industries and creating avenues for employment and regional development. In the present scenario, when the country is moving towards achieving self-reliance in critical minerals, it is imperative that mineral development takes place in a sustainable and environmentally responsible manner. Adoption of innovative technologies, improved exploration strategies, and efficient regulatory mechanisms will further enhance productivity while ensuring ecological balance and social well-being.

Organizing such conferences provides a valuable platform for professionals, researchers, and industry leaders to share experiences, exchange ideas, and evolve strategies for the responsible growth of the mining sector. I am confident that the deliberations during the conference will contribute significantly towards policy formulation, technological innovation, and sustainable resource management in the country.

I extend my warm greetings and best wishes to the organizers, delegates, and participants for the grand success of the conference.

(Pankaj Kulshrestha)

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जय प्रकाश द्विवेदी
अध्यक्ष-सह-प्रबंध निदेशक
Jai Prakash Dwivedi
Chairman-cum-Managing Director

वेस्टर्न कोलफील्ड्स लिमिटेड
(भारत सरकार का मिनी रत्न - श्रेणी। उपक्रम)
WESTERN COALFIELDS LIMITED
(A Miniratna-Cat. I Government of India Undertaking)
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Message

It is indeed a matter of great delight to learn that the Indian Mine Manager Association (Nagpur Chapter), along with esteemed partners, is organizing the National Conference on the theme "**Economic Development-Role of Mineral Industry**" (EDMI-2025) on 11-12 October 2025 in Nagpur.

The mineral industry is the very foundation of industrialization and modern economic progress. From fuelling our power plants to providing essential raw materials for infrastructure, manufacturing, and technological advancements, mining plays a decisive role in shaping the nation's growth trajectory. In India's march towards becoming a developed economy, the mineral sector stands as both a pillar of strength and a catalyst for transformation.

However, the true success of this industry will be defined not merely by the volume of minerals extracted, but by the responsibility with which they are harnessed. The challenges of climate change, ecological balance, and social harmony demand that we adopt sustainable mining practices, integrate cutting-edge technologies, and ensure equitable socio-economic development in mining regions.

I am heartened to note that EDMI-2025 will feature deliberations from experts across the country, providing a rare opportunity to share best practices, innovative solutions, and policy recommendations. The conclusions drawn here will have the potential to shape the future of mining in India-one that balances economic ambition with environmental responsibility and community welfare.

Western Coalfields Limited has always believed in this philosophy - that the wealth beneath the earth must translate into wealth for the people, empowerment for the communities, and sustainability for the planet. We are committed to pioneering initiatives that ensure mining remains a driver of inclusive growth for decades to come.

I extend my heartfelt congratulations to the organizers and wish EDMI-2025 resounding success. May this conference inspire all stakeholders to work collectively towards a mining sector that is efficient, ethical, and enduring-a true enabler of Atmanirbhar Bharat.

(Jai Prakash Dwivedi)

B. Sairam
Chairman cum Managing Director

बी. साईराम
अध्यक्ष सह प्रबन्ध निदेशक

नॉर्दर्न कोलफील्ड्स लिमिटेड
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MESSAGE

It gives me immense pleasure that the Indian Mine Managers' Association, Nagpur Branch, is organizing the National Conference on "Economic Development: Role of Mineral Industry (EDMI:2025)" at Nagpur.

The mineral industry plays a pivotal role in nation-building by ensuring energy security, supplying essential raw materials, and driving industrial and infrastructural growth. As we move towards the vision of a self-reliant India, it is essential to pursue sustainable mining practices that balance economic development with environmental stewardship and community welfare.

Northern Coalfields Limited, a subsidiary of Coal India Limited, is committed to enhancing productivity through technological innovation, green initiatives, and responsible mining. We firmly believe that such forums provide valuable opportunities for stakeholders to share knowledge, deliberate on emerging challenges, and frame strategies for the inclusive and sustainable growth of the mineral sector.

I extend my best wishes for the grand success of this conference and hope that the deliberations will contribute significantly to shaping the future of the mineral industry in India.

(B Sairam)

AJIT KUMAR SAXENA
Chairman-cum-Managing Director

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MESSAGE

It is indeed a privilege to extend my greetings to all participants of the National Conference on *"Economic Development – Role of Mineral Industry (EDMI-2025)"* organized by the Indian Mine Managers' Association, Nagpur Chapter. Mining and other natural resources industries play a pivotal role in driving economic growth, generating employment, and fostering infrastructure development.

At the same time, it is our collective responsibility to ensure that mining practices are sustainable, environmentally conscious, and socially inclusive. Conferences like EDMI-2025 provide an excellent platform for knowledge exchange,. showcasing innovations, and deliberating on challenges and opportunities that lie ahead for the mineral sector.

I am confident that the presentations, case studies, and discussions during this conference will offer valuable insights to all stakeholders and contribute significantly to shaping a balanced and progressive path for the Indian mining industry. I extend my best wishes for the success of the conference and hope it sets the stage for actionable recommendations toward sustainable economic development.

(Ajit Kumar Saxena)

Uday Anant Kaole
Chairman-cum-Managing Director
Office of the CMD,MCL
At/Po: Jagruti Vihar,Burla
Sambalpur-768020(Odisha)

MCL

ମହାନଦୀ କୋଲଫିଲଡସ ଲିମିଟେଡ
महानदी कोलफील्डस लिमिटेड
Mahanadi Coalfields Limited
(A subsidiary of Coal India Limited)

MESSAGE

It gives me immense pleasure to note that the Mine Managers' Association (Nagpur Chapter) is organizing the National Conference on *"Economic Development – Role of Mineral Industry"* (EDMI-2025) on 11–12 October 2025. This significant initiative brings together experts and stakeholders from across the mining sector to deliberate on the vital role the mineral industry plays in driving India's economic progress.

The mineral industry is one of the foundational pillars of India's economic framework. Its contributions to industrial growth, infrastructure development, employment generation and energy security are vital and far-reaching.

Bringing together a distinguished gathering of industry professionals, experts, policymakers, and corporate leaders from across the country, EDMI-2025 will serve as a rich source of insights and innovative practices. The recommendations emerging from deliberations on case studies and technical papers will undoubtedly pave the way for identifying new opportunities, embracing advanced technologies and strengthening the policy framework to support responsible and productive mining.

I commend the Mine Managers' Association (Nagpur Chapter) for its continued efforts in creating such a meaningful platform for exchange and collaboration.

Wishing the event grand success.

(Uday Anant Kaole)
Chairman-cum-Managing Director

हरीश दुहन
अध्यक्ष-सह-प्रबंध निदेशक
Harish Duhan
Chairman-cum-Managing Director

साऊथ ईस्टर्न कोलफील्ड्स लिमिटेड
South Eastern Coalfields Limited
मिनी रत्न कम्पनी (कोल इंडिया लिमिटेड की अनुषंगी कम्पनी)
A Mini Ratna Company (A Subsidiary of Coal India Limited)
CIN:U10102CT1985GOI003161

It gives me immense pleasure to convey my greetings and best wishes to all delegates and participants attending the **National Conference on "Economic Development – Role of Mineral Industry (EDMI: 2025)"**, being organised by the **Indian Mine Managers' Association (IMMA), Nagpur Chapter**, on 11–12 October. This landmark event represents more than a forum for professional exchange—it is a timely catalyst for shaping the next phase of India's mineral and mining evolution, which remains fundamental to our nation's economic growth, energy security, and self-reliance.

India stands today at a defining juncture in its development journey. As one of the world's fastest-growing major economies, having crossed the **$3 trillion milestone**, the country is steadily progressing toward the vision of a **"Viksit Bharat @2047"**—a developed, resilient, and globally competitive nation. The mineral and mining sector will be central to this journey, supplying critical raw materials for infrastructure, manufacturing, power, renewable energy, and emerging technologies—thereby strengthening India's industrial and strategic self-reliance.

The mining and natural resource industries power industrialisation, infrastructure, and employment. As India aims for global manufacturing leadership, responsible mineral supply will define sustainable growth. The sector is transforming through deeper exploration, private participation, technology, and sustainability. Coal India Limited (CIL), the world's largest coal producer, leads this change via Project DigiCoal, First Mile Connectivity, and a 5 GW renewable energy program. Policy reforms like the MDO model and mine revival via revenue sharing boost efficiency and transparency. South Eastern Coalfields Limited (SECL) contributes about 24% of CIL's output, driving 11 FMC projects, Paste Fill Mining at Singhali UG, and digital innovations such as DigiCoal and ICCC—demonstrating progress toward safer, cleaner, and smarter mining.

As India advances toward energy transition and mineral self-reliance, mining must evolve into a model of sustainable, transparent, and community-driven growth. Conferences like EDMI 2025, organised by IMMA Nagpur, play an important role in fostering collaboration, policy dialogue, and knowledge exchange. The insights and recommendations emerging from this event will contribute significantly to India's long-term vision of Viksit Bharat 2047, where economic development goes hand in hand with environmental stewardship and social progress.

On behalf of **South Eastern Coalfields Limited**, I extend my warm greetings to the Indian Mine Managers' Association, Nagpur Chapter, and best wishes for the grand success of EDMI 2025. May this conference inspire innovative thinking, lasting partnerships, and a shared commitment to building a responsible, resilient, and globally competitive mineral sector that powers India's sustainable prosperity.

(Harish Duhan)

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सतीश झा
Satish Jha
अध्यक्ष-सह-प्रबंध निदेशक
Chairman-cum-Managing Director

ECL

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

Date:28.09.2025

MESSAGE

It gives me immense pleasure to extend my warm greetings to all the organizers, delegates, and participants of the ***National Conference on Economic Development – Role of Mineral Industry (EDMI:2025)*** **being held on 11–12 October 2025 at Nagpur**.

The mineral industry continues to be a cornerstone of India's economic growth, powering industrialization, infrastructure development, energy security, and employment generation. As we strive to achieve self-reliance in critical minerals and adopt sustainable mining practices, forums like this conference play a vital role in fostering dialogue, sharing innovative ideas, and shaping policies that balance economic development with environmental stewardship.

I am confident that the deliberations during this conference will inspire actionable strategies and strengthen India's position as a global leader in sustainable mineral development.

I convey my best wishes for the grand success of the Congress and Exhibition and look forward to the fruitful deliberations that will emerge from this prestigious event.

Warm regards,

Satish Jha
Chairman-cum-Managing Director
Eastern Coalfields Limited

पंजीकृत कार्यालय / Regd. Office
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मनोज कुमार अग्रवाल
अध्यक्ष-सह-प्रबंध निदेशक

Manoj Kumar Agrawal
Chairman-cum-Managing Director

बीसीसीएल BCCL
भारत कोकिंग कोल लिमिटेड
Bharat Coking Coal Limited

भारत कोकिंग कोल लिमिटेड
(कोल इंडिया लिमिटेड की एक अनुषंगी कंपनी)
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(भारत सरकार का उपक्रम / A Government of India Undertaking)

MESSAGE

It gives me immense pleasure to know that the **Indian Mine Managers Association, Nagpur Chapter, (IMMA)** is organizing the 5th National Conference on ***"Economic Development – Role of Mineral Industry (EDMI-2025)"*** on 11–12 October 2025.

The mineral industry plays a pivotal role in the economic progress of our nation by creating employment, and supporting infrastructure development. Forums like EDMI provide an excellent opportunity for industry professionals, academicians, and policymakers to exchange ideas, share innovations, and deliberate on sustainable practices for the future.

I extend my best wishes to the organizers, participants, and delegates for the grand success of this conference. I am confident that the deliberations will contribute valuable insights towards strengthening India's mineral sector and driving inclusive growth.

Dated: 03/10/2025

(Manoj Kumar Agarwal)

Azadi Ka Amrit Mahotsav

इंद्र देव नारायण
अध्यक्ष–सह–प्रबंध निदेशक
INDRA DEV NARAYAN
CHAIRMAN-CUM-MANAGING DIRECTOR

MECL

मिनरल एक्सप्लोरेशन एंड कंसल्टेंसी लिमिटेड
(पूर्व में मिनरल एक्सप्लोरेशन कार्पोरेशन लिमिटेड)
(भारत सरकार का उद्यम)
MINERAL EXPLORATION AND CONSULTANCY LTD.
Formerly Mineral Exploration Corporation Ltd.
(A Government of India Enterprise)
A MINI RATNA I CPSE
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MESSAGE FROM CMD, MECL

National Conference On Economic Development. Role Of The Mineral Industry. 11–12 October 2025

It gives me immense pleasure to convey my best wishes to the organizers and participants of the National Conference on Economic Development and the Role of the Mineral Industry, being held on 11–12 October 2025 under the aegis of the Indian Mine Managers Association, Nagpur Branch, with Mineral Exploration & Consultancy Limited (MECL) as co-organizer.

The mineral industry today stands at a transformative juncture. Globally, mineral resources are increasingly recognized as the backbone of sustainable economic growth, technological advancement, and energy transition. Recent developments such as the growing demand for critical and strategic minerals, rapid strides in green technologies, and renewed emphasis on responsible mining practices are redefining the way nations approach mineral exploration and utilization. India, with its vast geological potential, is uniquely positioned to play a leading role in this global landscape.

For us, the way forward lies in adopting a holistic approach—ensuring uninterrupted supply of raw materials for industries, generating revenue and foreign exchange, and advancing technology, while simultaneously addressing social and environmental concerns, strengthening regulatory frameworks, and exploring overseas opportunities. At the same time, emphasis on waste management, energy production from minerals, and building resilient infrastructure will directly contribute to employment generation and industrialization.

This conference provides an opportune platform to deliberate on crucial issues: What policies can best unlock India's mineral wealth? How can we integrate global best practices into our regulatory and operational frameworks? What role should technology, sustainability, and community engagement play in shaping the mineral sector of tomorrow? The discussions and outcomes here will not only guide immediate strategies but also shape the long-term roadmap of the sector in India.

I am confident that the collective wisdom of policymakers, industry leaders, professionals, and researchers gathered here will help chart a future where the mineral industry contributes even more meaningfully to India's vision of Atmanirbhar Bharat and sustainable economic development.

I wish the conference great success and fruitful deliberations.

With kind regards

Indra Dev Narayan

निलेन्दु कुमार सिंह
अध्यक्ष-सह-प्रबंध निदेशक
Nilendu Kumar Singh
Chairman-cum-Managing Director

Fuelling Sustainable Growth
CENTRAL COALFIELDS LTD.

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(भारत सरकार का एक उपक्रम)
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IMMA MESSAGE

I am delighted to learn that Indian Mine Managers' Association (IMMA) Nagpur Chapter is organizing the "National Conference on Economic Development – Role of Mineral Industry" (EDMI-2025) at Nagpur.

India is among the top countries in mineral wealth. As many as 90 distinct minerals are known to be found here, varying in geographical distribution and economic significance. India's economic growth rate highly depends on the mineral sector. Surprisingly, only 10% of India's geological potential mining blocks are explored, indicating the untapped potential of the sector.

India's mineral based industries form the backbone of its industrial infrastructure, providing essential materials for construction, manufacturing, and transportation sectors.
With their widespread presence and diverse contributions, these industries drive employment, innovation, and economic prosperity across the nation, shaping India's industrial landscape and fostering sustainable development.

I congratulate IMMA for hosting a seminar on Role of Mineral Industry in economic development of the country at a time when mineral industry is facing challenges at environment and social front.
I am confident that deliberation on critical issues by industry experts, corporate leaders and stakeholders would go a long way in fortifying Mineral Industry.

I wish (EDMI-2025) a grand success.

(NILENDU KUMAR SINGH)

मनोज कुमार
अध्यक्ष-सह-प्रबंध निदेशक
Manoj Kumar
Chairman-cum-Managing Director

सीएमपीडीआई
मिनी रत्न
cmpdi
Mini Ratna

सेन्ट्रल माईन प्लानिंग एण्ड डिजाइन इन्स्टीच्यूट लिमिटेड
(कोल इण्डिया लिमिटेड की अनुषंगी कम्पनी / भारत सरकार का एक लोक उपक्रम)
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CORPORATE IDENTITY NUMBER - U14292JH1975GOI001223

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Message

It is heartening to note that Indian Mine Managers' Association, Nagpur Branch is going to organize a national conference on "ECONOMIC DEVELOPMENT -ROLE OF MINERAL INDUSTRY {EDMI:2025}" at Nagpur during 11th to 12th October, 2025. The publication of a souvenir on the eve of the conference is inspiring and praiseworthy.

The mineral industry is a fundamental driver of economic development, providing the raw materials essential for manufacturing, infrastructure, energy production, and advanced technologies. By supporting industrialization and facilitating global trade, the sector significantly contributes to national GDP and employment. When managed effectively, mineral resources, combined with innovation, education, and sound policies, can transform natural wealth into sustained economic growth.

In India, the mineral sector holds immense potential to advance energy security, industrialization, and sustainable development. It generates employment both directly in mines and indirectly in areas such as transportation, equipment maintenance, and construction. Revenue from taxes and royalties further enables the government to invest in roads, schools, hospitals, electricity, and other essential services, thereby benefiting society at large.

Beyond economic gains, mining can stimulate development in remote and underdeveloped regions by improving access to critical services. Responsible management of mineral resources, along with environmental protection and community welfare, can foster inclusive growth, modernization, and an improved quality of life for citizens.

I congratulate the Indian Mine Managers' Association, Nagpur Branch, for their commendable efforts in organizing this national conference and wish the conference a grand success.

(Manoj Kumar)
Chairman-cum-Managing Director

International Year of Cooperatives 2025
Cooperatives Build a Better World

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Achyut Ghatak
Director (Technical)
Coal India Limited

Message

It is a matter of great pride and privilege to extend my warm greetings to the Indian Mine Managers' Association (IMMA), Nagpur Chapter, on the occasion of its National Conference on *"Economic Development – Role of Mining Industry"* being held on 11–12 October, 2025 at Nagpur.

This conference provides an excellent platform for professionals from Mining, Academia, R&D, and Allied Sectors to engage in meaningful dialogue on the critical role mining plays in fostering economic development. As the backbone of the nation's industrial progress, the mining industry not only fuels our energy and infrastructure needs but also contributes significantly to employment and regional development.

Coal India Limited has always believed in nurturing professional excellence, promoting innovation, and encouraging responsible mining practices. Initiatives like these by IMMA help bring together thought leaders and stakeholders to deliberate on challenges, share best practices, and chart a sustainable path forward for the industry.

I extend my best wishes for the grand success of the conference and commend IMMA Nagpur Chapter for their continuous efforts in upholding professional standards and contributing positively to the growth of the mining fraternity.

(Achyut Ghatak)

डॉ. हेमंत शरद पांडे
निदेशक (मानव संसाधन)
Dr. Hemant Sharad Pande
Director (Human Resources)

5 DECADES OF UNEARTHING ENERGY

वेस्टर्न कोलफील्ड्स लिमिटेड
(भारत सरकार का मिनी रत्न–श्रेणी-I उपक्रम)
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कोल इस्टेट, सिविल लाइन्स, नागपुर (महाराष्ट्र) – ४४०००१
Coal Estate, Civil Lines, Nagpur, (M.S.) - 440001

MESSAGE

I am pleased to note that the Indian Mine Managers' Association is organizing the National Conference on "Economic Development – Role of Mineral Industry" (EDMI-2025) on 11–12 October, 2025. The subject is highly relevant as the mineral industry continues to be a key driver of India's economic progress, generating employment and resources, while also addressing environmental and social challenges.

At Western Coalfields Limited, we take pride in our role as a significant contributor to the nation's growth. Over the past year, WCL has provided thousands of direct and indirect employment opportunities, supporting local communities and enhancing livelihoods. Our contribution to the national exchequer through taxes and dividends has been substantial, reflecting our responsibility as a public sector enterprise committed to strengthening the economy.

Equally important is our focus on Corporate Social Responsibility (CSR). WCL has spent considerable funds on developmental activities such as supporting schools, building roads and bridges and improving healthcare services in mining-affected areas. These initiatives have positively impacted the lives of thousands of people and show our commitment to inclusive growth.

Alongside, we have launched forward-looking initiatives like "TARASH" to nurture young talents from economic weaker sections and "SANDEEP" for structured training in the field of military and paramilitary forces. These programs are preparing a future-ready youth and creating culture aligned with emerging needs of the Nation.

I am confident that IMMA will generate valuable insights and recommendations for balancing economic development with sustainability. I extend my best wishes for the grand success of this conference.

(Dr. Hemant Sharad Pande)

MESSAGE

It gives me immense pleasure to extend my warm greetings to all distinguished delegates, industry experts, academicians, and participants attending the **National Conference on Economic Development – Role of Mineral Industry (EDMI: 2025)**.

The mineral industry has always been a cornerstone of India's economic framework, contributing significantly to industrial growth, employment generation, and infrastructure development. In today's dynamic global economy, the sector's role in fostering **sustainable, inclusive, and innovation-driven growth** has become even more critical than ever.

Western Coalfields Limited (WCL), a leading subsidiary of Coal India Limited, has been at the forefront of the nation's energy sector not only through consistent coal production but also by exploring opportunities in **critical and strategic minerals** vital for India's energy transition and industrial self-reliance.

This conference serves as an invaluable platform for sharing ideas, addressing emerging challenges, and exploring innovative pathways for responsible and efficient utilization of mineral resources. Such collaborative deliberations are key to building a resilient, sustainable and self-reliant mining ecosystem.

On behalf of **Western Coalfields Limited**, I extend my best wishes for the grand success of **EDMI: 2025**. I am confident that the insights and recommendations emerging from this forum will contribute meaningfully to shaping the future of India's mineral industry and strengthening role in driving the nation's economic progress.

(Anandji Prasad)
Director (Technical), WCL

Date:08.10.2025

बिक्रम घोष
निदेशक (वित्त)
Bikram Ghosh
Director (Finance)

वेस्टर्नकोलफ़ील्ड्सलिमिटेड
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MESSAGE

The mining sector forms the backbone of many industries and is a vital contributor to India's GDP and employment generation. Yet, the economic role of mining is not confined merely to extraction, it extends to efficient resource management, cost optimization, financial discipline and transparent governance. The true impact of the mineral industry lies in how effectively resources are utilized to generate long-term socio-economic value.

In this backdrop, the forthcoming National Conference on "Economic Development - Role of Mineral Industry (EDMI-2025)", being organized by the Indian Mine Manager Association (Nagpur Chapter & others), holds immense significance. The focus on presenting more than 20, case studies will provide participants with real-world experiences and practical solutions to address sectoral challenges. Such deliberations will also help in creating a roadmap that ensures financial sustainability while fostering innovation and growth.

In today's scenario, mining enterprises are expected to operate with greater accountability, efficiency and transparency. This not only helps in reducing costs and maximizing productivity but also builds stakeholder trust, which is essential for long-term financial health. The discussions at this conference are expected to highlight best practices in areas like technology adoption, corporate governance and risk management, all of which are directly linked to financial performance and national development.

I am confident that the conference will serve as a valuable platform for all stakeholders to exchange ideas, identify opportunities, and commit towards responsible and economically sound mining practices.

Director (Finance)
Western Coalfields Limited

अजय मधुकर म्हेत्रे (भा.दु.से.)
मुख्य सतर्कता अधिकारी

AJAY MADHUKAR MHETRE, ITS
Chief Vigilance Officer

सत्यमेव जयते

मुख्य सतर्कता अधिकारी कार्यालय
वेस्टर्न कोलफील्ड्स लिमिटेड
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Message

The mineral industry plays a crucial role in driving the economic development of our nation. However, it is equally important to recognize that this growth must rest on the pillars of transparency, ethics, and accountability. The integrity of processes, vigilance in operations and adherence to fair practices ensure that the benefits of mining extend to all stakeholders in a just and sustainable manner.

I am pleased to learn that the *Indian Mine Manager Association (Nagpur Chapter & others)* is organizing the **National Conference on "Economic Development – Role of Mineral Industry (EDMI-2025)"**. The conference provides a timely platform to deliberate on how the mining sector can contribute to national development while maintaining the highest standards of governance.

The presentation of case studies will bring forth valuable perspectives on integrating vigilance with business practices, ensuring ethical compliance and reducing vulnerabilities to malpractices. A vigilant approach not only safeguards organizational resources but also strengthens public confidence in the sector. By aligning efficiency with integrity, the mineral industry can set benchmarks for responsible growth.

I strongly believe that such initiatives inspire industry leaders, professionals and policymakers to adopt a holistic view of development, where economic progress is matched with ethical conduct. It is only through sustained vigilance and moral responsibility that mining can continue to remain a true enabler of India's growth story.

I extend my best wishes to the organizers, speakers, and participants for the success of this conference.

Chief Vigilance Officer
Western Coalfields Limited

Editorial

The ***National Conference on *Economic Development: Role of Mineral Industry*** underscores a timeless truth — the strength of a nation's economy is deeply rooted in the strategic and sustainable development of its mineral wealth. This conference brings together an enthusiastic cross-section of stakeholders from coal, non-coal, and metal mining sectors, resulting in the presentation of nearly twenty insightful papers. Collectively, these contributions form a valuable repository of ideas that illuminate the path forward for India's mining sector and its expanding role in national economic growth.

Aligned with the conference themes — *Supplying Raw Materials, Generating Revenue and Foreign Exchange, Technological Advancement, Addressing Social and Environmental Concerns, Mineral Exploration Policy, Energy Production, Driving Industrialization, Employment Generation, Infrastructure Development, Regulatory Framework, Overseas Mining and Waste Management* — the discussions reaffirm that the mineral industry's contribution extends far beyond the extraction of raw materials. It serves as a catalyst for industrialization, providing essential inputs such as coal for energy, iron ore for steel, copper for infrastructure, and critical minerals vital for the green energy transition.

A central and recurring theme emerging from the deliberations is the imperative to move from raw material exportation toward domestic *value addition*. Strengthening downstream industries will enable the nation to capture a greater share of the global value chain, foster high-skill employment, and enhance industrial self-reliance. Papers on mineral governance and beneficiation present actionable policy pathways to achieve this transformation.

Equally emphasized is the need to harmonize economic potential with *environmental stewardship and social responsibility*. Sustainable mining is not a burden but a prerequisite for long-term prosperity. Best practices in environmental management, efficient water and energy use, carbon reduction, and robust mine closure and reclamation planning must define the future of mining. Moreover, building genuine partnerships with local communities through transparent revenue sharing, social investment, and participatory dialogue is essential to ensure that mineral development translates into shared prosperity.

The papers also highlight the importance of a *stable, transparent, and predictable regulatory framework* that balances investor confidence with equitable distribution of resource wealth. Collaborative engagement among government, industry, academia, and research institutions is vital for streamlining approvals, enhancing compliance, and accelerating project implementation.

Technology stands as the great enabler of the next phase of mining growth. Adoption of automation, digitalization, and advanced exploration methods can unlock hidden resources while improving safety, efficiency, and environmental performance. The mineral industry must lead this technological transformation as part of the nation's broader industrial evolution.

This conference is not merely an academic exercise — it is a declaration of intent. The proceedings now serve as a strategic roadmap for converting India's subterranean wealth into sustainable national prosperity. The collective challenge before policymakers, investors, engineers, and communities is to translate these insights into tangible action. Through vision, responsibility, and innovation, the mineral industry can and must power inclusive, resilient, and enduring economic growth.

The time for decisive action is now — the wealth beneath our feet awaits responsible harvest.

Dr. A.K. Raina
Prof. Manoj Tiwari

Technical Papers

Impact of Blast-Induced Ground Vibrations in Open-Pit Mines on Slope Stability – A Case Study

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1. Introduction

Blasting is widely recognized as one of the most effective and economical techniques for rock fragmentation and excavation in open-pit mining operations [1, 2]. However, only approximately one-third of the explosive energy contributes to rock breakage, while the remaining energy is wasted in undesirable effects such as blast-induced ground vibration, backbreak, flyrock, noise, and airblast [3, 4]. Among these, blast-induced ground vibration is particularly hazardous due to its potential to compromise the structural integrity of nearby infrastructure through ground wave-induced vibrations [5]. The most used parameter for quantifying blast-induced vibration is the peak particle velocity (PPV or v_{max}), used to define permissible vibration limits based on the resonance characteristics of nearby structures and materials [6].

To control blast-induced vibration, it is essential to determine the maximum charge per delay, typically by conducting a series of blasts and applying scaled distance equations. PPV is directly influenced by the maximum charge per delay and inversely related to the distance between the blast site and the monitoring point [7]. Ultimately, the goal of blast induced ground vibration assessment is to evaluate its impact on slope stability and nearby structures, thereby ensuring operational safety. This assessment depends on site-specific conditions, including the proximity of critical infrastructure. Open-pit slope stability is influenced by several factors such as the number of blast holes, hole diameter and depth, burden, spacing, explosive type and quantity, initiation pattern, delay timing, and the mechanical properties of the rock mass. While many studies have drawn parallels between blast vibrations and earthquake-induced seismic waves, it is important to note that blasting events are short lived yet repetitive, making their cumulative impact on slope stability significant [8,9].

The repetitive nature of production blasting exposes slopes to recurring dynamic loads, which must not be overlooked. Seismic or dynamic loading is a major contributor to slope instability and remains one of the most challenging issues in deep open-pit mining. There is ongoing debate among researchers regarding the most reliable methods for assessing slope stability under such dynamic conditions [10]. Ignoring these effects can result in inaccurate evaluations and potential slope failures. Therefore, the proper evaluation and monitoring of blast-induced ground vibrations are crucial to maintaining slope stability and reducing the risk of accidents [11]. Addressing these concerns is essential for the safe and efficient operation of open-pit mines. To assess the impact of blasting vibrations on slope stability, numerous studies have aimed to measure and mitigate the effects of these vibrations on rock slopes [12, 13]. Bazzi et al. [14] used a dynamic finite element method to analyze the effect of blasting vibrations on a faulted mine by evaluating acceleration-time waveforms.

Key input variables such as *S, B,* l_s, and maximum charge per delay (Q_{max}) were examined to evaluate both linear and non-linear relationships with FoS of slope stability. This approach through correlation allowed for a robust statistical interpretation of how different blasting parameters affect the geotechnical response of pit slopes. In addition, a sensitivity analysis was carried out to assess the effects of dynamic loading, specifically, blast-induced ground vibrations on slope stability by systematically varying the v_{max} and its corresponding horizontal seismic coefficient (k_h). The analysis aimed to determine the cumulative distribution of slope failure and dynamic response frequency associated with increasing seismic load intensities. The primary objective was to identify how varying levels of ground motion influence failure probability and potential instability. Overall, this study contributes to sustainable blasting practices by providing a field-based framework for assessing vibration-induced slope instability. It also highlights critical vibration thresholds that may compromise slope stability, thereby informing safer, more resilient, and sustainable mine operation.

2. Materials and Methods

2.1. Blast-Induced Ground Vibration Monitoring Data

To meet the stated objective, a field study was conducted in ACC limestone mine (Figure 1a). This captive mine with mechanized surface mining, uses deep hole drilling & blasting for ore excavation. Controlled blasting is done by non-electric-shock tube initiation (*NeSt*) system. Benching method is adopted with back hoe shovel (1.2 m^3) and tipper (20 T/30 T) combination. Presently the Mine operates with 5 benches (Figure 1b), i.e. (one OB/reject bench and 4 limestone benches). During the period of field investigations, a total of fourteen experimental blasts were conducted using site mix emulsion (SME).

Figure 1: (a) Location of the mine; (b) benches of the mine

Key blasting geometry parameters, including blast point location, blast hole diameter (mm), blast hole depth (mm), spacing (m), burden (m), stemming length (m), maximum charge per delay (kg), and distance from the blast point (m), were recorded. The average values of these parameters are presented in Table 1. Ground vibration data were measured in terms of PPV, frequency, duration, and vibration velocity. PPV values, initially recorded in mm/sec, were converted to m/sec using standard conversion formulas for simulation. All parameters for each blast event were compiled into a structured dataset for subsequent analysis. Additional slope-specific geotechnical parameters, such as volumetric weight, elastic modulus, Poisson's ratio, cohesion, and internal friction angle, were obtained from the technical department.

Table 1. Blasting geometry parameters used in this study.

Table 2. Summary statistics for pit slope blasts.

Parameter	Value
Blast Hole Diameter (mm)	115
Blast Hole Depth (m)	6.5-8.5
Spacing (m)	3.0-3.7
Burden (m)	2.5- 3.0
Stemming (m)	2.5- 3.0
Max. Charge per Delay (kg)	32.6- 51.44
Distance from Blasting Point (m)	109-229

Parameter	Pit slope
PPV (m/s)	0.0148
Frequency (Hz)	9.43
Acceleration (m/s^2)	0.87
k_h	0.08
k_v	0.05

The curve fit of v_{max} (in terms of peak vector sum) vs. distance from the blast site is shown in (2a) and distribution of the dominant frequency (2b).

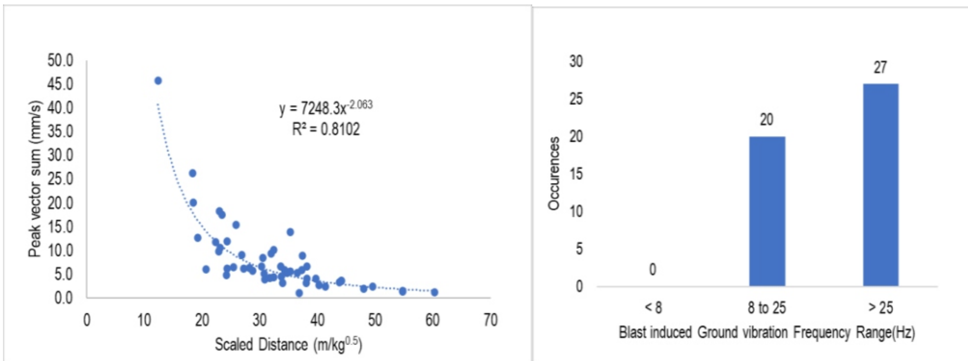


Figure 2. (a) Linear fit of PPV vs. distance from the blast site, (b) Frequency distribution of the dominant frequency

2.2. Slope Geometry and Material Assignment

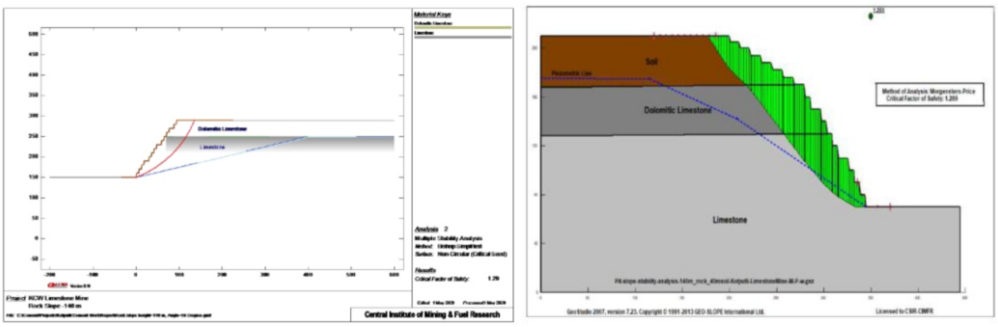


Figure 3. Geological profile of the layered formations along the slope (b) stability analysis of pit slope considering only rock slope and soil

Stability analysis was performed through Bishop Simplified and Morganstern-Price methods using the Slope Stability Analysis Software(s), GALENA (V 6.1) and 'SLIDE-6.0' respectively. These software(s) work on limit equilibrium method of analysis to determine the factor of safety (FoS). The FoS is defined as the ratio of resisting strength to the driving stress. The stability analysis has been performed considering non-circular and circular failure surfaces. The unit weight, cohesion and friction angle of slope forming rock masses were considered in the ranges of 26 - 28 kN/m^3, 200 - 250 kPa and 30^0 - 35^0 respectively. The unit weight, cohesion, and friction angle in respect of soil were considered in the ranges of 15 –

18 kN/m^3, 20 - 30 KPa and 15^0 - 20^0 respectively. The stability analyses were conducted considering fully drained conditions and a phreatic surface due to ground water. Typical outputs of stability analysis of pit slope considering only rock slope and soil & rock slope are shown in Fig. 3.

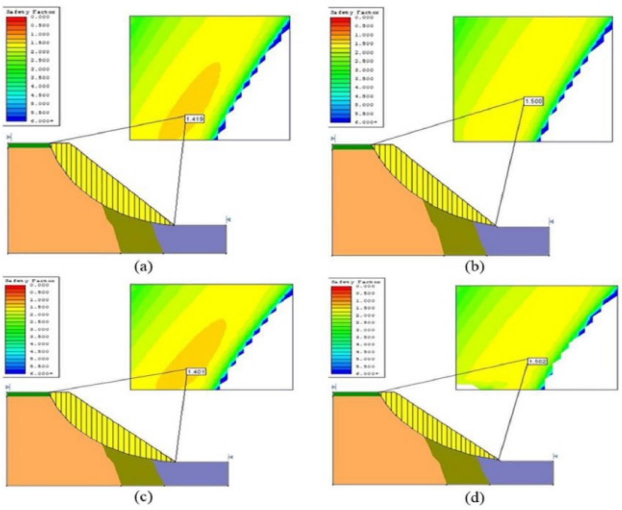
3. Results and Discussion

3.1. Slope Stability under Static Conditions

A static slope stability analysis was performed to assess the inherent stability of the pit slopes in the absence of external dynamic loading. Four classical LEM methods including Fellenius, Bishop Simplified, Janbu Simplified, and Spencer were employed to evaluate both slope profiles. The analysis utilized the average values of mechanical properties corresponding to the respective rock masses as input parameters.

For the pit slope, the lowest FoS was obtained using the Janbu method, which yielded a value of 1.401. The highest FoS was recorded using the Spencer method, with a value of 1.502. The Fellenius and Bishop methods produced closely aligned FoS values of 1.419 and 1.500, respectively, indicating minimal variation across methods as illustrated in Figure 4.

Table 3. Comparison of FoS values under static and dynamic loading conditions for pit slope using four LEM approaches



Methods	FoS (Static)	FoS (Dynamic)
Fellenius	1.419	1.225
Bishop	1.500	1.302
Janbu	1.401	1.198
Spencer	1.502	1.308

Figure 4. FoS for the west slope under static conditions: (a) the Fellenius method, (b) the Bishop method, (c) the Janbu method, and (d) the Spencer method.

3.2. Slope Stability under Dynamic (Seismic) Load Condition

To evaluate the impact of blast-induced ground vibrations on slope stability, a pseudo-static slope stability analysis was performed using the LEM based on the Mohr–Coulomb failure criterion. In this approach, horizontal seismic coefficients (k_h) were calculated from field-monitored ground vibration data, specifically v_{max} and vibration frequency. These coefficients represent the equivalent horizontal acceleration acting on the slope during blasting events. The seismic coefficient (k_h) was derived using the relation ($k_h = a/g$), where a is the acceleration computed from v_{max} and frequency, and $g = 9.8$ m/s^2 is the gravitational constant. The corresponding vertical seismic coefficient (k_v) was assumed as half the horizontal component, following standard pseudo-static design practices: ($k_v = 0.5\ k_h$). A summary of the dynamic input parameters for the slopes, along with the corresponding seismic coefficients, is presented in Table 2.The highest seismic load observed was k_h = 0.08 recorded during the blast 1, while the lowest was k_h = 0.02 observed during the blast 5. Based on these seismic coefficients, FoS values were calculated using four LEM techniques such as Fellenius, Bishop, Janbu, and Spencer under three loading scenarios: without dynamic load, and with minimum, average, and maximum seismic loads. The computed FoS values under both static and dynamic conditions for the pit slopes are summarized in Table 3.

The observed reduction in FoS after applying dynamic loads was approximately 13-14 % for the pit slope. This demonstrates the measurable and adverse impact of blasting-induced vibrations on slope stability. The reduction values are summarized in Table 4. In conclusion, while the current blasting practices at the mine generally maintain slope stability, the west slope requires closer monitoring and control, especially during high energy blasting events. Further detailed analysis is recommended to isolate the influence of individual factors such as slope geometry, bench configuration, and blast design on vibration intensity and slope response. This will help optimize future slope designs and blasting strategies to ensure continued safety in open-pit operations. Table 4.

Table 4. Reduction in FoS due to blast-induced dynamic loading.

Slope	FoS (Static)	FoS (Dynamic)	Reduction (%)
Pit	1.419	1.225	13.7
	1.500	1.302	13.2
	1.401	1.198	14.5
	1.502	1.308	12.9

4. CONCLUSIONS

Blasting is a widely adopted and cost-effective technique for rock fragmentation and excavation in open-pit mining. However, uncontrolled, or poorly executed blasting operations can produce excessive ground vibrations, which may compromise slope stability and pose risks to nearby infrastructure, equipment, and personnel. Therefore, evaluating the impact of blast-induced ground vibrations on slope stability is essential for ensuring safe and sustainable mining operations. This study presents a comprehensive field investigation conducted at the ACC limestone mine focusing on slope performance under both static and dynamic (pseudo-static) loading conditions. The investigation incorporated detailed field data, including pit geometry, lithological characteristics, blast design parameters, and ground vibration records. Laboratory testing was conducted on rock samples to validate the geomechanical properties used in the analysis.

Slope stability was assessed using SLIDE 6.0 software, and the influence of key blasting parameters on slope behavior was quantified using both Pearson and Spearman correlation analyses. Four standard limit equilibrium methods (LEMs)—Fellenius, Bishop, Janbu, and Spencer, based on the Mohr–Coulomb failure criterion, were employed to evaluate the FoS under varying load scenarios. The key findings and recommendations derived from this analysis are summarized below:

1. All the blasting geometry parameters, including spacing, burden, stemming length, charge per delay, and distance from the blast point, were incorporated into the analysis. The average recorded ground vibration values were: PPV = 14.88 mm/s, frequency = 9.43 Hz, duration = 1.51 s, and vibration velocity = 14.29 mm/s.

2. Field investigations revealed that the pit slopes are primarily composed of moderate to strong rock types, such as dolomite and limestone. These materials exhibit moderate to high strength, contributing to overall slope stability.

3. Under static conditions, pit slopes exhibited stable behavior, with all FoS values exceeding 1.0. The pit slope showed slightly higher stability, with FoS ranging from 1.401 to 1.502, primarily due to a lower average slope angle (44° vs. 47°).

4. Under average blast-induced dynamic loading, pit slopes remained stable (FoS > 1). However, under maximum seismic loading, the pit slope remains potentially stable. The Spencer method consistently produced the highest FoS under dynamic conditions (1.308), confirming its robustness in seismic analysis. Slope angle was found to be a significant factor in stability performance. Dynamic loading resulted in a reduction in FoS by approximately 13-14. % for the pit slope, emphasizing the need for slope angle optimization in design phases

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Cautious Controlled Blasting in Hard Rock for Rock Excavation of High-Rise Building Project: Challenges and Solutions

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Abstract

Controlled blasting in hard rock environments presents significant challenges, especially when high-rise construction is to be carried out in close proximity to existing structures. The risk of excessive ground vibrations and fly rock becomes pronounced when the blasting takes place within a distance of 4-5 meters from sensitive structures. The undesirable side effects of blasting are ground vibration, noise/air overpressure, flyrock, dust and fumes etc. The annoying circumstances as a result of these impacts at many times lead to unfavourable public confrontations ad sometimes even litigations. In such scenarios, it is imperative to adopt advanced and cautious blasting techniques that ensure both safety and efficacy.

The general objective of rock breakage by blasting is to obtain desired fragmentation with minimum disturbance to surrounding environment. This objective can be understood by better understanding of rock geology and proper implementation of different blast design parameters. A proper blast design not only results in proper fragmentation but also reduces undesirable side effects. This technical paper presents a comprehensive discussion on the challenges, requirements, and best practices for controlled blasting in hard rock for high-rise building projects. Special emphasis is laid on the use of closed space line drilling and pre-split blasting as methods to reduce ground vibrations and minimize fly rock, ensuring the structural integrity and safety of adjacent properties.

1. Introduction

Urban expansion and the need for vertical development have increasingly necessitated the construction of high-rise buildings on sites with hard rock substrata. In densely populated urban environments, these construction projects often take place within a few meters of existing structures, placing stringent constraints on blasting operations. The primary objectives are to fragment hard rock efficiently for excavation while rigorously controlling the adverse effects typically associated with blasting, namely ground vibrations and fly rock.

The focus of this paper is on the nuanced application of controlled blasting when the buffer distance to adjacent structures is limited to 3-5 meters. The discussion covers the challenges that arise in such contexts and the advanced methods used to mitigate risks and meet safety standards.

2. Field experiments on controlled blasting

Mumbai is the country's fastest growing metropolitan area with infra development projects such as High speed Bullet train and underground metro rail projects. To cater need of growing population, many redevelopment projects are taking place and being replaced by high rise buildings. One of the redevelopment project is being developed by Godrej Properties in name of Godrej Bayview at Vashi, Mumbai. The proposed high rise buildings comprises of 52 stories with deep excavation up to the depth of 22.0 m in hard basaltic rock by the system of cautious controlled blasting. The sensitive and critical structures includes residential buildings, depleted structures and adjacent schools from edge of excavation line varies at the distance of 5.0 m to 15.0 m as shown in figure.1 and figure.2. The respective cautious controlled blasting techniques are used to minimise blast incused side effects during rock excavation:

- Line Drilling.
- Pre-Split Blasting.
- Use of 32 mm holes.
- Restricting charge per delay.
- Bottom hole initiation.
- Selective deck charging.
- Optimising specific charge and burden.
- Use of proper muffling system.
- Proper stemming material(2-3 mm) and stemming column.
- Adequate delay period.


Figure 1 and 2-Residential and depleted structures near excavation project.

3. Challenges of Blasting Near Structures

Blasting in hard rock close to existing high-rise buildings introduces a complex set of challenges, including but not limited to:

- Ground Vibrations: Uncontrolled vibrations can result in structural damage, from minor cracks to severe instability, particularly in older or sensitive buildings.
- Fly Rock: High-velocity rock fragments pose a direct hazard to structures, equipment, and personnel. The risk is amplified by the minimal standoff distance.
- Air Overpressure: Rapid release of energy may cause overpressure that can damage glass, façade elements, and sensitive installations.
- Regulatory Compliance: Urban sites are governed by stringent vibration and safety limits, requiring continuous monitoring and adaptive techniques.
- Public Safety and Perception: Blasting can induce fear and resistance among the public, necessitating transparent practices and robust safety records.

4. Mechanisms of Ground Vibrations and Fly Rock

When an explosive charge inside a blast hole is detonated, the explosive is converted in to a hot gases at intense pressure. A steep wave front travels in to the rock, crushing it for roughly twice the radius of the original blasthole, depending upon the resistance of rock. Many radial cracks start to form as the cavity expands. However, a few of the cracks become dominant and the others stop growing. The expanding gases continue to work on the rock, extending the cracks, and moving the rock upward and outward. This activity takes place in the zone of intended work on rock, breaking it and moving it for excavation.

The detonation of explosives in hard rock generates seismic waves, manifesting as ground vibrations. The amplitude and frequency of these vibrations depend on factors such as explosive type, charge weight per delay, rock properties, and proximity to structures. Fly rock is generated when fragments of rock are propelled beyond the intended excavation area due to excessive energy release or poor blast design.

When blasting occurs within 3-4 meters of existing structures, the energy imparted to the ground and rock mass must be meticulously controlled to avoid exceeding safe vibration thresholds and to eliminate the risk of fly rock.

5. Special Methods of Controlled Blasting

5.1 Closed Space Line Drilling

Line drilling is one of the techniques for overbreak control. In line drilling, closed spaced, small-diameter holes along the perimeter of the intended excavation line. This method serves multiple purposes:

- Creating a 'cut line' that guides the breakage along pre-determined planes.
- Reducing the concentration of explosive energy at any single point, thus lowering vibration levels.
- Minimizing the risk of overbreak and uncontrolled rock ejection.

The typical spacing of holes is 350 mm, and the diameter of holes 110 mm, depending on site conditions. The holes were left uncharged to act as stress relief planes. Line drilling was implemented adjacent to sensitive structures all along the periphery of excavation line showing half cylindrical holes after excavation in figure.3

Figure 3.Line Drilling with projections of half cylindrical holes after excavation by blasting.

Advantages:

- Excellent control over fragmentation and breakage boundaries.
- Noticeable reduction in peak particle velocity (PPV) near sensitive structures.
- Significant decrease in occurrences of fly rock.

Limitations:

- Increased drilling time and costs due to high hole density.
- Requires precision in drilling alignment and depth control.

5.2 Pre-Split Blasting

Pre-split blasting is a technique wherein a continuous row of closely spaced holes is drilled along the final excavation contour and lightly charged. The objective is to induce a controlled fracture plane ahead of the main production blast. The pre splitting was practiced at the final line of excavation/Periphery of the excavation box. It was preferred to go with small diameter 32 mm holes , as pre-split blasting is itself potential to generate excessive vibrations levels. The site specific of pre-split blast design for the prevailing rock are given in Table 1 and figure.4. The blasting technique in this project is adopted to reduce blast induced ground vibrations and high wall damage. Pre splitting produced very good results in terms of controlling overbreak, damage and ground vibrations. The presplitting charging is shown in figure. 5 respectively. In view of very good results in pre splitting, it was considered to implement this technique all through the periphery of the final excavation line.

Mechanism:

- Pre-split holes are typically spaced 0.5 m apart and charged with low-density explosives to ensure the controlled propagation of cracks.
- Once the pre-split line is established, subsequent production blasts are designed to break rock towards this pre-formed fracture, reducing movement and the tendency for blocks to eject as fly rock.

Benefits:

- Prevents excessive ground vibrations from affecting structures adjacent to the blast site.
- Provides a stable rock face with minimal damage beyond the designed excavation boundary.
- Reduces the risk of fly rock by guiding the energy and rock movement inward.

Table 1 Blast design parameters for pre –splitting

Parameter	Value /description
Diameter of holes	32 mm
Angle of holes	90 °
Spacing	0.5m
Bench Height	1.5m
Depth	2.4 m
Charge per hole	0.125kg
Initiation system	Bottom hole
Stemming column	0.5m
Hole –hole delay	17ms

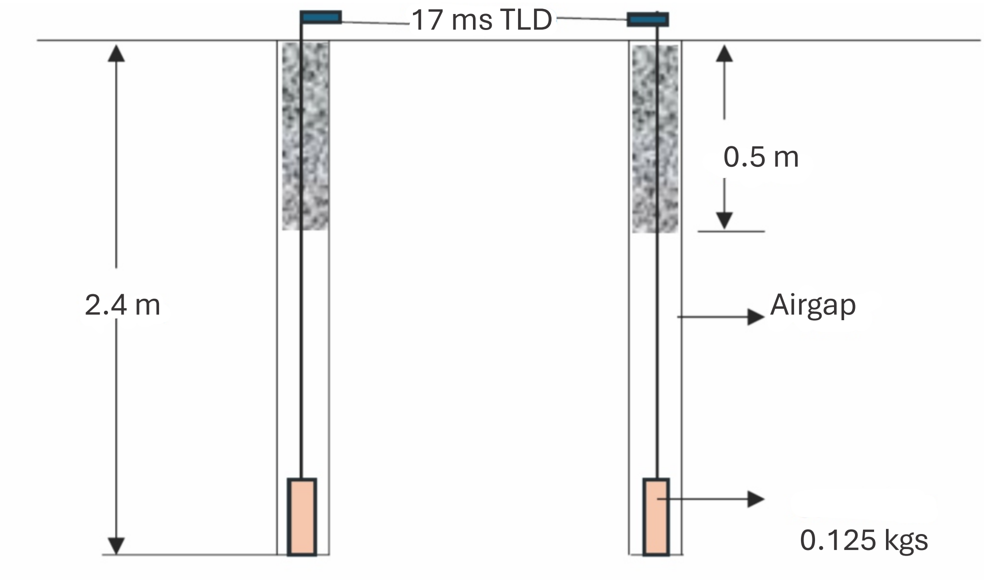

Figure 4. Pre-split blast design parameters with 32 mm jack hammer drill holes.

Figure 5. Pre-split blast charging with creation of crack holes

5.3 Fly Rock Control

To control flyrock effectively, it is important to understand the influence of various factors which may affect the maximum flyrock distance. The most significant factors are-

1. Improper Burden.
2. Powder factor.
3. Improper delays and initiation.
4. Drilling errors.
5. Stemming column height and type of stemming material.
6. Presence of water in blast holes.

Fly rock can be controlled by proper blast design and by muffling of blast .Without proper blast design, muffling will not be effective . Proper blast design and accurate implementation of the blast are the two areas of fundamental concern for controlling the fly rock . The third important parameter is understanding the local geology and adjusting the explosive charge with regard to the geological features . The reliable and effective method of controlling fly rock fragments from the mouth of the blast holes (vertical fly rock on the rear side) is the height of stemming columns . it has been observed that the fly rock particularly toward the rear side , was effectively controlled by maintaining the height of stemming column in all holes greater that the burden . The height of stemming column should be 1.2 ~ 1.5 time the effective burden in all holes . A good stemming material should retain bore hole pressure till the burden rock starts to move . Dry angular material under the effect of the impulsive gas pressure tends to form a compaction arch which locks into the wall of a blast holes , thus increases its resistance to ejection . It was observed that 2-3 mm rock cutting gives a better result in interlocking and containing gases within holes for effective blast. In watery holes, only sand free of clayey materials should be used as stemming material .

Muffling or covering of holes including entire area to be blasted is one of the most common methods to contains flying fragments particularly when blasting is done within the danger zone . for initial rounds of blasts already available guidelines by previous researchers (Jimeno et al ., 1995) were used and it was refined further for zero tolerance to fly rock . No blasting should be carried out without proper muffling as shown in figure 6.

Figure.6 Two layred muffling system used to control flyrock.

6. Production Blast Design

A free face is created using jack hammer drilling with 32 mm holes by the box cut method. After preparing the vertical bench, production blasting is performed with 32 mm diameter holes to manage vibration and fly rock. The number of holes per blast is determined by vibration limits instead of production goals; production is increased by blasting more frequently. Blast hole charge patterns and design parameters are shown in figure 7 and table 2, with hole depths ranging from 1.5 to 2.3 m based on rock conditions and vibration limits. Trial blasts are used to optimize the number of holes, charge per delay, and control measures for vibration and noise, resulting in safer and more productive operations.

Table 2 Blast design parameters

Parameter	Value /description
Diameter of holes	32mm
Angle of holes	80 °
Burden	0.7m to 1.0m
Spacing	1.0 m to 1.25m
Depth	1.5m and 2.3m
Charge per hole	0.250 kg to 0.500 kg
Specific charge	0.23~0.3kg/m3
Initiation pattern	Bottom Initiation
Initiation System	Shock tube initiation with 450 ms DTH and 17,25,42ms with TLD ,4 m long twin detonator systems
Stemming column	01.0 m to 1.5 m
No of holes per delay	1
Delay between hole-hole	17/25ms
Delay between Row- Row	42ms

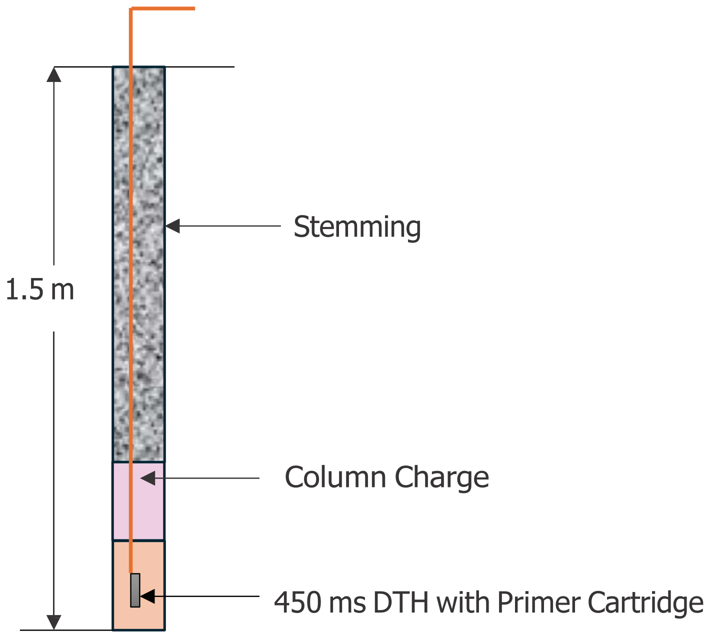

Figure 7.Blast hole charge pattern for 1.5 m depth of hole

Blast performance analysis was conducted using criteria such as degree of fragmentation, vibration intensity, and fly rock projectile. Back break and air overpressure were assessed as secondary parameters. Fragmentation was evaluated with a software tool called Wipfrag to determine the mean fragment size; all blast performance indicators are summarized in Table 3. Vibration intensity did not exceed 4 mm/s at the nearest ordinary structures, with frequencies above 25 Hz. The fragment size was suitable for the excavators used on site, facilitating excavation and disposal of muck, and the blast met safety requirements.

Tab 3 Blast Performance Indicating Parameters

Sr No	Blast performance Indicator	Value
1	Fragmentation (mean fragment size)	0.32 m
2	Vibration Intensity (PPV) At 50m	1.85 mm/s
3	Fly Rock projectile at 5 m	Nil
4	Air overpressure at 50m	118 db
5	Back Break	0~0.30 m

The uniformity index measured was 1.78 using WipFrag software, which falls within the typical range of 0.6 to 2.2 (Cunningham 1983). Lower values indicate non-uniform muck piles, while higher values mean fragments are closer to the mean size; thus, the observed value suggests good uniformity. It's important to note that when blast designs prioritise reducing ground vibration, air overpressure, and fly rock, optimal fragment size may not always be achieved, so trade-offs must be considered.

7.Conclusion

Construction activities for High rise buildings projects involving blasting present significant challenges within urban environments. A comprehensive suite of controlled blasting techniques was employed to minimise adverse effects during rock excavation at the Godrej Bayview, Vashi excavations project. Controlled blasts were designed and executed successfully, ensuring that environmental impacts were effectively constrained. Strategies such as line drilling and pre-splitting were utilised to control issues including back break, fly rock, ground vibration, and air overpressure, all maintained within prescribed limits.

Site-specific ground vibration studies, structural assessments, and regulatory guidelines informed the establishment of permissible vibration thresholds: less than 5 mm/s for standard structures. The use of heavy rubber blasting mats successfully confined fly rock within a 5-metre radius. Additional controls included limiting blast hole diameter to 32 mm, maintaining a specific charge between 0.23 and 0.3 kg/m^3, and restricting bench heights to 1.5–2.3 m. Production rates frequently surpassed the target range of 200-300 m^3 per day. Vibration intensity consistently remained below 4 mm/s near ordinary structures.

8 Acknowledgements

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FROM WASTE TO RESOURCE: IRON ORE TAILINGS AS A SUSTAINABLE GEOMATERIAL FOR EARTH RETAINING STRUCTURES

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Abstract

The global mining industry, while foundational to modern infrastructure, produces immense volumes of solid waste, with Iron Ore Tailings (IOTs) representing one of the largest waste streams. Historically, these tailings have been managed as a disposal problem, stored in large, conventional slurry impoundments. However, catastrophic failures of these Tailings Storage Facilities (TSFs), such as the disasters in Mariana and Brumadinho, Brazil, have exposed this approach as environmentally and socially unsustainable, prompting a paradigm shift in the industry. This shift necessitates a move from perpetual containment of IOTs as hazardous waste to their recognition as a valuable secondary resource. This research provides a comprehensive review of the technical basis for utilizing IOTs as a primary geomaterial for the construction of safe, economical, and sustainable retaining structures.

The sheer scale of IOTs generation, estimated to exceed 1.4 billion metric tons/Year globally, demands high-volume valorisation solutions, with large-scale geotechnical applications being a top priority. A comparative analysis of geotechnical properties reveals that IOTs often possess superior characteristics to conventional quarried aggregates, making them an ideal candidate for engineered applications. For example, IOTs have a higher specific gravity (2.9–4.7) and friction angle (31°–42°) compared to sand (2.65–2.70 and 30°–34°, respectively).
While un-stabilized IOTs can be used for structural fills due to their high friction angle and density, their low permeability and susceptibility to liquefaction often require stabilization. The study explores various stabilization techniques, from traditional binders like cement to innovative alkali-activated binders and polymers, highlighting that the optimal choice depends on project-specific goals. The application of IOTs in earth retaining structures, including embankments, Mechanically Stabilized Earth (MSE) walls, and even pavements, demonstrates their potential as a versatile, high-performance construction material. This paper also emphasizes on recent findings to support the transition of IOTs from a significant liability to a critical asset in the pursuit of a more sustainable and safer mining and construction industry.

Keywords: *Iron Ore Tailings (IOTs), Tailings Storage Facilities (TSFs), Geomaterials, Earth Retaining Structures, Stabilization, Slope Stability*

Stability Enhancement of Dump Slopes using High Strength Paralink & Macdrain composite Materials

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Introduction

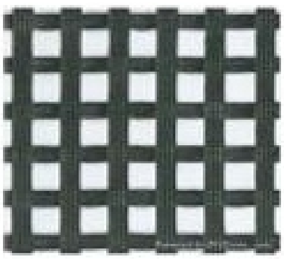
The stability of an overburden dump slope is a major concern for safe and smooth mining operations. The implementation of High Strength Paralink in a dump slope can enhance the factor of safety and help in preventing slope movement.

High Strength Paralink is used in contact with soil, earth, rock or other materials in geotechnical and civil engineering applications, as an integral part of a human-made structure, or system (ASTM D4439). The High Strength Paralink is made made from synthetic polymers such as polypropylene, polyester, polyethylene, polyamide, PVC etc. in the form of rolls. These materials are highly resistant to biological and chemical degradation.

The application of High Strength Paralink is vast as they are used for separation, filtration, reinforcement, protection, waterproofing, erosion control, drainage etc. The most used High Strength Paralink are geo-composite drainage, High Strength Paralinks, geotextile and geomembranes.

High Strength Paralinks

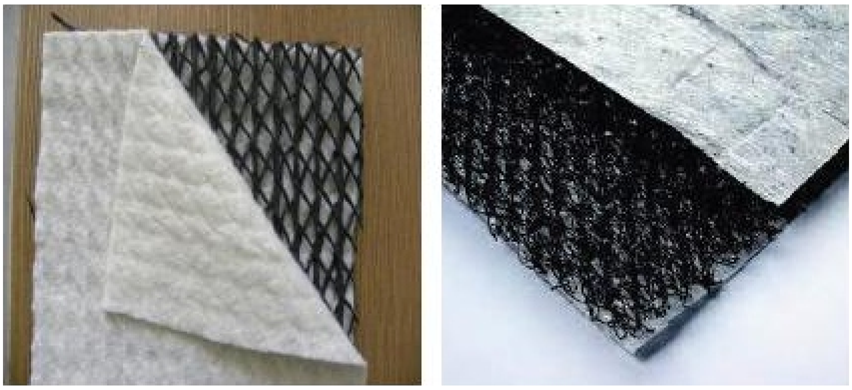
High Strength Paralinks are planar, polymeric structure consisting of a regular open network of integrally connected, tensile elements, which may be linked by bonding, or interlooping or interlacing, whose openings are larger than the constituents. It has a grid-like configuration that has a large aperture between individual ribs. The main function of High Strength Paralink is to provide reinforcement to the pavements, soil slopes, overburden dumps and retaining walls.



High Strength Paralink

MacDrain Composite drainage system

MacDrain composite drains, consists of a geonet bonded with Mactextile layer (s) on one or both sides, are used for drainage in both horizontal & vertical directions / situations.



Typical MacDrain Composite Drain System

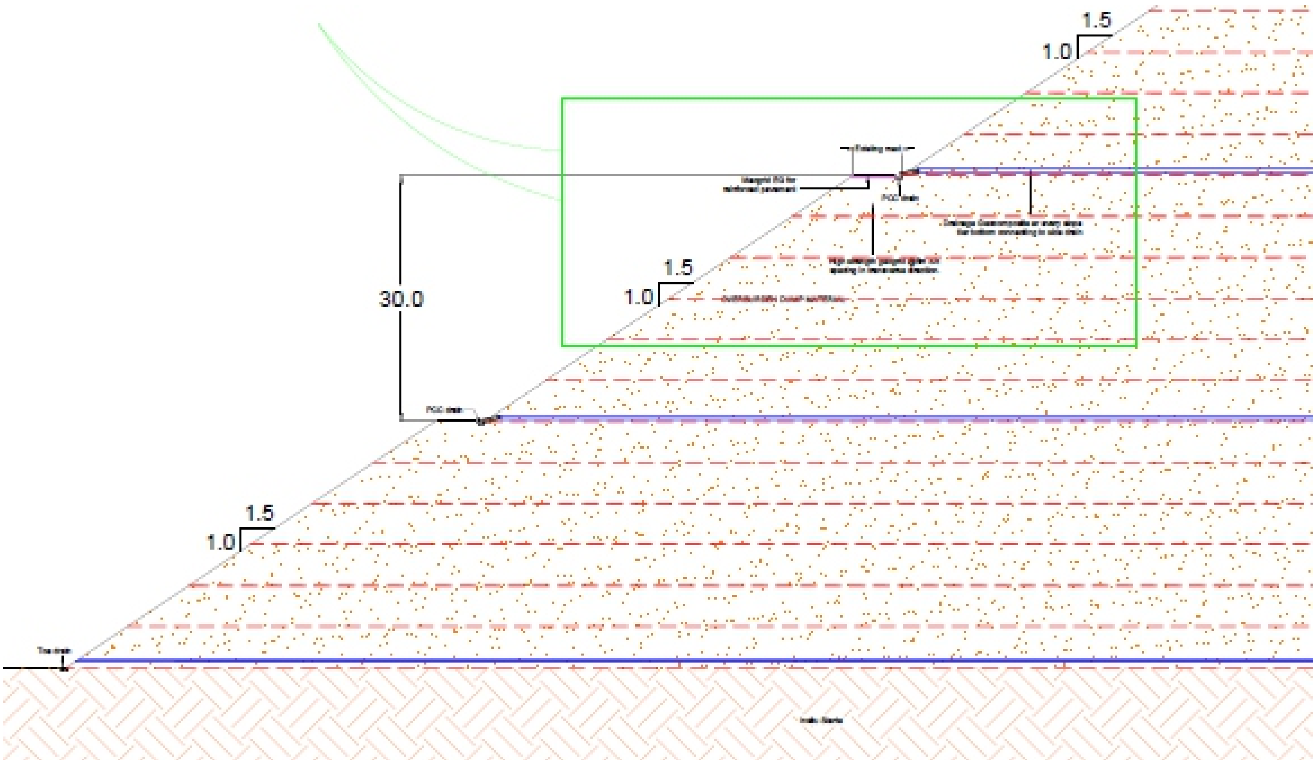
Mechanism of Stress Distribution

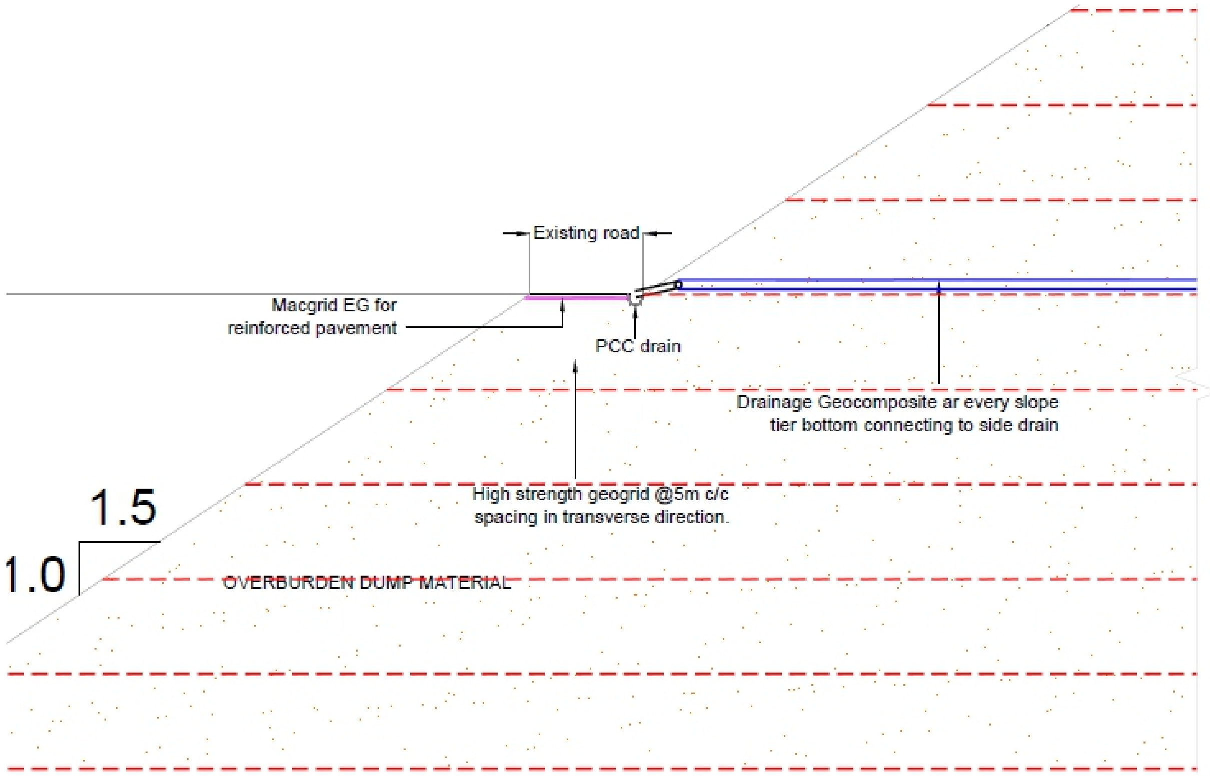
The outward movement reinforced soil mass can be restricted by placing the High Strength Paralinks layers horizontally within a dump slope. The High Strength Paralink strips interact with the dump mass by adding a tensile force and this tensile force is transferred to the dump mass through High Strength Paralink–soil interaction mechanisms. The interaction between High Strength Paralinks and soil depends on the particle size distribution of dump material and aperture size of High Strength Paralinks.

High Strength Paralinks have large apertures that allow the soil or dump material to be continuous through the inclusion. The stresses are transferred to the soil through passive soil resistance on transverse members of the grid. However, in textiles, the stresses are transferred through the friction created across its entire surface area (Montanelli 2008). The friction between High Strength Paralink and dump particles plays a crucial role as the dump particles trap between the High Strength Paralink apertures.

Therefore, slope movement is prevented, as the High Strength Paralinks come in tension during slope failure. A suitable High Strength Paralink is selected based on its strength and aperture size that depends on the particle size distribution of dump material. The dump particles trapped into the High Strength Paralink aperture thus increase the interface properties between High Strength Paralink and overburden dump, which increases the stability of dump slopes.

Sketch Representation showing Use of High Strength Paralinks for Dump Stability :-





Use of High Strength Paralink in Other Major Infrastructure Sectors in India

Even New Technical codes for using High Strength Paralink for different applications in Railways & Road Projects have already been published and such Technologies along-with proper design (using below mentioned Indian Standards/codes & International Indian Standards/codes) are already being used in many significant Railways & Road Projects. Here are the snapshots of :-

- RDSO 2020 / GE : IRS 0004 – Comprehensive Guidelines and Specifications for Railway Formation.
- IRC SP:59 – 2019 – Guidelines for Use of High Strength Paralink in Road Pavements & Associated Works.

Stability of Overburden Dump Slopes in Surface Coal Mining: Mechanisms, Assessment Methods, and Mitigation Strategies

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Abstract
Overburden (OB) dump slopes are indispensable in open-cast coal mining operations, yet their stability remains one of the most pressing geotechnical and environmental concerns. Slope failures in dumps can lead to catastrophic economic losses, human casualties, and environmental degradation. This paper reviews the mechanisms of dump slope instability, summarizes global failure cases, and examines state-of-the-art methods for stability analysis, including limit equilibrium, finite element, finite difference, and probabilistic approaches. It further explores the influence of rainfall, particle size, dilatancy, shear strength parameters, testing scale effects, vegetation, and geotextiles on slope performance. Case histories and laboratory investigations highlight the significance of both natural and engineered stabilization measures. The paper concludes by identifying research gaps and emphasizing the need for integrated monitoring and numerical modeling approaches for dump slope risk management.

Keywords: overburden dumps; slope stability; limit equilibrium method; finite element method; rainfall; dilatancy; shear strength; vegetation; geotextiles.

1. Introduction

Surface mining generates vast quantities of overburden material, which is typically stored in external or internal dump slopes adjacent to active pits. The stability of these dumps is influenced by factors such as slope geometry, material properties, rainfall infiltration, and construction methods (Poulsen et al. 2014; Geete et al. 2023). Numerous dump slope failures have been reported globally, underscoring the geotechnical and environmental risks associated with these man-made structures (Shende et al. 2025; Upadhyay, Sharma, and Singh 1990).

Research into OB dump stability spans traditional limit equilibrium methods (Bishop 1955; Morgenstern and Price 1965) to advanced numerical modeling approaches such as FEM, DEM, and probabilistic simulations (Koner and Chakravarty 2010; Nguyen and Vu 2017). At the same time, site-specific influences such as rainfall (Sahu, Mohanty, and Dash 2022), particle size (Wang, Xu, and Li 2019), dilatancy (Das and Migliaccio 2009), and vegetation (Zhang, Li, and Wang 2021) are being increasingly recognized.

This paper reviews the mechanisms of dump slope failure, presents notable case studies, compares analytical and numerical approaches, and evaluates material and environmental factors affecting stability.

2. Mechanisms of Overburden Dump Failure

Failure in OB dumps can manifest as rotational slips, translational slides, or progressive deformations driven by both internal and external factors (Rajhans, Behera, and Pradhan 2022).

Heterogeneity of dumped material, loose placement, and inadequate compaction significantly reduce shear strength (Koner and Chakravarty 2015; Sreekanth and Prasad 2016).

Foundation weakness is also critical: failures are often initiated at the dump-foundation interface, particularly when the foundation comprises weathered shale or clay (Chen et al. 2024). Rainfall infiltration exacerbates this by raising pore water pressures and triggering loss of suction in unsaturated zones (Leung and Smith 2006).

Progressive failures linked to residual shear strength mobilization have been documented in large external dumps (Sjoblom and Islam 2015). The combined effect of geometry, material variability, and external triggers highlights the need for site-specific stability assessments (Poulsen et al. 2013; Fernando and Nag 2003).

3. Case Histories of Overburden Dump Failures

Several high-profile failures illustrate the risks associated with OB dumps:

a) In India, slope collapses have been attributed to steep dump angles, weak foundations, and monsoon infiltration (Geete et al. 2023; Rajak et al. 2018).
b) Australian case studies highlight rotational failures in Latrobe Valley due to hydrogeological influences (Fernando and Nag 2003).
c) In China, large waste rock dumps have experienced failures linked to particle breakage and weak sub layers (Wang, Xu, and Li 2019).
d) Poulsen et al. (2014) reported a catastrophic dump failure in Queensland, emphasizing the need for continuous monitoring and back-analysis.

These failures underscore the importance of rigorous design, monitoring, and adoption of remedial measures such as toe berms, drainage systems, and slope re-profiling (Hurlimann and Ballantyne 2000).

4. Methods of Stability Assessment

4.1 Limit Equilibrium Methods (LEM)

LEM remains the cornerstone of slope stability analysis due to its simplicity and engineering practicality (Bishop 1955; Morgenstern and Price 1965). It allows estimation of the factor of safety for assumed slip surfaces but cannot capture stress–strain distributions or progressive failure.

4.2 Finite Element and Finite Difference Methods (FEM/FDM)

FEM and FDM enable modelling of complex geometries, heterogeneities, and coupled hydro-mechanical processes (Banerjee and Chawla 2017; El-Naggar 2002). For example, Rudra, Piri, and Sarkar (2024) used FEM to simulate particle size effects and material heterogeneity in OB dumps, while Koner and Chakravarty (2010) demonstrated the efficacy of DEM in capturing granular interactions.

4.3 Probabilistic Approaches

Uncertainties in material properties and loading conditions necessitate probabilistic analysis. Monte Carlo simulations provide probability of failure estimates, offering a risk-based perspective beyond deterministic safety factors (Nguyen and Vu 2017).

4.4 Field Monitoring and Back-Analysis

Complementary to numerical modelling, field monitoring techniques such as inclinometers, piezometers, and GPS surveys are vital for early warning (Bawden and Nicholson 2003). Back-analysis of failed dumps provides insights into shear strength mobilization and failure triggers (Poulsen et al. 2013).

5. Influence of Environmental and Material Factors

5.1 Rainfall

Rainfall infiltration significantly affects stability by increasing pore pressure and reducing matric suction (Leung and Smith 2006; Sahu, Mohanty, and Dash 2022). Numerical models show transient responses to rainfall, highlighting the need for real-time monitoring during monsoons.

5.2 Particle Size Distribution

Dump material often contains a wide range of particle sizes. Larger blocks provide interlocking resistance, while fines fill voids but may reduce drainage capacity (Bussière, Bath, and Girard 2010). Laboratory and field studies confirm that poorly graded dumps are more prone to instability (Wang, Xu, and Li 2019).

5.3 Dilatancy

Unsaturated spoil exhibits dilatancy, which enhances stability at low confining stresses (Das and Migliaccio 2009). However, under wetting conditions this advantage diminishes, contributing to sudden failures during rainfall.

5.4 Shear Strength Parameters

Shear strength depends on particle angularity, gradation, and compaction (Saatcioglu and Hryciw 1995). Accurate determination is critical for slope design. Small shear box tests often underestimate strength due to boundary effects, while large boxes better capture true particle interactions (Reddy and Rao 2011; Singh and Jha 2012; Reddy, Ramana, and Singh 2019).

5.5 Vegetation

Vegetation provides mechanical reinforcement through root anchorage and improves hydrological balance by evapotranspiration (Zhang, Li, and Wang 2021). Eco-engineering approaches using grasses and shrubs have shown success in stabilizing reclaimed dumps.

5.6 Geosynthetics

Geotextiles and geogrids offer engineered reinforcement and drainage enhancement (Singh, Sahoo, and Panda 2018; Chern and Chou 2011). Field monitoring of geosynthetic-reinforced slopes shows improved long-term performance, although cost considerations remain significant.

6. Discussion

The stability of OB dumps is governed by a complex interplay of material, environmental, and design factors. While LEM remains widely used in practice, FEM/FDM and probabilistic methods provide better insights into heterogeneity and uncertainty (Koner and Chakravarty 2010; Nguyen and Vu 2017). Laboratory studies emphasize the importance of scale effects in shear strength testing (Reddy and Rao 2011; Singh and Jha 2012). Case studies from India, Australia, and China demonstrate the recurring role of rainfall, weak foundations, and construction practices in triggering failures (Poulsen et al. 2014; Rajak et al. 2018; Geete et al. 2023).

Emerging approaches such as coupled hydro-mechanical modelling (Sahu, Mohanty, and Dash 2022), probabilistic risk assessment (Nguyen and Vu 2017), and eco-stabilization with vegetation (Zhang, Li, and Wang 2021) offer promising directions. Integration of field monitoring with numerical simulations represents the future of OB dump slope management (Bawden and Nicholson 2003).

7. Conclusions

a) OB dump stability remains a critical challenge in surface mining, with multiple case histories underscoring the risks of failure.
b) Traditional methods like LEM provide useful approximations but are limited in capturing progressive failure and heterogeneity.
c) Advanced FEM/FDM and probabilistic approaches enable better understanding of coupled processes and uncertainties.
d) Rainfall, particle size distribution, dilatancy, and scale effects in shear testing significantly influence design parameters.
e) Vegetation and geosynthetics provide viable long-term stabilization strategies, complementing conventional drainage and re-profiling methods.
f) Future research should focus on integrating field monitoring, probabilistic modelling, and sustainable stabilization measures.

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Innovative Slope Stability Monitoring Instrument for O/C

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Abstract: Open cast mining is the integral part of future mining system. Open cast mine are going wider and deeper with a serious problem of stability of benches and overburden dumps. Despite of several attempts many dump and high wall failure occurred in past in different subsidiaries of CIL causing loss of life and property. There are several methods that are in vogue for slope monitoring, these include Survey Methods, Laser Based Technique, and Radar Technique for Slope Monitoring in open cast. Each method has its own merit and demerit. Slope domain involve detailed analysis of their stability, real time monitoring with best possible equipment. This paper deals with the smart sensor technology, which has been developed to solve the slope monitoring problem and give the real time information for the mode of failure of slope for the safety of men and machine working in open cast, and this instrument provide safe working environment in open cast which is the need of hour.

Keywords: Slope stability; Monitoring instrument; Opencast

Introduction:

The Real Time Slope Monitoring Device is a system designed in view to analyze strata displacement typically on the level of open cast mines. Real Time monitoring system designed on the virtue of digital embedded system with ease to handle and tough to environment. Generalized System topology can be viewed as follow.

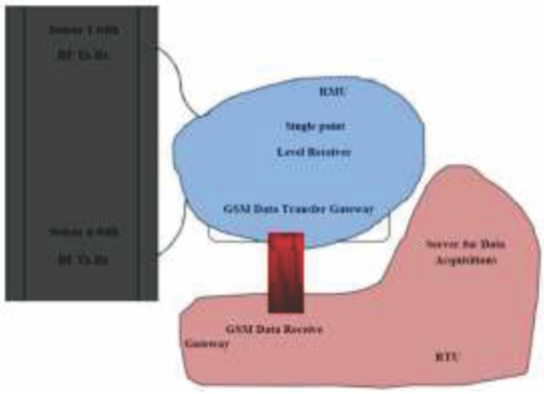

Figure 1: System Block Diagram

Methodology:

Real Time Monitoring Device works in three tier system with its data flow as Sensor Transmitter Unit to Remote monitoring Unit (RMU) and then Remote monitoring Unit (RMU) to Remote Terminating Unit (RTU). In this system primary focus has given to precise measurement of soil displacement in particular level of open cast mine. To measure this level, a unique motorized mechanism will in move corresponds to metal detector sensor under ABS Chamber.

This microcontroller based high time- resolute circuit will monitor the position of sensor and decode this value for further wireless transmission. As viewed in figure below sensor displacement will be measure of soil displacement. System has been develop in order to measure upward as well as downward movement below the soil, however degree of displacement can be customized and calibrated by programming software as per requirement. This displacement measure can further be decoded in wireless frame format for transferring its value to single point receiver wireless or Remote Monitoring Unit (RMU). Localized wireless used for this system will work in license free ISM band with highly secured data encrypted system. All this system has made compatible to work with DC power supply in composed with solar system with appropriate back up.

In this Real Time Monitoring system multi-transmission can be put on single level of opencast mine data of which.

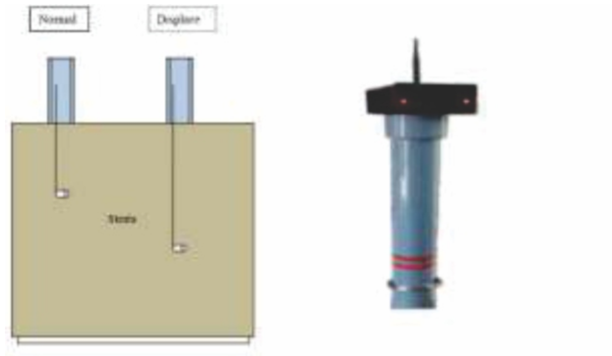

Figure 4: Generalize Mechanism Sesnsor
Figure 3: Developed sensor mechanism with transmitter system

All these transmitter receiver pairs are able to work in following network topology as shown in figure In these topologies, ID will be assigned to each wireless transmitter which will be decoded by receiver in “teach and learn” genetic algorithm pattern with parental orphan hypothesis, thus devices can be added or reduced at any time with attachment to single receiver.

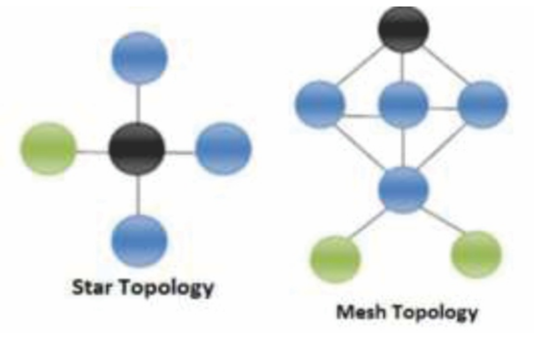

Fig.4- Multi Sensor Network Topologies

Next to then this data of single receiver can be further restored with temporarily assigned stack-hip management pattern in microcontroller, due to which controller system makes it feasible to transfer data in another data gateways. Data obtained from this gateway can be further processed with GSM/GPRS for RTU (Remote Terminal Unit) which will be located in central monitoring system.

Again this total system with bilateral data processing unit can be work solar back-up.

Fig.5- RMU with RF-GSM Gateway

Data transferred by RMU will be received by RTU which will be received by Remote PC with serial data transfer methods with proper data transfer rates. A single USB based connection can be used for this. This RTU will transfer all data received from multiple RMU to server with serial data interface.

Again this server can be customized with and as per client requirement for further data acquisitions. Currently this server will be compatible to all window based system for delivering SMS to mobile numbers as mention in system. This data acquisition also able to show trend in soil displacement which can further be used for any safety analytics.

Fig.6- RTU with GUI for advance Data Acquisition

Environmental Protection:

A customize robust enclosure with ABS Chamber has been used for all field based system which will be look as follows, As display above this enclosure may be equipped with battery in coal/mining fields. This this Real Time Monitoring device embedding with all digital features can be suitably used with its entire technical enhancement for open cast mining to meet its some safety requirements.

Fig.7- ABS Chamber Compatible for Solar Mountings

Interpretation:

There are various instruments available over the counter for slope monitoring of dumps. Some are contact based, and some are laser based and some are radar based. Each one has its own limitations. Contact based instruments are time consuming and prone to human errors. The laser-based instruments are quite reliable but have a distance limitation and have limited capability to scan. The radar-based system is very popular but very costly both in operation and maintenance. The continuous slope monitoring device is very cheaper with respect to cost and easy in installation as well as low maintenance cost.

Usefulness:

An immediate warning when movement occurs greatly increasing the safety of men and reducing costly damage to equipment. Real time slope monitoring system is very much useful, cheaper, reliable and efficient self-powered with solar panel arrangement fitted with adequate warning system, self-diagnosis, self-calibration, self-identification and self-adaption function.

Conclusion:

In nutshell such real time slope monitoring system can be installed in open cast which will give warning in case of slope failure for safety of men and machine working in open cast. This device will be a real tool, very cheaper for Real time monitoring of slope in open cast.

References:

1) Logan, Kenneth Scott. "Analysis of wireless tilt meters for ground stability monitoring." (2008)

"3 M"

By

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MOCKERY

OF

MINES & MINERALS

What should be the Shape and size of the "Lease Hold Area"

Many important things are neglected while deciding

The shape & size of the Lease Area

To be allotted to the Lease holder such as

It is observed that the lease area/s is/are decided on the basis of the Khasra (Village Map) of the area. No justification is given as why & how the quantum of the area has been arrived at. Shape of the few areas is shared in this document. A mind blogging doubt/question arises in the mind HOW I am going to utilize the area and "DOES" the area supports all the activity which are possible or planned or required or are must at the "Mine Head"

It is essential that while "Deciding Shape and Size" of the "Lease Hold Area" it is necessary to consider following (in my opinion) in addition to Geographical features like, River/Nallah etc. :

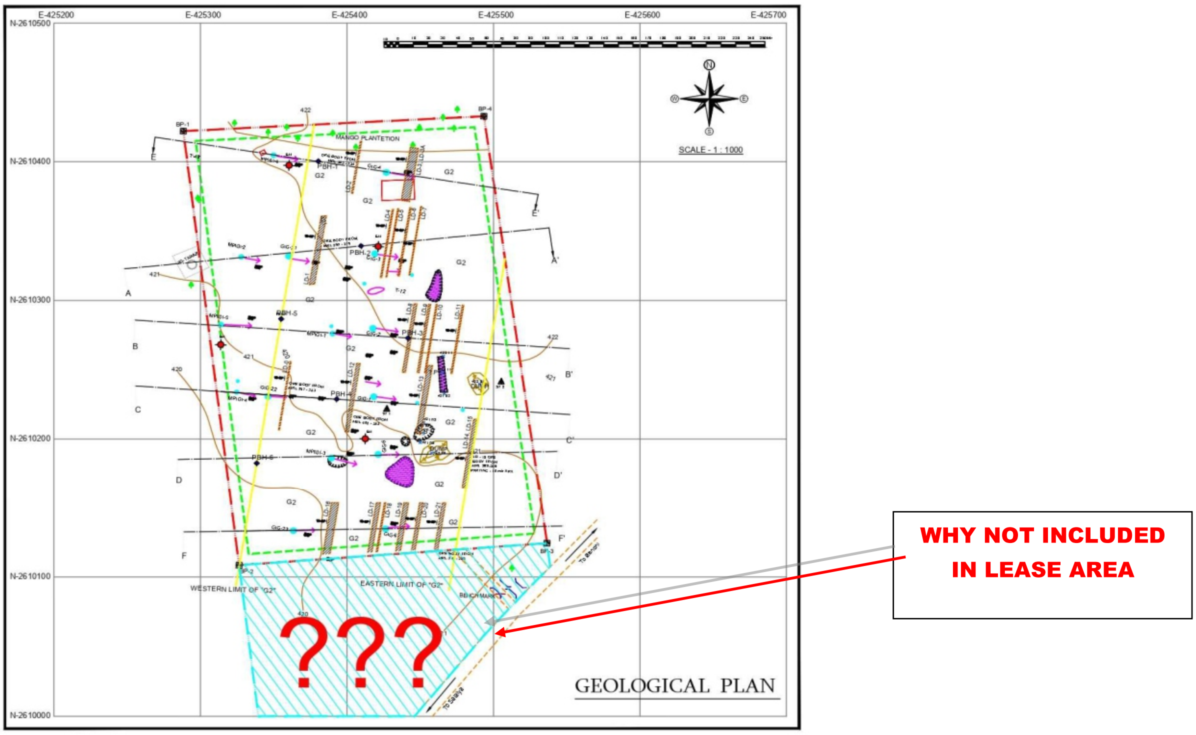
1. The mining methods which is/are likely to be practiced or can be practiced.
   Likely places/shape and quantum of the "Blocked Ore" ["0" ZERO BLOCKED ORE SHOULD BE THE AIM] under various categories such as –
    a. Barrier Zone,
    b. Bench Slope in Open Cast Mines &
    c. Other safety pillars in underground
2. Area for Disposal of OB/Waste Rock Material and for all the material above "Thresh Hold Value of the mineral present in the area and absolute waste, Unsalable Material of grade between "Cut off Value and Thresh Hold Value" e.g. in case of Manganese (Mn) +15% Mn

Content, in general, is cut off grade while + 10 % Mn content is "Thresh Hold Value". This results in to compulsory Storage of Material between 10 to 15 % Mn Content grade of Manganese Ore

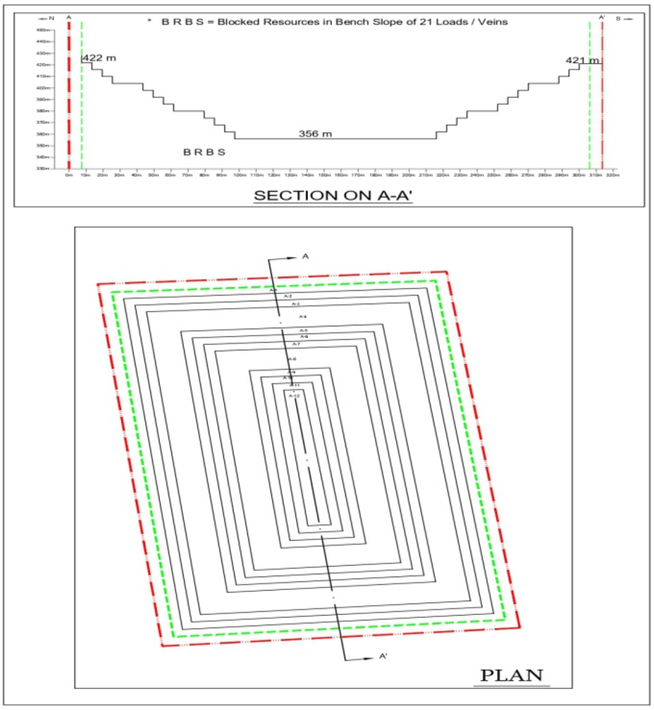
3. Stocking Yard For ROM and Saleable Material/Mineral
4. Cleaning / Sorting Area with space for storage of different grade of Mineral/Minerals.
5. Space for the "Beneficiation Plant if any".
6. Tailing Dam for "5" above if required.
7. Space for Smelter/Refining particularly for "Precious Metal like GOLD/Silver" etc.
8. Access “ROAD" to "Lease Hold Area" for minimum capacity load of +50 M.T. is need of the day. (DMF).
9. The OB/Waste Rock, if suitable for production of “M-SAND" then provides area for such plant.
10. Last But Most Important Possibility Of All Or Any One Of The Ore Body/Vein Etc May Continue To Such A Depth That Workings Are Likely To Go Beyond The Specified "Lease Hold Area".

<u>The attached are few shapes of the Mining Leases/ Area:</u>

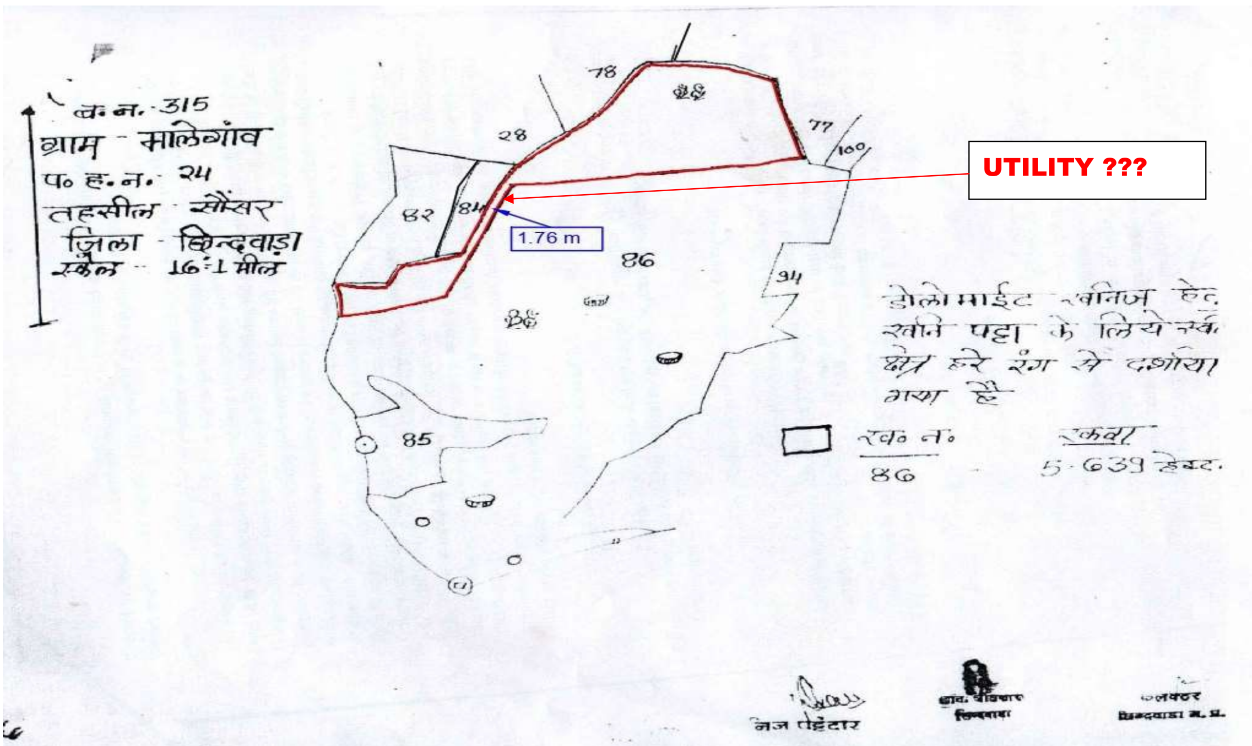
IMALIYA GOLIMALIYA GOLD & BASE METAL BLOCK



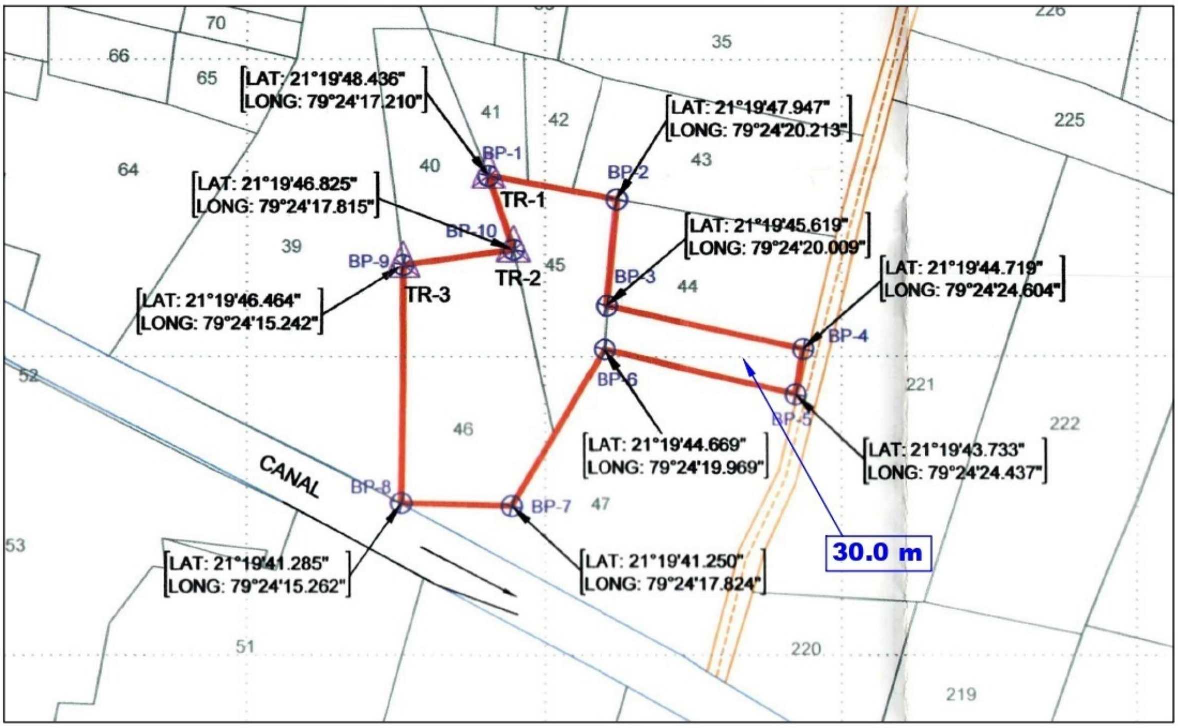
IMALIYA GOLD & BASE METAL BLOCK



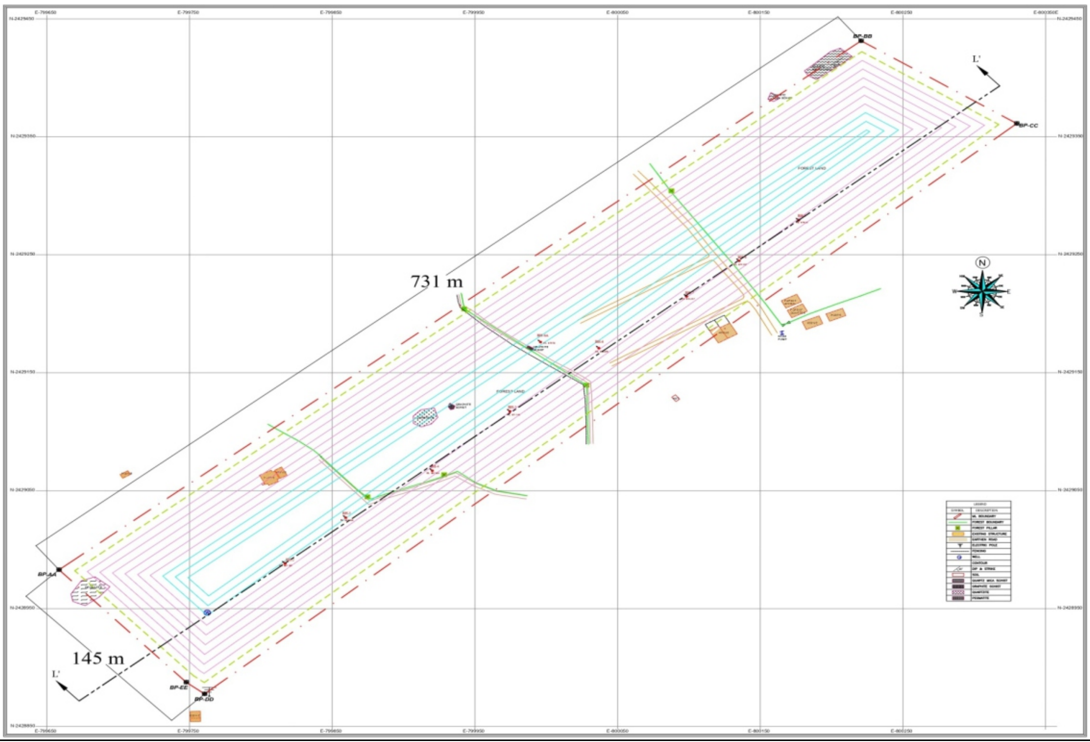
MALEGAON DOLOMINE MINE



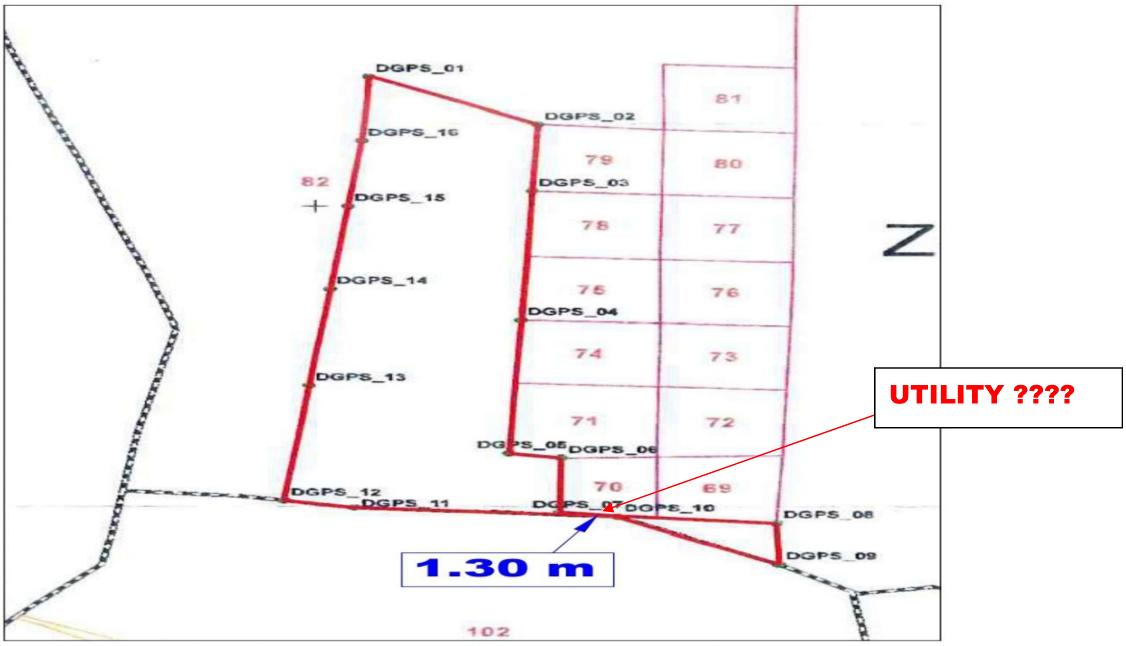
WADEGAON MANGANESE ORE MINE



GAUTHANA GRAPHITE BLOCK



ZENDEPAR IRON ORE MINE



AUCTION OF MINERAL BLOCK

"AUCTION OF MINERAL BLOCK" AS ON DATE IS "A TOTAL" FAILURE

SUGGESTION/S FOR MAKING AUCTION A "SUCCESS"

A. SOME FACTS AS ON DATE:

❖ **Auctions are held basically for two categories of areas :**

1. **Greenfield Projects : These areas can be divided further as follows-**
   - **OLD ABANDONED MINES e.g. -Mandri-Panchala, Lanjera Futala.**
   - **New, freshly explored areas like "Imaliya Gold Fields" of Madhya Pradesh, in District Katni etc.**
2. **Brownfield Projects: Existing Mines but the lease is expired on completion of 50 years from the date of first grant.**
3. **Further the Auction is held for two categories i.e.**
   - **"ML" : Mining Lease.**
   - **"CL" : Composite License (Permission for Mining after Exploration as per UNFC Norms)**

❖ **Auction/s are held and "Preferred / Successful Bidders" are declared one.**

❖ **"LOI" is issued as "Preferred Bidder" after completion of financial obligations.**

The problem starts from the first step/day as it is not clear to whom the area belongs for example

➢ **Private Land**

- Active agricultural activities.
- Agricultural Land but no activity, "Barren"
- Comes under "TIGER CORRIDOR" etc

➢ **Grampanchayat:**

-Owners - Grampanchayat

- **As per latest Revenue records area belongs to Grampanchayat, but Forest claiming that as per the 1912/13 records the land belongs to them.**
- **Land either with Irrigation or small Irrigation & all rights of use are given to "District Collector" but again claimed by "Forest Department" as it belongs to them and "NOC" is must from them.**

"THE BASIC RERASON FOR THE CURRENT SITUATUION IS "LAND RECORDS" AS THEY ARE NOT TALLYING IN VARIOS DEPARTMETNS INVOLVED IN THE PROCESS OF AUCTIONING AND EACH AND EVRY DEPARTMENT CREATING HURDLES INSTEAD OF SUPPPRTING THE PROCESS"

❖ SUGGESTION:

1. **LAND RECORDS SHOULD BE THE SAME WITH ALL THE GOVERNMENT DEPARTMENTS AND THE "NOTICE OF AUCTION" AS WELL AS "LOI" SHOULD MENTION THE CLEAR STATUS.**
2. **Forest/Wild Life/Reserve Forest (All Concerning "FOREST") the clearances must be obtained prior to notification for "Auction" irrespective of whether the Auction is for Mining Lease (ML) or for Composite License(CL).**
3. **The Preferred/Successful Bidder will obtain clearances from IBM i.e. Approval of Mining Plan"; EC, CTE and CTO.**
4. **Exploration to be carried out under the guidance of State Geology and Mining Department and the cost will be paid by Successful bidder over a time span of twenty five years FROM THE DATE OF SIGNING/EXECUTION OF LEASE DEED OR COMMENCEMENT OF MINING WHICH EVER IS LATER. A Bank Guarantee for the entire amount will be submitted by "Successful Bidder" for the "Total Cost of Exploration (Drilling, Chemical Analysis etc)" valid for 5 (Five years) with encashment period of one year beyond the life of B.G. The bank guarantee will be reduced progressively at the end of each year/period by the amount paid towards exploration by the "successful Bidder". Bank Guarantee will be renewed at the end of 5 years or whenever the Mine Plan is modified before commencement of "Mining".**

In case of negative result of exploration and/or in case of negative "Feasibility Report" the Bank Guarantee will be returned with "No Claim" certificate.

In the event any forest land is involved all clearances from "Forest Department whether Central or State" will be obtained by the Government. The Afforestation required, if any, suitable land will be located by the Sate Geological Department in association with respective "Forest Department". The successful bidder will pay the entire cost towards procurement of any private land and Afforestation if required.

TIME ALLOTTED as per "NIT": TOTAL (36 -3)=33 MONTHS "NOT P0SSIBLE". MAY BE MODIFIED TO 5 (FIVE) YEARS

- **BID OFFER: AS per The Mineral Auction Rule2015, Clause No 7.3.1 "Bidding Parameters" is linked to "Revenue". It is not clear whether this amount is payable for the "FIRST YEAR" only or FOR EACH YEAR for the "ENTIRE LIFE OF THE SUBJECT MINE LEASE".**
- **"Quote "**

  ILLUSTRATION Referred" under "Mineral (Auction) Rule 2015" - Rule 7.3 Bidding Parameters

  Sub Rule No.7.3.1

  - Final offer 10%

  - ASP INR 4000/Ton (of AVERAGE GRADE_)

  - Annual Production 2 Million Ton (20,00,000)

  - Expected Revenue 4000 X 20,00,000 = 800,0000,000.00 OR INR 800 CR

  - Amount Payable by the Holder of Mining Lease. 10 % 800.00 Cr = 80 CR

- **Unquote "**

One Actual Case Part of LOI enclosed as Annexure - I. For "Manganese Ore"

- Final offer INR 45295.00 %

- ASP Say INR 1/Ton

- Annual Production Say 1 Ton (One)

- Expected Revenue 1 X 1 =INR 1.00

- Amount Payable by the Holder of Mining Lease. 45,295 % of INR 1.00

= INR 45295.00

- Cost of Mining 1 (One) Ton to Bidder = INR 45295 - 1 + Cost of Production.

- Say Cost of Production is INR 0.50

- Cash In 1.0

- Cash Out 45295.00 + 0.50 = 45295.50

- NET CASH IN = 1 - 45295.50 = - INR (45294.50) LOSS

THIS IS DIRECTLY ENCOURAGING THE PREFERRED/SUCCESSFUL BIDDER TO INDULGE INTO ALL KIND 0F ILLEGAL AND UNETHICAL PRACTICES, I CAN SHARE FEW OF THEM ACROSS THE TABLE BUT REFRAIN TO MENTION HERE DUE NATIONAL INTREST AND PUBLIC AT LARGE

HOW & *FROM WHERE* THE FINANCES ARE GOING TO BE GENERATED TO "SUSTAIN THE MINING" ???

C. SUGGESTED ALTERNATIVES FOR BIDDING OFFER & INTIAL PAYMENT ETC:

1. SUSPEND ALL THE PRESENT AUCTIONED BLOCKS "ACROSS THE BOARD" & ALSO ALL FORTHCOMING MINERAL AUCTION/S TILL THE "MINERAL AUCTION RULES, 2015 ARE MODIFIED OR RE-ADDRESSED
2. GIVE PREFERENCE TO EARLIER PREFFERED / SUCCESSFUL BIDDER IF HE MATCHES THE LATEST HIGHEST BID/OFFER
3. BIDDING TO BE DONE AGAINST THE ASP OF THE LOWEST GRADE OF THE MINERAL AS ON THE DATE OF PUBLICATION OF NIT

Bidding Offer: Percent share of the ASP of the lowest, SALEABLE GRADE" of the subject Mineral to be quoted by Bidder.

Initial Amount Payable by the Preferred Bidder per Ton for the Total Resources as per Geological Report Submitted along with "NIT".

Additional Amount will be payable by the Preferred/ Successful Bidder every five years based on the approved Mining Plan or whenever the mining plan is Modified and fresh Resources Calculated towards the amount of Resources increased in the subject document prior to approval by IBM

Say:

Resources Quoted in NIT	100 MT
ASP mentioned in NIT	INR Say 1.00
Price offered by Bidder Say	10 %
Initial Amount Payable By Successful Bidder	= (100 X 1 X 10)/100
	= INR 10.00 (To be paid in 50 installment, after commencement of Mining before 15 Th

Day of each financial Year and the first installment will be paid before commencement of the Mining

Amount Payable after Commencement of Mining and whenever the Resources are Readdressed/Recalculated/Reassessed and are more than the Resources referred in NIT

=[(Recalculated Resources - Resources as Per NIT) X 1 X 10]/100

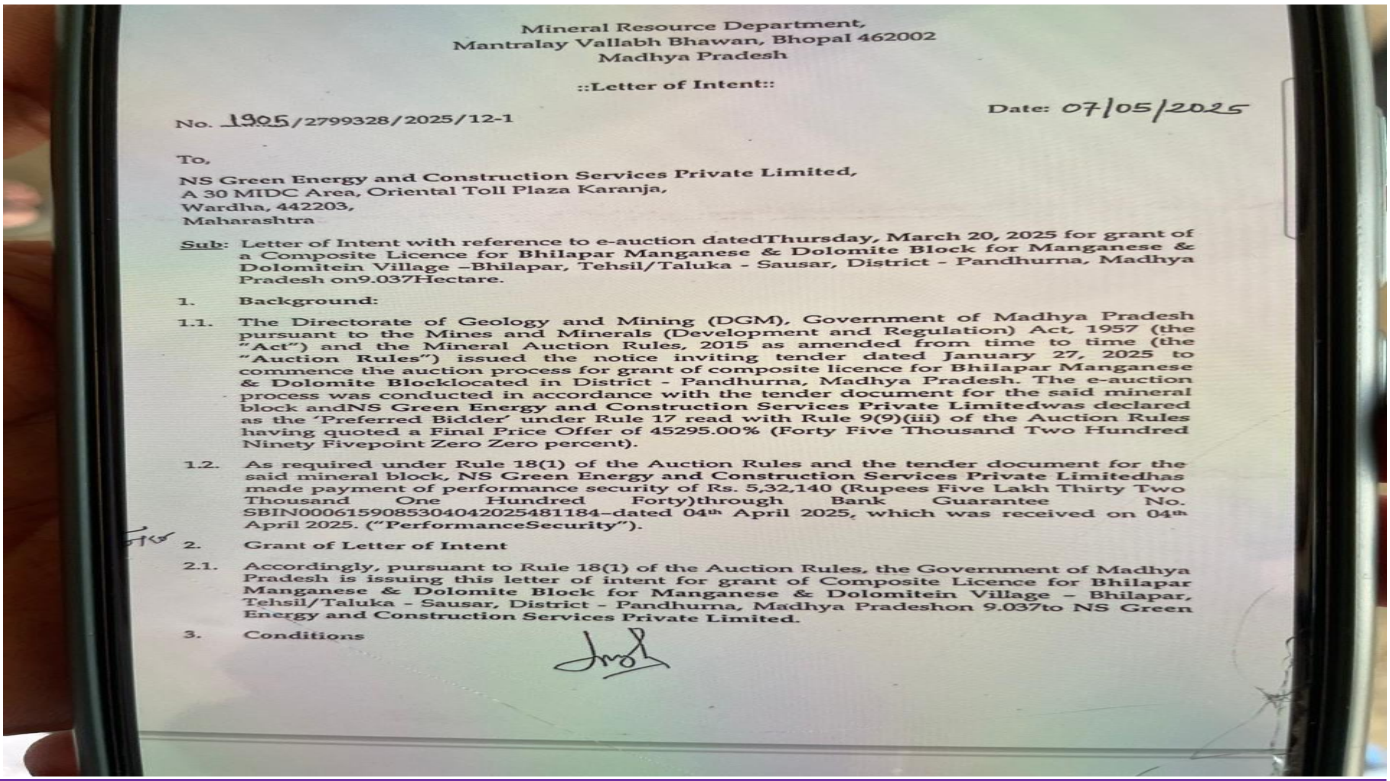
e.g. The Resources are recalculated and are Now 150 MT

Initial Resources as quoted in the NIT = 100 T

= Additional Amount to be paid by Successful Bidder / Lessee will be:

=[(150 -100) X 1 X 10]/100

= (50 X 1 X 10)/100 = INR 5.00 **(To be paid in 50 Years, after commencement of Mining at the beginning or part of 5 (Five) Year depending on the validity/approval of Mine Plan/Review of Mining Plan or Modification in Mining Plan.**



Mineral Resource Department,
Mantralay Vallabh Bhawan, Bhopal 462002
Madhya Pradesh

::Letter of Intent::

No. 1905/2799328/2025/12-1

Date: 07/05/2025

To,

NS Green Energy and Construction Services Private Limited,
A 30 MIDC Area, Oriental Toll Plaza Karanja,
Wardha, 442203,
Maharashtra

Sub: Letter of Intent with reference to e-auction datedThursday, March 20, 2025 for grant of a Composite Licence for Bhilapar Manganese & Dolomite Block for Manganese & Dolomitein Village –Bhilapar, Tehsil/Taluka - Sausar, District - Pandhurna, Madhya Pradesh on9.037Hectare.

1. Background:

1.1. The Directorate of Geology and Mining (DGM), Government of Madhya Pradesh pursuant to the Mines and Minerals (Development and Regulation) Act, 1957 (the "Act") and the Mineral Auction Rules, 2015 as amended from time to time (the "Auction Rules") issued the notice inviting tender dated January 27, 2025 to commence the auction process for grant of composite licence for Bhilapar Manganese & Dolomite Blocklocated in District - Pandhurna, Madhya Pradesh. The e-auction process was conducted in accordance with the tender document for the said mineral block andNS Green Energy and Construction Services Private Limitedwas declared as the 'Preferred Bidder' under Rule 17 read with Rule 9(9)(iii) of the Auction Rules having quoted a Final Price Offer of 45295.00% (Forty Five Thousand Two Hundred Ninety Fivepoint Zero Zero percent).

1.2. As required under Rule 18(1) of the Auction Rules and the tender document for the said mineral block, NS Green Energy and Construction Services Private Limitedhas made payment of performance security of Rs. 5,32,140 (Rupees Five Lakh Thirty Two Thousand One Hundred Forty)through Bank Guarantee No. SBIN000615908530404202548 1184–dated 04th April 2025, which was received on 04th April 2025. ("PerformanceSecurity").

2. Grant of Letter of Intent

2.1. Accordingly, pursuant to Rule 18(1) of the Auction Rules, the Government of Madhya Pradesh is issuing this letter of intent for grant of Composite Licence for Bhilapar Manganese & Dolomite Block for Manganese & Dolomitein Village – Bhilapar, Tehsil/Taluka - Sausar, District - Pandhurna, Madhya Pradeshon 9.037to NS Green Energy and Construction Services Private Limited.

3. Conditions

MINES AND MINERALS DEVELOPMENT AND REGULATION

AMENDMENT BILL 2025

S.N.	OLD LAW	NEW CHANGES	SUGGESTION
1	Definition Mineral Exchange	Formation of Mineral Exchange for trading of Minerals "Electronic Market Place".	NIL
2	Lease Area Extension (Deep Seated Mineral)	10% - ML 30 % - CL	AMOUNT OF "Extension" of Lease Area should be considered after submission of "Geo Technical Studies, in particular "Studies regarding Probable Subsidence" i.e. effect on the various structure/s on the surface etc.
3	Sale from Captive Mines 50 % Limit	Limit Removed	Welcome Suggestion
4	Sale of Old Dumps	National Mineral Exploration Trust	NIL
5	National Mineral Exploration Trust	National Mineral Exploration & Development Trust	Should take up "Forest and other Wild Life Clearances" etc
6	Critical Minerals	Critical Minerals	NIL
7	Market Development "No Provision"	Specific Additional Payment: Different rules etc	No additional "DUES", instead there should be incentive for discovering strategic & useful minerals for the benefit of National Economy in the Form "Low Rate of Royalty" and rebate in "INCOME TAX"

By

Arun B. Deoras

B.Sc. Hons (Min). A.I.S.M. FCC

Mining Consultant & Valuer

301, Yash Enclave, Plot No. 259, K1 Buty Layout, Shivaji nagar

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DECISION MAKING MODEL FOR PROCUREMENT OF LAND ON LEASE AND RETURN IT LAND OWNER AFTER USE- AN ALTERNATIVE TO CONVENTIONAL LAND ACQUISITION; CASE STUDY FOR RANIGANJ AND RAJMAHAL COALFIELDS

Sarojkanti Sahana*
Saptaswa Sahana**

ABSTRACT:

This paper intends to find out an alternative to the conventional land acquisition policy for mining industry. It provides a decision-making model for selecting a suitable land procurement policy for a coal company, taking care of the minimum guaranteed benefits admissible under the land law of the concerned State Government, aspiration of the landowners and cost-benefit analysis for the company. It provides the scope for returning the land to landowner after using, reclaiming and restoring the yield the same.

A. INTRODUCTION – NEED FOR AN ALTERNATIVE MODEL FOR PROCUREMENT OF LAND FOR MINING:

In Raniganj, Saharjuri and Rajmahal Coalfields UNDER Eastern Coalfields Limited, land is procured mostly through of sale deeds by direct negotiation with Landowners and acquisition of land under Coal Bearing Areas (Acquisition & development) Act, 1957. Although RFCTLARR at 2013 is in vogue now, but it is rarely used for land acquisition in Jharkhand and never used in West Bengal due to various reasons. However, present land procurement patterns are characterised by following aspects –

- Land transfer is permanent in nature. Ownership of land is transferred permanently to ECL.
- Landowner has no right over the land after handing over title and possession of the land to ECL.
- Coal Company has to pay Land revenue and all other admissible taxes, rents etc. continuously and perpetually.
- Coal Company cannot transfer/ sell/ lease or alienate the land without permission of the Central Government.
- Coal Company cannot return back the land to the original landowner even if it is found afterwards that the land will not be needed for any reason whatsoever.
- Coal Company has to provide R&R benefits including employment in addition to land value which is quite high particularly in case of land acquisition under CBA (A&D) Act after the cut-off date i.e. 1st September 2015

On the other hand, it is a fact that the Coal Company (in this case, ECL) requires land only for the mining operation and other project activities of a particular mine and there is practically no need to hold the procured land after completion of the concerned activity or any other activity that necessitates utilization of the land.

In view of the above, there is need for an alternative land procurement model for the company which will eliminate the problems and difficulties as described above. But what are the desirable qualities of the alternative model?

B. DESIRABLE ATTRIBUTES OF THE ALTERNATIVE LAND PROCUREMENT MODEL FOR MINING

- Transfer of land should be non-permanent in nature;
- It should be coherent with the policies of State Government;
- Legal title of the land should remain with landowner;
- It should suit with the character of land and landowners of the locality;
- It should be able to meet expectations of the landowners;
- It should be able to improve business opportunity of the Company;
- It should promote trust and image of the company in society

To formulate a suitable model for the aforesaid purpose, some decision points have been identified and it has been tried to draw conclusions based on logical selection from available alternatives. Statistical models and analysis have been used at several places for this purpose.

C. DECISION POINT 1: WHAT TYPE OF LAND TRANSFER?

From the available options it is found that a suitable lease or Rent Policy of the organization, which will be acceptable to the landowners, can be a good solution of the above riddle. From the two alternatives, it is found that, renting a land to an organization is far less attractive to landowner and the company because renting is characterized by –

i. Short term lending;
ii. No/ minimum upfront payment and only annual or monthly rent is received;
iii. Less opportunity of recovering true value of the land;
iv. When the land is degraded by mining operation there is less scope of getting the land back with restored fertility level
v. Landlord has the authority to change terms and conditions providing a short notice which may pose uncertainty of land availability over the planned period of project-operation.

Conclusion:

Hence, it appears a proper lease model may only be treated as a good alternative to permanent land-procurement practice which are in vogue now. However, for identifying basic attributes of an acceptable land procurement model we have to understand the private tenancy land ('Raiyat Land') and appetite of its owners at first.

D. PRIVATE LAND- ATTACHMENT AND APPETITE OF LANDOWNERS (IN RETURN OF THEIR LAND)

Private tenancy lands are the lands recorded in favour of private entities in the revenue records of the State Government. Psychological involvement and expectations of owners of the land are characterized by following factors:

1. Lands have been either inherited from ancestors through generations or have been obtained investing substantial share of hard-earned income.
2. Lands are viewed as assets which will never depreciate.
3. Lands are capable of supplying livelihood to the generations to come.
4. Lands can be easily sold or mortgaged to pull out the owner from distress or sudden financial need.
5. Landowner expects a guaranteed return which will not be dependent on market volatility or business decisions of a company.
6. Keeping in view the fact that, value of land appreciates faster than any other asset or liquid money, Landowner wants a suitable return which should be higher than the gain obtainable through opportunity of normal investment in the market.
7. There is emotional attachment also for the land which has been inherited through generations. Alienation of such land generally gives the owner a psychological shock. Only a provocation of hefty return can relieve such psychological pain

E. DECISION POINT 2: RETURNING LAND AFTER EXPIRY OF LEASE

Returning land to the landowner is an important aspect in case of lease. Unlike other normal cases, where land is generally taken on lease and developed for different purposes, the Coal Company will take the land for excavation that will eventually degrade the land. So, Landowner will not take the land back to his possession unless it is properly recycled to restore the shape and productivity level to a certain degree close to pre-mining condition. So, mere filling the voids and doing physical reclamation, that ECL is doing at present, probably will suffice in case of lease of land.
For restoration of land, which is basically an *environmental remediation* process, following broad tasks are to be carried out.

Pre-mining Stage:

- Geomorphological, hydro-geological and other scientific studies to ascertain thickness, character and chemical composition as well as water permeability/ retention characteristic of the bed rocks and top cover.

Mining Stage:

- Specific plan and technique to be adopted to excavate and preserve the top cover (soil) separately.

Post-mining Stage:

- Filling the voids with landfills and cover the same by top soil. Do necessary dozing operation for compaction of filled layers. Degree of compaction should be determined in consultation with experts in the field of environment and agriculture because many experts prefer lower degree of compaction for subsequent farming.
- Ensure proper gradient to match terrain of nearby areas for natural drainage for run-off water. This is needed to stop accumulation of water in the filled area that may be contaminated mixing with filling material and ultimately discharge to rivers/ ponds etc. causing water-pollution.
- Biological reclamation- to reinstate eco-system of the area by (a) selective plantation and (b) leaving the area undisturbed and hydrated for some period for self-colonization of flora and fauna.
- Alternatively, for restoration of fertility and production level of the land, pilot farming of vegetation for few years may be carried out. Landowners may be involved in this process or this can be done deploying third party farming organization.

Conclusion:
*Restoration of land productivity before returning it to landowner after lease period is needed. If filling and reclamation operation takes 2-3 years and post-reclamation farming is done for at least 5 to 7 years total time required after completion of mining operation is **8 to 10 years or more**. Land can be returned ensuring chemical composition and consistency level of top layer and productivity level of the land on a par with pre-mining stage or close to the same*

F. DECISION POINT 3: TENURE OF LEASE:

Land can be obtained under

(a) Short term lease (up to 10 years,),
(b) Mid-term lease (15 or 20 years) or
(c) Long term lease (30 years or more).

Short term lease is not attractive to the landowners because it has all the negative qualities of a 'Rent' that have been described in the Para-A (Introduction). As evident in the data models short-term lease associates with smaller pay period but larger amount annuity to ensure paying back total lease amount to the landowner at a short period. Hence, it requires fund outflow from the project at a faster rate. Short term lease model may only be selected for small OC Patches or small underground depillaring panels having maximum life span of 3-4 years.

Long term lease amounts to larger pay and longer pay-period; hence, more attractive to the landowners. This causes larger investment on land which is detrimental to the financial health of the project. Obviously, it is less preferable to the company.

Mid-term lease balances both and may be preferred moderate to large projects. Because,
- This provides sufficient time to the Project Authority to fill up the voids, to compact and stabilize the layers, to carry out reclamation and restoration jobs before finally returning the lands back to landowners.
- Even for large projects having long project-lives, project activities may be suitably planned, scheduled and phased in such a manner that total operation up to restoration of land may be completed in a particular area within 20 years.
- Landowner also becomes happy to get guaranteed income for a moderate period of time.
- Another important criterion for selecting this tenure is the annuity provision for livelihood specified in the Second schedule of RFCTLARR Act. In the said provision, Annuity of sum ₹ 2000/ month has been recommended for **twenty years**. Although, this provision does not mandatorily apply on the lease procurement of land but spirit of the provision indicates that, Government apricates payment annuity at the specified rate for 20 years is capable of compensating loss of livelihood of the landowner.

Conclusion: Considering average time required for restoration of land after mining operation as 8 to 10 years -

A. Mid-term lease (20 years) may be opted when project life is more than 7 years
B. Mid-term lease (15 years) may be opted when project life is 5-7 years
C. Short term lease (up to 10 years,) may be opted when project life is 3-4 years

D. Long term lease (30 years or more) should be avoided, except in special circumstances, as it forfeits most of the benefits of lease transfer and burdens the project large investment on land.

G. **DECISION POINT 4: SELECTION OF LEASE MODEL FOR PAYOUT**

Most of the Coal Companies have no specific in-house lease policy and guide line for determining components of the payments to landowner. However, both the West Bengal and Jharkhand have their own lease policies. We may formulate a lease policy taking example for ECL in coherence with the State policies which will not only provide a justified and acceptable basis for the model but will also do away with the possibility of future legal conflict regarding inappropriate payment or exploitation of common people. Both the Government settles lease agreement for a period of thirty years. However, Jharkhand Government collects total payable amount at the at the time of execution of lease whereas West Bengal Government bifurcates the total amount in two parts. *One is the lease premium which is an initial upfront payment and another one is Annual Lease rent which is paid annually*.

Lease model of the West Bengal Government is preferable because –

1.Company has to incur small initial capital investment as upfront payment

2. Total Lease rent is paid over a long period of time which provides financial advantage to the project.

3. Payment of guaranteed annuity stabilises financial condition of landowner for a certain duration.

Conclusion:

Lease model of West Bengal Government may be selected ensuring that total payable amount does not fall below that of Jharkhand Government.

H. **BASIS OF THE ASSUMPTIONS AND CRITERIA USED IN STATISTICAL CALCULATIONS**

Assumptions made and used in the statistical calculations of the model are as under:

I. **Average land value:** It is observed that land value varies widely in West Bengal depending on situation of the lands. Market price of the land varies from the range of ₹ 5-10 Lakhs/ acre in remote rural mouzas to 60-80 Lakhs in mouzas of Asansol Municipal Corporation and developed areas around Raniganj. In Jharkhand, highest rate of market price of Dhani-I land is close to ₹ 16 Lakh per acre. Market price of other types of land in the State is less than that. Considering the fact that majority of land are to obtained in rural areas in coming days, statistical calculations, for understanding the basic concepts of proposed lease model, has been furnished on this paper considering average land value as ₹ 12 Lakh/ acre. This is representative of most of lands in Jharkhand and lower range of land values at remote areas of West Bengal.

   However Statistical-Decision-Making-Models have been prepared considering land values as –

   (A) ₹ 12 Lakh/ acre which is representative of low range of land values,
   (B) ₹ 35 Lakh/ acre which is representative of medium range of land values and
   (C) ₹ 70 Lakh/ acre which is representative of highest range of land values

II. **Capitalized value of the returned land:** ECL is going to use the land for mining purpose. True value can be obtained only by valuation done by registered valuer after restoration process and the same will depend on actual quality and efficacy of the restoration. However, for the sake of calculation, value of the degraded land returned to the landowner is anticipated as half of the market price.

I. **DECISION POINT 5: SELECTION OF PAYMENT- RATES AND FREQUENCY**

Calculation pattern adopted by two State Governments are different. Gist of the calculation patterns are as under:

1. **Jharkhand:** As per Sankalp 48/Ra dated 04-12-2018 of Jharkhand Government. Salami=Market price, Lagan=1% of Salami, Cess=75% of Lagan.
2. **West Bengal**: As per WBLR Manual for settlement of Government land on lease: Lease Premium = 40% and Annual Rent = 4% of Market price.

It has been observed that, as per the standard Government policies total payable amounts derived from two models differ in magnitude. However, if the rate of Annual Lease Rent of the West Bengal model is enhanced from 4% to 4.75 % in case of lease tenure of 20 years, 5.75% for lease tenure of 15 years and 7.75% for lease tenure of 10 years then total payable amount becomes equal. Sample calculations for pay-out considering both the States (lease tenure of 20 years) for land value ₹ 12 lakh/ acre are given below:

Jharkhand:

Salami	Lagan	Cess	Lagan + Cess	Lease Tenure (Yr)	Total Lagan & Cess	Total Amount	Remark
1200000	12000	9000	21000	30	630000	1830000	Govt. Policy
1200000	**12000**	**9000**	**21000**	**20**	**420000**	**1620000**	**Variant-1**
1200000	**12000**	**9000**	**21000**	**15**	**315000**	**1515000**	**Variant-2**
1200000	**12000**	**9000**	**21000**	**10**	**210000**	**1410000**	**Variant-3**

West Bengal

Initial Lease Premium:		Annual Lease Rent		Total amount of annual Lease Rent	Lease Tenure (Yr)	Total Amount	Remark
Rate (% of Market Value)	Amount	Rate (% of Market Value)	Amount				
40%	480000	4%	48000	1440000	30	1920000	Govt. Policy
40%	480000	**4.75%**	57000	1140000	20	1620000	**Variant-1**
40%	480000	**5.75%**	69000	1035000	15	1515000	**Variant-2**
40%	**480000**	**7.75%**	**93000**	**930000**	10	**1410000**	**Variant-3**

Conclusion: Depending on the lease tenure of 10, 15 and 20 years rate of annuity on account of Annual Lease Rent is to be set at 4.75%, 5.75% and 7.75% respectively

[As per the selected variants Upfront Payment (Lease Premium) is ₹ 480000.00 and Annual Lease Rent is ₹ 93000, ₹ 69000 and ₹57000.00 for lease periods of 10, 15 and 20 years respectively. Corresponding monthly annuity becomes ₹ 7750, ₹ 5750 and ₹ 4750.00 respectively.]

J. DECISION POINT 6: ADDITIONAL PAYMENTS AS PREMIUMS ON ANNUITY

These payments are not mandatory by virtue of any existing law; but premiums are the incentives to the landowner which attract him to build a cosy relationship with the business of organization. Premiums impregnate trust in the mind of landowner that the organization wants to take care of his livelihood and financial stability in addition to paying him fair compensation of the land. This payment has two suggested components.

a. **Livelihood Premium**:

This is for compensating loss of livelihood of the landowner due to alienation of his land. Guidance for this premium has been taken from the second Schedule of RFCTLARR Act, 2013. The suggested rate there is ₹ 2000/ month per affected family. In our model premium cannot be family dependent. In R&R Policy of CIL, 2012 there is provision for one-time lump-sum payment of ₹ 5 Lakh/ acre in lieu of employment. Monthly annuity on account of this for **20 years is ₹ 2083/acre**.

Conclusion:

Livelihood premium for our model has been set to ₹ 2000.00/ acre/ month and it has been kept equal irrespective of periods of lease.

b. **Shallow Depth Coal Reserve Premium:**

This premium is for sharing part of the financial gain that ECL may enjoy using the particular land. Coal reserve at shallow depth definitely provides added business advantage to the mining company. It has been tried to fix a premium for the landowner based on average thickness of mineable and saleable coal seam within 100 M depth. Average thickness of coal seams considering total excavation area of the approved project/ mine is to be calculated for this purpose. Statistical representation of annuity for various options of premium rate (₹/ Te/ acre of shallow depth coal reserve) is as under:

For Lease period of 20 years:

Land Area		Seam	Density	Coal	Total amount of Premium on Coal Reserve (₹/ Acre) for different rates (₹/Te/Acre)					
Acre	Sq. M	Thickness (M)	of Coal (Te/ M^{3})	reserve (Te)	2	3	3.5	4	4.5	5
Total premium (In ₹) (Lease for 20 years)										
1	4047	30	1.40	169968	339936	509904	594888	679872	764857	849841
1	4047	20	1.40	113312	226624	339936	396592	453248	509904	566560
1	4047	10	1.40	56656	113312	169968	198296	226624	254952	283280
Annuity in ₹/ acre/ month: (Lease for 20 years)										
1	4047	30	1.40	169968	1416	2125	2479	2833	3187	3541
1	4047	20	1.40	113312	944	1416	1652	1889	2125	2361
1	4047	10	1.40	56656	472	708	826	944	1062	1180

Observation on this premium for 20 years' lease period:

So, it is found that for different premium rates (from ₹ 2.0 0 to ₹ 5.00/ Te of coal reserve/ acre) total premium varies from ₹ 1,13,312 to ₹ 8,49,840 depending on thickness of coal seams available beneath the land. Annuity derived from above amounts varies within the range of ₹ 472/ month to ₹ 3541/ month depending on same factors. ***Total premium and Annuity for the rate ₹ 3 per Te per Acre with respect to thickness range of 30 M exactly matches with that for the rate ₹ 4.5 per Te per Acre with respect to thickness range of 20 M. Total premium value for this variant equals to the arithmetic mean value of the whole range***.

Values for thickness range 0-10 M is trifle and hence eliminated from consideration. Monthly annuity Value of sum ₹ 2125/- is selected for the thickness range 0-20 M. For the thickness range above 30 M calculation has been done for 30 M thickness of seam. However, if thickness of the same increases the premium value will also increase proportionately. **Hence, a maximum value for above 20 M thickness range is set at ₹ 2300.00 only**.

Observation on this premium for other lease periods:

Calculation for lease periods of 10 and 15 years have been calculated also and given below. However, range and frequency of dataset has been reduced on trial and error method to offset high return admissible on account of Annual-lease-rent-annuity. This will control total annuity payment/ year and will not allow the annual growth rates of capitalized value of land under control. Selected premium annuities have been shown in different colours in the table.

For Lease period of 15 years:										
Land Area		Seam	Density	Coal	Total amount of Premium on Coal Reserve (₹/ Acre) for different rates (₹/Te/Acre)					
Acre	Sq. M	Thickness (M)	of Coal (Te/ M^{3})	reserve (Te)	1	1.5	2	2.5	3	3.5
Total premium (In ₹) (Lease for 15 years)										
1	4047	30	1.40	169968	169968	254952	339936	424920	509904	594888
1	4047	20	1.40	113312	113312	169968	226624	283280	339936	396592
1	4047	10	1.40	56656	56656	84984	113312	141640	169968	198296
Annuity in ₹/ acre/ month: (Lease for 15 years)										
1	4047	30	1.40	169968	944	1416	1889	2361	2833	3305
1	4047	20	1.40	113312	630	944	1259	1574	1889	2203
1	4047	10	1.40	56656	315	472	630	787	944	1102

For Lease period of 10 years:										
Land Area		Seam	Density	Coal	Total amount of Premium on Coal Reserve (₹/ Acre) for different rates (₹/Te/Acre)					
Acre	Sq. M	Thickness (M)	of Coal (Te/ M^{3})	reserve (Te)	1	1.5	2	2.5	3	3.5
Total premium (In ₹) (Lease for 10 years)										
1	4047	30	1.40	169968	169968	254952	339936	424920	509904	594888

1	4047	20	1.40	113312	113312	169968	226624	283280	339936	396592
1	4047	10	1.40	56656	56656	84984	113312	141640	169968	198296
Annuity in ₹/ acre/ month: (Lease for 10 years)										
1	4047	30	1.40	169968	1416	2125	2833	3541	4249	4957
1	4047	20	1.40	113312	944	1416	1889	2361	2833	3305
1	4047	10	1.40	56656	472	708	944	1180	1416	1652

Conclusion:

Final data matrix of 'Shallow depth Reserve premium' for different lease tenure and seam thickness ranges are as under:

Lease tenure (Years)	Seam Thickness	Premium on reserve per acre (₹/Te)	Maximum Annuity for 20/ 30 M (₹/ Acre/Month)	Maximum Annuity limit (₹/ Acre/Month)
20	0-20 M	4.5	2125	2125.00
	>20 M	3	2125	2300.00
15	0-20 M	2	1259	1260.00
	>20 M	1.5	1416	1500.00
10	0-20 M	1.5	1416	1417.00
	>20 M	1	1416	1500.00

K. EFFECT OF THE SELECTED PARAMETERS FROM THE POINT OF VIEW OF LANDOWNER:

As it has been already discussed earlier that landowner has the expectation for a commendable financially stable and guaranteed return over a reasonably long period of time when he takes a decision to hand over the land to ECL for mining. So, it is necessary to assess whether our selected criteria and parameters can meet his expectation up to a certain degree. Following tables shows basic information like amounts of annuity, payback period, annual growth rate of the capitalized value of land etc. for different lease periods:

1. **For Lease period of 20 years:**

For Lease period of 20 years: Land value: ₹ 12 Lakh/ acre				Amounts for land value and Livelihood Premium only		Annuity for land value and coal reserve Premium only		Amounts for combined Annuity for land value and All Premiums	
Sl. No.	Item	Payment Frequency	Payment duration	Unit	Amount (₹)	Amount (Seam thickness up to 20)	Amount (Seam thickness >20)	Premium for Thickness up to 20 M	Premium for Thickness >20
A.	Upfront Payment	One time	One time	₹/ acre	480000	480000	480000	480000	480000
B.	Annuity (Land)	Yearly	for 20 Years	₹/ acre	57000	57000	57000	57000	57000
		Monthly	for 240 Months	₹/ acre	4750	4750	4750	4750	4750
C.	Annuity (Premium)	Monthly	for 240 Months	₹/ acre	2000	2125	2300	4125	4300
D.	Annuity (Total)	Monthly	for 240 Months	₹/ acre	6750	6875	7050	8875	9050
		Yearly	for 20 Years	₹/ acre	81000	82500	84600	106500	108600
E.	Total monetary payment:	Total	20 Years	₹	2100000	2130000	2172000	2610000	2652000

Payback Calculation (For Lease period of 20 years):							
		land value and Livelihood Premium only		Annuity for land value and coal reserve Premium only		Amounts for combined Annuity for land value and All Premiums	
Sl. No.	Item	Unit	Livelihood Premium	Premium for Thickness up to 20 M	Premium for Thickness >20	Combined Premium (Thickness up to 20 M)	Combined Premium (Thickness > 20 M)
A	Market value of land	₹/ Acre	1200000	1200000	1200000	1200000	1200000
B	Total Payback Value	₹/ Acre	2100000	2130000	2172000	2610000	2652000
C.	Total Pay-Period	Years	20	20	20	20	20
D.	Payback Period of land value	Years	14.81	14.55	14.18	11.27	11.05
E.	Additional paying period after payback:	Years	5.19	5.45	5.82	8.73	8.95
F.	Additional Amount paid over land value:	₹/ Acre	900000	930000	972000	1410000	1452000
G.	Annual growth rate of land value (including value of returned land)	%	6.25	6.38	6.55	8.38	8.55
Note: Value of Degraded land returned to the Landowner is assumed half of the market price (₹ 6 Lakh here)							

Observation for statistical model for 20 years:

It is observed that landowner gets total return of ₹ 2652000.00 along with the restored land at the end. This brings him annuity around ₹ 9050/month for 20 years. Land value is fully paid up just after 11 years but he will continue to get annuity for approximately nine more years. Annual growth rate for value of his asset (including the value of returned land) is 8.55 % which is more than present rate of interest of term deposits in Government Bank. Growth rate for lower seam thickness will be slightly less, but it is still expected to be hovering around 8% which is not bad.

2. For Lease period of 15 years:

Annuity and Total Payback value (For Lease period of 15 years:):									
				Amounts for land value and Livelihood Premium		Amounts for Annuity for land value and coal reserve Premium		Amounts for Annuity for land value and All Premiums	
Sl. No.	Item	Frequency	Payment Tenure	Unit	Amount (Livelihood Premium Annuity)	Amount (Thickness up to 20)	Amount (Thickness >20)	Premium for Thickness up to 20 M	Premium for Thickness >20
A.	Upfront Payment		One time	₹/ acre	480000	480000	480000	480000	480000
B.	Annuity (Land)	Yearly	for 15 Years	₹/ acre	69000	69000	69000	69000	69000
		Monthly	for 180 Months	₹/ acre	5750	5750	5750	5750	5750

C.	Annuity (Premium)	Monthly	for 180 Months	₹/ acre	2000	1260	1500	3260	3500
D.	Annuity (Total)	Monthly	for 180 Months	₹/ acre	7750	7010	7250	9010	9250
		Yearly	for 15 Years	₹/ acre	93000	84120	87000	108120	111000
E.	Total monetary payment:	Toatl	Total Payment	₹	1875000	1741800	1785000	2101800	2145000

Payback Calculation (For Lease period of 15 years):			Values for different options of Premiums				
Sl. No.	Item	Unit	Livelihood Premium	Premium for Thickness up to 20 M	Premium for Thickness >20	Combined Premium (Thickness up to 20 M)	Combined Premium (Thickness > 20 M)
A	Market value of land	₹/ Acre	1200000	1200000	1200000	1200000	1200000
B	Total Payback Value	₹/ Acre	1875000	1741800	1785000	2101800	2145000
C.	Total Pay-Period	Years	15	15	15	15	15
D.	Payback Period of land value	Years	12.90	14.27	13.79	11.10	10.81
E.	Additional paying period after payback:	Years	2.10	0.73	1.21	3.90	4.19
F.	Additional Amount paid over land value:	₹/ Acre	675000	541800	585000	901800	945000
G.	Annual growth rate of land value (including value of returned land)	%	7.08	6.34	6.58	8.34	8.58
Note: Value of Degraded land returned to the Landowner is assumed half of the market price (₹ 6 Lakh here)							

Observation for statistical model for 15 years:

It is observed that landowner gets total return of ₹ 2145000.00 along with the restored land at the end. This brings him annuity around ₹ 9250/month for 15 years. Land value is fully paid up before 11 years but he will continue to get annuity for approximately four more years. Annual growth rate for value of his asset (including the value of returned land) is 8.58 % which is more than present rate of interest of term deposits in Government Bank. Growth rate for lower seam thickness will be slightly less, but it is still expected to be hovering around 8% which is not bad.

3. **For Lease period of 10 years:**

Annuity and Total Payback value (For Lease period of 10 years:):			
	Amounts for land value and Livelihood Premium	Amounts for Annuity for land value and coal reserve Premium	Amounts for Annuity for land value and All Premiums

Sl. No.	Item	Frequency	Payment Tenure	Unit	Amount (Livelihood Premium Annuity)	Amount (Thickness upto 20)	Amount (Thickness >20)	Premium for Thickness up to 20 M	Premium for Thickness >20
A.	Upfront Payment		One time	₹/ acre	480000	480000	480000	480000	480000
B.	Annuity (Land)	Yearly	for 10 Years	₹/ acre	93000	93000	93000	93000	93000
		Monthly	for 180 Months	₹/ acre	7750	7750	7750	7750	7750
C.	Annuity (Premium)	Monthly	for 180 Months	₹/ acre	2000	1417	1500	3417	3500
D.	Annuity (Total)	Monthly	for 180 Months	₹/ acre	9750	9167	9250	11167	11250
		Yearly	for 10 Years	₹/ acre	117000	110004	111000	134004	135000
E.	Total monetary payment:	Toatl	Total Payment	₹	1650000	1580040	1590000	1820040	1830000

Payback Calculation (For Lease period of 10 years):			**Values for different options of Premiums**				
Sl. No.	Item	Unit	Livelihood Premium	Premium for Thickness up to 20 M	Premium for Thickness >20	Combined Premium (Thickness up to 20 M)	Combined Premium (Thickness > 20 M)
A	Market value of land	₹/ Acre	1200000	1200000	1200000	1200000	1200000
B	Total Payback Value	₹/ Acre	1650000	1580040	1590000	1820040	1830000
C.	Total Pay-Period	Years	10	10	10	10	10
D.	Payback Period of land value	Years	10.26	10.91	10.81	8.95	8.89
E.	Additional paying period after payback:	Years	-0.26	-0.91	-0.81	1.05	1.11
F.	Additional Amount paid over land value:	₹/ Acre	450000	380040	390000	620040	630000
G.	Annual growth rate of land value (including value of returned land)	%	8.75	8.17	8.25	10.17	10.25
Note: Value of Degraded land returned to the Landowner is assumed half of the market price (₹ 6 Lakh here)							

Observation for statistical model for 10 years:

It is observed that landowner gets total return of ₹ 1830000.00 along with the restored land at the end. This brings him annuity around ₹ 11250/month for 15 years. Land value is fully paid up before 9 years but he will *continue to get annuity for approximately another year. Annual growth rate for value of his asset (including the value of returned land) is 10.25 % which is more than present rate of interest of term deposits in Government Bank. Growth rate for lower seam thickness will be slightly less, but it is still expected to be hovering around 10% which is extremely lucrative from landowner's point of view.*

Now, it will be an interesting point to notice if high rate of return for a short period and quick return of the land can offset the thinner volume of total return he receives from the land.

L. EFFECT OF THE SELECTED PARAMETERS FROM THE POINT OF VIEW OF COAL COMPANY:

Effect of the proposed lease model for different lease-periods on the project compared to various other land procurement modes can be observed in the following table (assumed Land value is ₹ 12 Lakh/ acre and capitalized return value of land is ₹ 6 Lakh/ acre):

Cost-Benefit Analysis					
Land Area (Acre):	1	Seam Thickness (Metre):		30	
Coal Reserve (Te/ac):	169968	Selling price (₹/ Te):		1800	
Revenue/ acre (₹ Lakh):	3059				
Revenue/ acre (₹ Lakh)	3059	Land value: ₹ 12 Lakh/ acre			
Cost (in ₹ Lakh)	Land	Employment	Total	Share of revenue (%)	investment/ year
Acquisition (With Employment)	12.00	175.00	187.00	6.11%	9.35
Acquisition (Without Employment)	48.00	8.50	56.50	1.85%	2.83
Purchase (with Employment)	2.50	175.00	177.50	5.80%	8.88
Purchase (without Employment)	45.00	0.00	45.00	1.47%	2.25
Lease (10 Years)	18.30	0.00	18.30	0.60%	1.83
Lease (15 Years)	21.45	0.00	21.45	0.70%	1.43
Lease (20 Years)	26.52	0.00	26.52	0.87%	1.33
Assumptions: 1. Average PAF/ acre in Bansdiha/ Taljhari = 1.70; 2. Highest rate provided for industrial land (₹ Lakh/ acre) in Bansra West Bengal: 22.50 3. Employment cost: ₹ 3.50 crore which involves 2 acres of land					

Above observation shows that

- *Acquisition under CBA, RFCTLARR Act etc. with provision of employment is the costliest option.*
- *Purchase of land without employment, even with highest offered compensation at present, is the cheapest among permanent land procurement options.*
- *Lease models are further cheaper for this land value.*
- *With the increase of lease period, total capital investment increases but annual outflow rate of investment decreases*
- *For lower range of land value land consumes less than 1% of earned revenue and that is really encouraging.*

However, with increase of land value the scenario changes. Above cost analysis for highest range of land value (assumed @ ₹ 70 Lakh/ acre in corporation areas) has been done and effect can be seen in the table below:

Cost-Benefit Analysis				
Land Area (Acre):	1	Seam Thickness (Metre):		3o
Coal Reserve (Te/ac)	169968	Selling price (₹/ Te)		1800
Revenue/ acre (₹ Lakh)	3059			
Cost (in ₹ Lakh)	Land	Employment	Total	Share of revenue (%)
Acuisition (With Employment)	70	175	245	8.01%

Acuisition (Without Employment)	280	8.5	288.5	9.43%
Purchase (with Employment)	2.5	175	177.5	5.80%
Purchase (without Employment)	45	0	45	1.47%
Lease Model (10 Yrs)	86	0	86	2.81%
Lease Model (15 Yrs)	94.68	0	94.68	3.00%
Lease Model (20 Yrs)	105	0	105	3.43%
Assumptions: as above				

Interestingly, here we see that,

- Capital investment per acre of land acquisition (without Employment) has surpassed even cost with employment options.
- Purchase (without Employment) is the cheapest option among all. It is even cheaper than the proposed lease models. However, it should be kept in mind that, purchase at cheaper negotiated value will not be easy in coming days as it is creating huge discrepancy compared to payment received against land acquired under other acquisition acts. If landowners begins demanding land values at par with other modes then, the present benefit will vanish in future.
- Obviously, high land value has collected its toll by eating up 2.81% to 3.43% of the earned revenue per acre. But still it is cheaper wherever purchase without employment is not possible.
- Attempt should be made to keep Lease period as low as possible through negotiation with landowners for lessening financial load of the project

M. COMPARISON OF THE INDICES OF LEASE MODELS HAVING DIFFERENT VARIANTS:

Values of different indices derived for different ranges of land values and different options of lease periods are provided in the table below:

			Lease tenure		
Sl.No.	Cost Item (₹ Lakh)	Land value	20 years	15 years	10 years
1	Upfront Payment (Initial Lease Premium)	12.00	4.80	4.80	4.80
		35.00	14.00	14.00	14.00
		70.00	28.00	28.00	28.00
2	Yearly Annuity (Total)	12.00	1.09	1.11	1.35
		35.00	2.18	2.43	3.13
		70.00	3.84	4.45	5.85
3	Total monetary payment	12.00	26.52	21.45	18.30
		35.00	57.57	50.48	45.33
		70.00	104.82	96.68	86.45
4	Capitalized value of returned land	12.00	6.00	6.00	6.00
		35.00	17.50	17.50	17.50
		70.00	35.00	35.00	35.00

Sl.No.	Cost Item (₹ Lakh)	Land value	20 years	15 years	10 years
5	Payback Period of land value	12.00	11.05	10.81	8.89
		35.00	16.07	14.39	11.17
		70.00	18.22	15.75	11.98
6	Total monetary growth of land value	12.00	14.52	9.45	6.30
		35.00	22.57	15.49	10.33
		70.00	34.82	24.68	16.45
7	Annual growth rate of land value	12.00	8.55%	8.58%	10.25%
		35.00	5.72%	6.28%	7.95%
		70.00	4.99%	5.68%	7.35%
8	Investment of ECL/ year/Acre	12.00	1.33	1.43	1.83
		35.00	2.88	3.37	4.53

		70.00	5.25	6.31	8.60
9	Share of revenue consumed by land cost (%)	12.00	0.87%	0.70%	0.60%
		35.00	1.88%	2.00%	1.48%
		70.00	3.43%	3.00%	2.81%

Obserbations:

While taking decisions regarding lease periods for a lease procurement of land of particular land value following analysis regarding variance of indices as shown in the above table will of immensely important:

1. Land value has great impact on the volume of 'Total Monetary Payment' to landowner as well as 'Yearly Annuity (Total) payment' and 'Upfront Payment (Initial Lease Premium)' compared to lease impact of lease period. However, market value of land is not under control of ECL.
2. volume of 'Total Monetary Payment' increases with lease period but Yearly Annuity (Total) decreases with increase of lease period.
3. Absolute growth of the value of land increases with lease period but Annual growth rate of land value diminishes with the same. However, in spite of higher rate of return for a short tenure of lease landowner may probably be interested for longer lease period due to security of income for longer period and fattier volume of total return
4. From ECL's point of view, although total investment on land increases with increase of lease period, investment on land per acre per year decreases with increase of lease period.
5. All the indices indicate that, wherever yearly fund outflow is to be controlled and kept within a limit for the financial feasibility of the project, a lease for 15 to 20 years will be preferable. On the contrary, shorter lease period will assist project by lessening total volume of pay-out on account of land in other cases. It is evident from the index ' Share of revenue consumed by land cost (%)', which has the tendency to decrease with decrease of lease period that gives soothing effect on the total expenditure of project

N. FINAL OUTLINE OF THE PROPOSED MODEL:

Proposed model is for obtaining land from recorded landowner on Lease. Basic criteria of the lease are:

- Lease model of West Bengal Government may be selected ensuring that total payable amount does not fall below that of Jharkhand Government.
    - Tenure of lease:
        a) Mid-term lease (20 years) may be opted when project life is more than 7 years
        b) Mid-term lease (15 years) may be opted when project life is 5-7 years
        c) Short term lease (up to 10 years,) may be opted when project life is 3-4 years
        d) Long term lease (30 years or more) should be avoided, except in special circumstances, as it forfeits most of the benefits of lease transfer and burdens the project large investment on land.
- Consideration for landowner: There will be two parts-
  (A) An upfront payment [can be termed as 'Lease premium'] which is equal to 40% of market value of land and
  (B) An annuity consisting of (a) Annual lease premium for land, (b) livelihood premium and (b) Shallow Reserve Premium.
    a) **Annual lease premium for land**: Depending on the lease tenure of 10, 15 and 20 years, rate of annuity on account of Annual Lease Rent is to be set at 4.75%, 5.75% and 7.75% of notified market price of land respectively.
    b) **Livelihood Premium:** Livelihood premium for our model has been set to ₹ 2000.00/ acre/ month pro rata basis and it has been kept equal irrespective of periods of lease.
    c) **Shallow Depth Coal Reserve Premium:**

Lease tenure (Years)	Seam Thickness	Premium on reserve per acre (₹/Te)	Annuity (₹/ Acre/Month)
20	0-20 M	4.5	2125.00

	>20 M	3	2300.00
15	0-20 M	2	1260.00
	>20 M	1.5	1500.00
10	0-20 M	1.5	1417.00
	>20 M	1	1500.00

- Payment mode: Payment should be made directly to Bank Account of landowner through RTGS. Landowner should get opportunity to opt frequency of the annuity (Monthly/ quarterly/ Annual).
- Return of the land: Land is to be returned to the landowners after expiry of lease tenure. If filling and reclamation operation takes 2-3 years and post-reclamation farming is done for at least 5 to 7 years total time required after completion of mining operation is 8 to 10 years or more. Land can be returned ensuring chemical composition and consistency level of top layer and productivity level of the land on a par with pre-mining stage or close to the same
- Other criteria: 1. Decisions regarding particular lease model and lease period should be guided by analysis of financial indices as mentioned in para 'O'.
  2. During selection of lease period all possible projects that can be taken up for exploiting total coal of all seams beneath the land should be considered.
  3. For making the scheme more attractive an incremental premium pattern may be adopted instead of flat premium.

O. OTHER ADDITIVE BENEFITS:

Few more benefits may also be offered to have good social bonding with the land losers. A Photo-Identity card as a recognition of land provider to ECL may be issued to each landowner Following benefits may be extended to them by virtue of the said card:

I. Facility of free medical treatment at the ECL Hospitals;
II. Facility of schooling of their children at ECL funded schools;
III. Facility of attending skill development programs at Training Institutes of ECL or customized programs arranged by ECL for them

P. ARRANGEMENT OF FUND:

Fund is to be provided from the provisions made in the approved project report. Upfront payment is to be made from initial capital outflow. Annuities are to managed from annual expenditures.

Q. PROS AND CONS:

Pros:

1. No permanent acquisition of land hence no risk of legal complications related to ownership of land
2. Cost of employment is avoided;
3. Unnecessary intake of unskilled workforce is avoided
4. No revenues and dues are to be paid;
5. Total cost on account of land procurement will be much less compared to land purchase/ acquisition.

Cons:

1. Employment is the prime attraction of local landowners. They may not be interested even though compensated sufficiently by ECL;
2. ECL is doing some social duty towards employment generation through land procurement mode at present. This will cease to happen in the current model.
3. Additional work for restoration of land will need additional effort. (Requirement of additional fund for this purpose will be minimal as there is already a provision of this in the 'Mine-closure-plan')

R. FURTHER ACTIONS REQUIRED

- All the activities for data and information collection regarding geo-morphological and chemical qualities of soil and strata at pre-mining stage are to be carried out. Expert agencies are to be engaged for this job.

- Activities as described above during mining and at post-mining stage are to be carried out religiously. Proper SOP is to be formulated and institutions/ departments are to established for implementation and monitoring of the same.
- Back-filling of voids and restoration the land to its original shape and fertility level is a very important criterion in this model. Actions required for this purpose have been described above. Till now ECL has not practised this. Sufficient infrastructure and investment is required to ensure actual implementation of this aspect.
- This model has been prepared based on available records and ideas regarding the coalfields of West Bengal and Jharkhand under command area of ECL. Further study may be required by some expert agency before taking actual decisions.
- Sufficient propaganda and counselling camps might have to be organized to make landowners aware of the lease options and the benefits admissible to them. Expert organizations/ NGOs may be engaged for this purpose.
- Legal provisions regarding the lease mode needs to be examined also.

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Small Blockages. Big Impact — Keeping OCM Production Flowing

By Prashant Kabra

#Smartmining 24x7

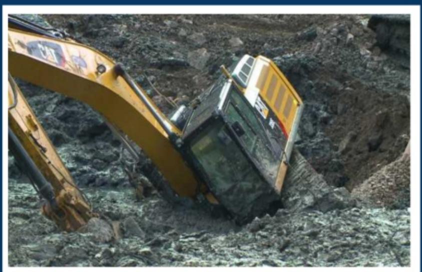
OCM = Open cast Mine

Key performance measure = Production Output of Coal

OCM - Coal Production process flow - key steps

Challenges:-

Overburden (OB) Removal- Equipment breakdown & Stucking on road
Coal Extraction- Slope failure, Poor bench design
Coal Handling & Transport - Road congestion



Day to day Impact:

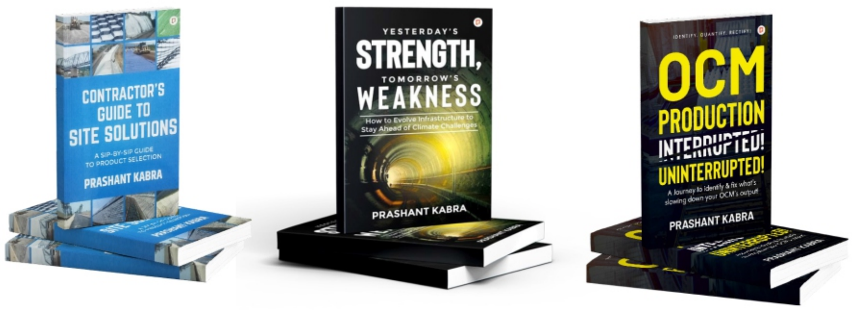
Variation in daily output from OCM
Rise of Sudden troubleshooting at Site
Frequent mechanical failures while mining
Hassle of taking approvals for Unplanned tasks

"**365 days** of problem-solving &
Resolving day to day Blockages"

Prashant Kabra

Engineer, MBA & PhD (Final stage)
from Nagpur

Entrepreneur and Author of



Our Journey

1995 – Started mining products trading
1999 – Expanded Pan-India network
2003 – Added HEMM product trading
2007 – Brought global solutions to India
2011 – Launched OEM replacement innovations
2015 – Entered contractual mining projects
2019 – Diversified into infra & mining services
2023 – Focused on safety & protection
2025 – Emerging as expert problem-solvers in infra & mining

Our contributed in 11000+ OCM & Infra projects

With 11,000+ sites, we are trusted leaders in delivering innovative, sustainable solutions for slope stabilization, erosion control for infrastructure & mining safety."

Innovated & Brainstormed with Trusted Global leaders :

WCL, MCL, CCL, BCCL, SCCL, Indian Railways, NHAI, Metro, Jal Nigam, HSM, RITES, Ircon, DFCCIL, RVNL, Govt of Telangana, PWD, MSRDC, NMRDA, Defence, Tata power, JSW, Taj Hotel, L&T, Nayara Energy

A : Identify key areas! of blockages

Identify! Quantify! Rectify!

Once Blockages are identify

it's time to check

what's urgent and what's not urgent!

Blockages are identify!

Urgencies ko map!

Why these blockages happened why this became urgent - it's important to find gaps else this will happen again.

**Out of many …
6 situations with
tools & measures…**

"SMART Mining 24x7"

"Every issue at OCM site , Demands different solutions!"


Overburden Slope Instability and erosion
#2


Drainage And Seepage Issues
#3
realme Shot on realme 7 Pro


Dirty Wheels follows to Degradation
#4


Heat Up surrounding of Mines
#5

"Solution in action"

Final Outcome:

Before

After

"Solution in action"

Final Outcome:

Before

After

This is just a glimpse to many possibilities that can be easily implemented to ensure smooth running of a OCM plant.

“Let’s meet,discuss & resolve !”

Mining is Positive by: Ajay Kumar Jain

Thinking of Societies about Mining :

- Every where is listen that Mining is a **Negative activity** . Why?????
- **Work Against Nature .**
- **How much know Society about Mining.**
- **What Common Complaints** ?????
- **Common Complaints** of Land Degradation, Deforestation , Water pollution, Surface water pollution, river effected, Ground water effected, Air Pollution , Displacement of Local Communities, Loss of top-soil or agriculture lands, Effect on Fertility of crops , Loss of Livelihoods , Health risks, Ground vibrations, smoke , noise , dust , Bad road condition due to Mineral transports , mine drainage, land subsidence extra extra lots of countless……blame .
- **Mining** is Primary Industry means ***maa*** (*Vardaan* or Backbone of Industries) for lots of development of various Secondary and Tertiary industries etc. Mining provides Raw Material, Fuel for them. Most of Development & Technology Employment (direct & indirect) get due to Existence of Mining.
- **Public blame** mines for environmental impact etc *bla- bla* varies local domain to social issues then viral per milli-second speed (faster than intiation of explosive energy of *palak chhapakte*) as active media in every hand. Here Request good things of Mining should viral . ***Matlab Mines ke achchhe kaam bhi to popular hona chahiye through Societies.***

Think !

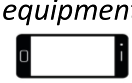
- **Think !!! We Can ! Live Without Mining** . Here Six reasons why **we can't live without Mining**:

*1. jo **hamare toothpaste me** calcium & **namak hai** ,soap me limestone , telcom-powder me talc ke baad breakfast table per crockery use karte usme china clay.*

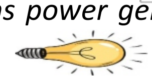
*2. jo **Ae diwaar nahi Tutegi ..Ambuja Cement se bani Hai** (Limestone) , Birla Opus , Asian ka Royal Paint (dolomite) hai.*

*3. jo **hum safer** karte hai means we use bicyle/ moter-bike/car/bus/train/ship/aircraft and will use spacecraft (iron , aluminium , copper, Natural Gases etc) also.*

*4. jo humsab **kaam karte hai** means mechanical-electrical-electronics equipment/instrument / furniture/ enfr-astructure etc (critical minerals , precious metals etc)*



*5. jo **easy life hai khana Tyaar hai** , AC ki hava , LED Light ki chamak means power generation from fossil fuels.(coal, methane beds, natural oils, gas etc)*



*6. Medical **care** where lots of medicine manufacturing with use of metals , non – metals minerals.*

After that Why do people hate Mining ?????

Actually do not see connection between Mining and End Products they consume . While Society enjoy a comfort life due to **Gift or boon of mining industry** . Mining is need all know that it is continued since pre-historical era & still running & will require for new gens .

Need to Change of Perception : How we *CAN !* earn Value

- **Policy**: The inverse impact of Mining should be reduced or minimised through way to Sustainable or responsible Mining.
- **Action**:
- 1. **Pre Mining** :

EBITA Cash Flow (Project Financial Planning , Cost and Cash Flow estimation), Social Responsibility, Think about Closure Planning (FMC Projection) before start Mining . Think How Community will Support in favour of mining from beginning to end of mining .

- 2. **In Mining** :

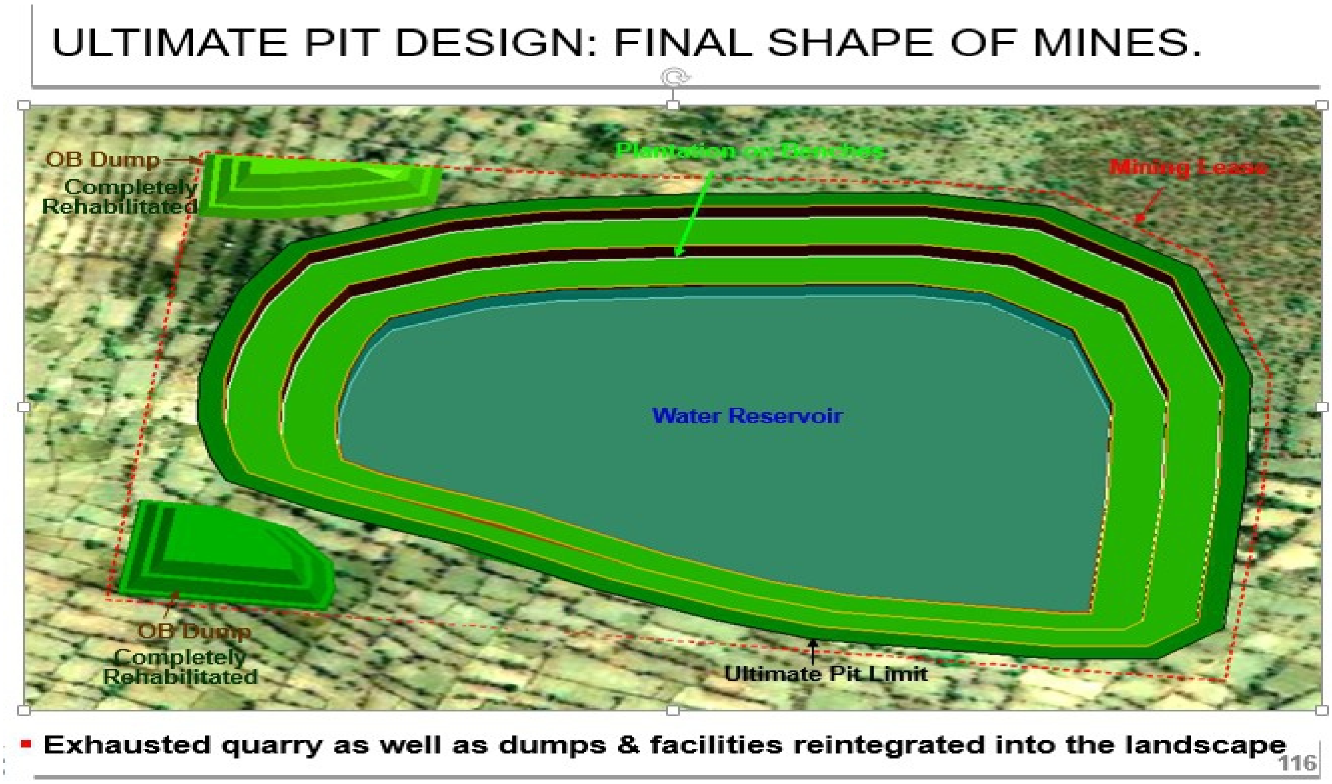
Zero harm in core and buffer zone through scientific & systematic work , review should a continuous process through Assessment, Evaluation, Analysis , Examination, Inspection and Remedial for corrective . Therapeutic, Restorative , Rehabilitative , Mitigative the impact of mining operation and allied services .

- 3. **Post Mining**:

Don’t wait for last two years . Step wise step covers through PMCP , ultimate FMCP work should useful to society . We bound to return post mining safe , secure and useful to Society after restoration(original) who gifted us before start mining .

Need to Change of Perception : How we *CAN !* earn Value

- Society is our customer as well as claimer . And Mine is a Supplier .
- How we go for satisfy the our customer .
- Only if our work accordingly our Policy. Example Leader is become a **brand** if he fulfil his commitment during his power in parliament. Otherwise Public punish him with *Zero from Hero*.
- Our Commitment should that Mining should positive with zero harm. Society will start to vote for branding to Mining . Our **BRAND** is possible if no space for evils due to result of mining .
- We do a **good work** in mining but **Public does not know** because we never express or convey through **Propaganda or share the news of our good things of mining among Societies** , public, govt (except our mining related deptt) therefore sharing in Public is an initiation is must for show **Positive of Mining.** Mining is an art and this art like by public will be called **Mining Tourism .** Permanent or final closed mine which acceptable by Society is boon of mining . Our best mining impression for permanent place of public interest and **source of recurring income** is called **Geo-tourism** in my view. Lots of Examples are for motivating towards Geotourism. Few are illustrated here for discussion.



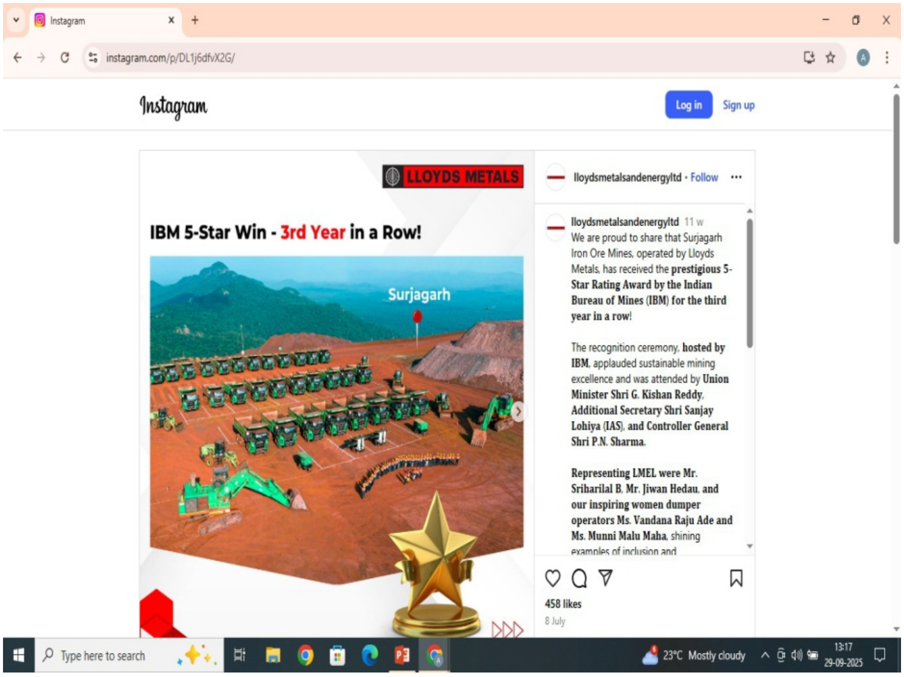
Legal Support

- **Regulation No. 110 of MMR 1961**: Protective works before a mine is closed
  clause : Protective work in specified time as writing in order of Inspector.
  If Owner fail in specific time then Inspector may get the work
  executed by any other agency and cost will bear by owner .
- **Rule 21(4) of MCDR 2017:** ML can not abandon a mine unless FMCP approved and worked for **Protective , Reclamation & Rehabilitation work done (PPR)**according with FMCP.
- **Rule 21(5) of MCDR 2017:** Liability on Owner for PRR Work to pay expenditure over **Financial Assurance (FA)** for existing ML before 2015**/ Performance Security (PS)** for ML through E Mineral Auction or Agreement after 2017.
- **Rule 22 of MCDR 2017: Mine Closure Plan : PMCP & FMCP.** Satisfy to authority about no reserves is remaining in mine which wish to finally closed .
- **Rule 26 of MCDR 2017: Responsibility of Holder of ML for PRR Work.**
- **Rule 27 of MCDR 2017: FA** @ 5 Lakh per Ha for A category and Rs…. Lakh for B category.
- Rule 24 of MCDR 2017: If non submission of FMCP then forfeiture of FA.
- **Rule 35 of MCDR 2017**: Sustainable Mining . At least Three Star Rating .
- Rule 22 of M(OAHCEM)CR 2016: Termination : Lessee pay PRR expenses if any above PS.

Few Example

Pre Mining :

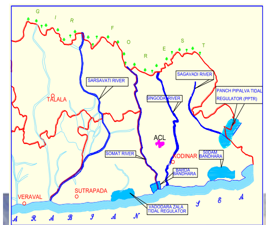
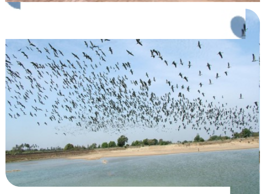
- Surjagargh Iron Mining :
- The Surjagarh iron ore mine, operated by [Lloyds Metals & Energy Ltd]() in Garchiroli Distt of Maharashtra State is presented as India's first "**green mine**" due to its eco-friendly initiatives, including the use of **battery-operated heavy equipment**, **electric-powered drills, transport units etc**.



In Mining : ambuja Cement: *Giant Compressive Strength*

- Conventional Mining convert into Non –Conventional and Eco-friendly Mining in 1994 in Ambujanagar.
- First Company who introduced Surface Miner and innovated Multicap Dumper in Limestone mines. Result that all limestone mines of Gujarat are using surface miner now.
- Water Positive Company: Water Harvesting , linkge of rivers , water streams and major dam construction in Saurashtra, **Control on Salinity ingress** in Saurashtra etc .
- **Final Mine Closure** of Rampura, GALM(part), VLM, Solaj mines convert into Geoturism. Good Cricket Field development in Vadnagar in Mined Out Area.
- **Post Mining step** in fully excavated area: Agrifarm Development , revegetation and regeneration of natural ecosystem in Sugala Mines. Presently other part of mines on this way.
- **Even One cement plant established in mined out area before 2000, example Gaj Ambuja, Kodinar (Gujarat)** .
- Multi specility Hospital where Knee replacement surgery is possible , Villagers become entrepreneur in their Skill & Entrepreneurship Development Centre (**SEDI**) , their Nursing products and auto parts assembling , ladies mesons demand is more . Handicapped Care and education, Para Olympic games are few noble work.



Example from our City

- **Saoner geotourism** is centered around its unique Eco-Mine Tourism initiative, which includes guided tours of an active underground coal mine and the adjacent WCL Eco-Park. Visitors can experience the thrilling world of mining, explore educational exhibits on the coal industry, and enjoy the park's family-friendly attractions like a toy train and picnic areas. This unique geo-tourism experience combines adventure with education, offering a glimpse into India's energy sector in a sustainable, environmentally-focused way.

WCL Eco Park Saoner
Playgrounds, Recreation Centers, Tourist Attractions
Open 11:00 AM - 06:00 PM , 11:00 AM - 06:00 PM See Hours
9W8G+6J2, Savner, Bajaj Colony, Maharashtra 441107,

Example :

- WIELICZKA Salt mines, Krakow-Poland. Whatever sculptures are there, including a church, all are made of rock salt. A portion 135 meters deep and 3 kms length has been converted to a beautiful tourist spot. Some glimpses...

Post Mining :

- **Eden Project** :
- Before

After

- Reclaimed a quarry into an educational visitor attraction (>1 million visitors every year)
- Directly created >450 jobs
- Generates £150 million per year for local economy

Eden Project Work:

- Multiple greenhouse complex. World's largest greenhouse.
- Artificial biomes have plants from all over the world
- Outdoor biomes, planted landscapes and sculptures
- Classrooms and exhibition spaces
- Harvested sanitized rain water
- Energy from wind turbines and geo thermal electricity is planned to generate 4 MW power

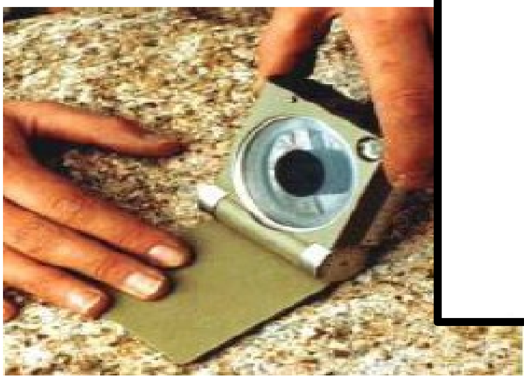
Way Forwards ....

- **Mining** is an art to attract our Societies.
- **Auther's Suggestion** :Most of opencast mining converted into pond / water lake at where there is no any filling material then go for water based Cash Crop like **MAKHANA** , **Singada**, **Kamal-Kakdi**, Fishing , Swimming club, Car Washing , Filtration project, Mineral Water Porject, Soft- drink project , Cruise , Boating, Developed Fruit Tree Garden surrounding mines , floating solar panel for power generation , water fall to generate hydro electricity where geographical advantage etc .
- **GEOTURISM is A BUSINESS** hence Treat the Mining work as an future investment .
- Post Mining Scenario is in sculpture or permanent craft for massage to new generations. Like We remember the work of our Fore-Father like **Mohan-Jo-Daro** civilisation.
- Mines reputation should with **BRAND therefore Public proud on our mining work.**
- **Way to Recurring Income even after Mining or Post Mining . Local Employment even after mining also.**
- **Propaganda or share the news of our good things of mining among Societies** , public for proving the **Positive of Mining.**

Bharat ki Surkashit , Susangthith , Suvyavsthith Khan !

Takniki ke saath samradhi Sahit Bharat ki Shaan !!!

Film on Eden Project




THANK
YOU

Digital Initaitives in O/C Mines

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Abstract — **This paper highlights the role of digital initiative in opencast mining. Opencast mining is integral part of future mining system. About 95% coal production is coming from opencast. The present demand of coal production is increasing trend creating tremendous pressure. Mining is war in peace time. We are fighting with mighty nature. Opencast Mining is going wider and deeper with steep gradient, adverse geological condition posing serious problem of stability of dump and high wall and others safety related hazards. Aging of equipment and manpower is another problem for smooth operation of O/c mine. Shortage of skilled manpower due to retirement is another issue. The coal seam is poor quality with low incubation period high moisture content which is prone to spontaneous heating hampering the quality of coal which is big issue at present. Presence of excess Black Cotton soil, problems of land acquisition, close habitations nearby mining areas with compliance of various mining and environmental related laws are another problem for smooth operation of O/c mines. Today is digital age. Every activity is digitally controlled and monitored. The Digital journey starts with capturing of data which will be utilized for planning, execution and productivity with safety improvement of the mines. Digital initiatives are tool to overcome the problem. It is way to address the above noted challenges. It is an approach to run mining business more efficiently and sustainably. Digital initiatives are use of electronic tools, system device and resources that generate, store or process data to change a business module and provide new revenue producing opportunity**

Keywords— Digital, Initiative, Opencast Mining

I. Introduction

Opencast mining is integral part of future mining system. About 95% coal production is coming from opencast. The graph of production from opencast is increasing trend but there is tremendous pressure of production to meet the present demand. Opencast Mining is going wider and deeper with steep gradient, adverse geological condition posing serious problem of dump and high wall stability with big constrain of production and others safety related hazards. Aging of equipment and manpower is another problem for smooth operation of the mine. Shortage of skilled manpower due to retirement is another issue. The coal seam is poor quality with low incubation period with high moisture content which is prone to spontaneous heating hampering the quality of coal which is big issue at present. Presence of Black Cotton soil, land acquisition, close habitations nearby mining areas with compliance of various mining and Environmental related laws are another problem for smooth operation of opencast mines.

Today is digital age. Every activity is digitally controlled and monitored. The Digital journey start with capturing of data which will be utilized for planning, execution and productivity with safety improvement of the mines. Digital initiatives is a tool to overcome the problem. It is way to address the above noted challenges. It is an approach to run mining business more efficiently and sustainably. Digital initiatives is use of electronic tools, system device and resources that generate, store or process data to change a business module and provide new revenue producing opportunity

Aim of Digital initiatives in O/C: Keeping view of vision of CIL for "Adopting the best practices from mine to market".

- **"Mine smarter not harder" so plan the mine and mine the plan**
- Real Time information and collaboration
- This automation opens up new market and yield
- Precision mining technology to process only good quality coal.
- Increase productivity 15-20% with operational efficiency and safety
- Allow to operate mining works at difficult Geo-Mining conditions with due safety.
- Solve the problem with lack of skilled manpower in O/C mining operation with increased productivity.
- Sustainability
- It will decrease operational cost & Maintenance cost
- Improve safety status in different ways
- Decrease Negative staff influence
- Real time Management & processing of statistics and data
- Automatic dispatching & optimization
- Increase equipment life by proper maintenance in time.
- Reduce fuel consumption.

The digital drivers of these models fall in to two main categories.

- The rise of internet of things
- The rise of big data

There are four pillars of the digital initiatives in mines.

- Mine Planning
- Mine Monitoring
- Data Management
- Data Analytic and predictions

Mine Planning:

Mine planning covers from creation of digital resources to exploitation of the resources and its dispatch. This area covers the following.

- Creation digital topography/Survey records
- Creation of digital resource

- Creation of digital mine plan
- Creation of Digital Mine Schedules
- Creation of digital mine dispatch.

Mine Monitoring:
Once the planning is completed, need to be monitored in real time. Following Mine Parameters will be monitored on real time basis.

- Manpower Management
- Material (Ore/Waste) Management
- Equipment/Fleet Management
- Environment Management
- Inventory Management
- Grade Control and Blending
- Slope Management
- Mine Safety
- Cost Management

Data Recording/Management
This is first step in the digitization of mine. The data is captured from various sources like satellite image, total station, probe, Sensor transmitter etc. The recording of the data should be stored and retrieved in the proper time.
Hence, date management go through four cycles.

- Data recording
- Data Storage
- Data retrieval
- Data Collaboration

Data Analytic and Prediction:
Once the data is captured, in depth analysis will be carried out for further improvement.

Current Digital initiatives taken in CIL and its Subsidiaries:

- CIL has achieved saving of INR8 Billion through E-Tendering and reverse auction on E-Procurement platform. The company is leveraging ECT for other business operation such as Finance, Material, Management, Personnel, Production and Sales & Marketing. CIL has also implemented GPS/GPRS based vehicle tracking, Electronic Surveillance and RFID Tagged trucks to restrict unauthorized activity.

- NCL a CIL subsidiary plan to use unmanned aerial vehicles, UAVs for survey and ground profile of 4 to its 10 mines. The miner has introduced operator independent truck dispatch system (OITDS) in 5 Mega Project and laser scanner and automated total station for surveying and monitoring the mine. A digital drive is being taken through machine learning by adopting software in Drag-line and Shovels and providing real time interface facility for monitoring equipment and Pay Load data as well as vehicle health.

Digital Initiatives adopted in O/C:
Real Time Slope Monitoring Device for stability of dumps and high wall.

- Drone Survey is being done for stability of dumps and high wall.
- RFID tag and boom barrier
- Geo fencing, GPS/GPRS based vehicle tracking system to restrict unauthorized entry.
- CCTV Camera, extensive use of CCTV camera for various activities
- Robotic Total Station, Digital Plani Meter
- On line training and meeting through video conferencing
- Bio-metric attendance in all mines
- E-Procurement & E-Tendering
- E-Office & ERP
- Use of Slope Stability Radar for Dump Stability.
- Smart pump truck for explosive charging

Future scope of work for digital initiatives in O/C :

- More use of automated total station for survey related work.
- Use of Drone Survey for mine planning & other safety related job.
- Introduction of OITDS (Operator independent truck dispatch system.)
- Use of more Nos. of slope stability radar for dump stability
- Use of mining surveillance system (MSS) a satellite-based surveillance network to check the illegal mining & other safety & security related work
- Blast design software and Blast information and management system(BIMS)
- Sensor based float with alarm for continuous water level measurement.
- Digital image analysis technique for fragmentation assessment.
- Use of 3-D laser profiler.
- Burden finder, high speed photography with MAS (Motion Analysis Software)
- Borehole TV Camera for hole deviation.

Limitations of Digital Initiatives:

- Lack of Technical Skill & poor training facilities and awareness.
- Poor network connectivity and bandwidth issues.
- Mindset of existing resources.
- Data integrity and protection.
- Absence of historical database for decision making.
- Lack of proper instrumentation.
- Lack of trained manpower for data collection and interpretation.
- Lack of R & D support.

Conclusion: Digital India is the dream of our honourable Prime Minister Shri Modi Ji. If we want to achieve the dream of our respected Prime Minister and for real improvement in mining industries we must go for Digital initiatives in our mines and then we can also match with the existing international standards.

For implementing Digital initiative in mines our valuable experience people and young talent of Digital India needs to collaborated to fulfil the demand of production, productivity, machine efficiency, safety and security at desired level.

Then only coming days will be sunrise day for mining industries.

REFERENCES

National seminar for digital initiatives in mining sector.

Challenges in Indigenous Bauxite Resources and Promoting Responsible Mine Closure — A Step Toward Ātmanirbhar Bhārat in Aluminium Production

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West Coast Mines, Hindalco Industries Limited, Kolhapur

Abstract

Hindalco Industries Limited (HIL), a flagship company of the Aditya Birla Group and India's largest integrated primary aluminium producer, operates a vertically integrated value chain from bauxite mining to downstream fabrication. Central to this is the Belagavi Alumina Refinery, which has a production capacity of 350,000 tons annually and employs around 2,000 people. For over 40 years, the refinery has primarily depended on bauxite deposits in Kolhapur District, Maharashtra, sourced from key mining leases including Durgamanwadi and Dhangarwadi mines.

In response to evolving operational and environmental considerations, HIL formally closed and surrendered two principal leases: Dhangarwadi and Durgamanwadi. The company secured Final Mine Closure Plan (FMCP) approval from the Indian Bureau of Mines (IBM) for both leases on 30th September 2025, demonstrating compliance with stringent environmental reclamation standards.

The FMCP implementation included comprehensive reclamation and rehabilitation (R&R) activities such as backfilling mined-out pits, and executing three-tier afforestation using native species. At Dhangarwadi, additional measures involved the development of rainwater harvesting structures, conversion of a mined-out area into a water pond, afforestation with native species, and installation of proper fencing as per regulatory standards.

While these closures reinforce HIL's commitment to environmental stewardship, they have introduced a significant challenge of mineral scarcity for the Belagavi Alumina Plant. Currently, raw material supply is sustained through imports and procurement from other states. To secure long-term sustainability, HIL is actively preparing to participate in upcoming mineral block auctions in Maharashtra. Acquisition of new concessions is critical for ensuring a stable raw material supply, projected to generate economic value of INR 2,500–3,000 crores for the government exchequer, supporting both industrial continuity and regional development.

The case of HIL's Kolhapur bauxite mines serves as a comprehensive model for balancing industrial demand, stringent environmental compliance, and forward-looking mineral resource management in India.

Introduction

Bauxite, the primary ore of aluminium, holds critical strategic and industrial importance in rapidly industrializing economies such as India. Aluminium's versatile applications across aerospace, automotive, construction, electrical transmission, packaging, and downstream manufacturing underscore its indispensability to national development. Consequently, the domestic availability of bauxite directly impacts the capacity and sustainability of India's aluminium production. India ranks among the top five countries globally in bauxite reserves, with approximately 3 billion tons spread across Odisha, Jharkhand, Chhattisgarh, Gujarat, and Maharashtra.

In Maharashtra, bauxite deposits are mainly concentrated in the Kolhapur, Satara, and Ratnagiri districts. These deposits typically occur as lateritic cappings over basaltic formations, presenting geological complexities that influence mining methods, extraction efficiency, and environmental management. Ore thickness is often shallow, necessitating carefully balanced operational planning to optimize productivity while preserving ecological integrity.

Hindalco Industries Limited (HIL)'s Belagavi Alumina Refinery, located in Karnataka, serves as a crucial node in India's aluminium value chain. Commissioned several decades ago, it relies predominantly on bauxite sourced from the Kolhapur district, situated approximately 100–150 km away. The proximity of these deposits has historically enabled logistical efficiency, reduced transportation costs, and ensured steady raw material supply. With an annual production capacity of 350,000 tons and a workforce of around 2,000 employees, the refinery plays a vital economic role. Continuous bauxite supply is essential not only for alumina production but also for downstream aluminium smelting and fabrication of products such as sheets, foils, extrusions, and alloy wheels.

Disruptions in raw material sourcing thus carry direct operational, economic, and strategic consequences for both HIL and the regional industrial ecosystem.

Maharashtra presents a paradox in bauxite mining: while endowed with significant mineral wealth—especially in the Kolhapur plateau region—the state's ecologically sensitive zones, wildlife sanctuaries, and strict regulatory frameworks impose substantial operational constraints. Although bauxite deposits exist in abundance, environmental and statutory restrictions limit extraction intensity, often requiring alternative compliance approaches such as financial contributions for reclamation and rehabilitation (R&R) instead of conventional mining.

Mining activities in Kolhapur have a history spanning over 50 years. HIL began operations in 1968 with five mining leases, followed by an additional lease in 2008. Throughout, the company has prioritized responsible mining practices, including controlled excavation, preservation of native flora, and ecological restoration of mined-out areas. These efforts have maintained hydrological stability, minimized soil erosion, and sustained seasonal water channels. For instance, partially regenerated mined-out zones have contributed to soil stabilization and reduced landscape fragmentation. Low-impact extraction methods have helped preserve the ecological viability and biodiversity of virgin lease areas.

Mining operations have also delivered significant socio-economic benefits to local communities, including direct employment, skill development, and regional industrial growth. The Belagavi refinery's dependence on Kolhapur bauxite extends its impact across a broader supply chain encompassing transportation, ancillary services, and downstream aluminium processing industries. However, mineral depletion and regulatory restrictions necessitated the surrender of the Durgamanwadi and Dhangarwadi leases. While this reduces the operational footprint, it also opens avenues for strategic intervention, such as participating in mineral block auctions. These auctions are expected to generate substantial economic value—estimated between INR 2,500 and 3,000 crores—for both state and central governments, alongside creating new employment opportunities. Ensuring operational continuity at Belagavi remains central to HIL's strategic vision. Lease surrenders, though necessary, require proactive steps to secure long-term bauxite supply. By fulfilling statutory obligations through Final Mine Closure Plan (FMCP) activities and planning for future mineral block acquisitions, HIL aims to mitigate operational risks while sustaining mineral supply stability.

Maharashtra's mining landscape, marked by abundant resources constrained by environmental and regulatory factors, highlights the critical need for strategic foresight, adaptive operational planning, and responsible mining practices. HIL's approach in Kolhapur exemplifies a balanced model where industrial objectives, environmental stewardship, and regulatory compliance coexist to support sustainable production and regional development.

This article provides a comprehensive, multi-dimensional analysis of HIL's mining operations in Kolhapur. Key objectives include:

1. Documenting operational and environmental practices in Durgamanwadi and Dhangarwadi mines.
2. Analyzing land-use patterns and ecological restoration efforts.
3. Reviewing statutory compliance processes, including FMCP approvals and alternative R&R strategies.
4. Highlighting strategic adaptations to ensure industrial continuity at the Belagavi refinery.
5. Offering a case study framework for sustainable bauxite mining applicable to similar ecologically sensitive regions in India and globally.

Mining Practices Employed at HIL Mines while the Mine was in Operation:

When Durgamanwadi and Dhangarwadi mines was in operation, HIL has adopted a range of sustainable and environmentally sensitive mining practices to minimize the ecological footprint of its operations. Mining activities are carefully planned and executed in small, manageable areas to limit environmental disturbance and facilitate efficient reclamation. The introduction of ripper dozers allows for gentle earth-cutting with minimal noise, dust, and ground vibrations, eliminating the need for drilling and blasting. Systematic handling of overburden and well-organized dump management ensure site stability and reduce ecological disruption. To preserve soil fertility, topsoil is meticulously conserved during excavation and reused in reclamation efforts to promote natural vegetation growth. Mobile crushers and screening units have replaced stationary crushers, enabling mining to be localized to smaller zones, thereby reducing vehicle movements, diesel consumption, and dust generation along haul roads. Effective dust suppression was maintained through atomized spraying systems on crushers and regular water spraying on haul roads by mobile tankers, resulting in consistently low dust levels. Additionally, rainwater harvesting structures and percolation ponds was developed within the mining areas to capture stormwater, which was then used for dust control and afforestation, significantly reducing groundwater dependency. These integrated practices reflect HIL's commitment to responsible mining, balancing operational efficiency with environmental stewardship.

HIL Pioneering Final Mine Closure Plan (FMCP) Implementation

The Final Mine Closure Plan (FMCP) represents the culminating legal and ecological obligation in the lifecycle of any mineral concession in India. It is a statutory mechanism meticulously designed to ensure that mining, a necessary but disruptive activity, ends with the comprehensive rehabilitation and ecological restoration of the mined-out area. The foundation of the FMCP lies within the primary regulatory framework governing the sector: the Mines and Minerals (Development and Regulation) Act, 1957 (MMDR Act), and its subordinate legislation, the Mineral Conservation and Development Rules, 2017 (MCDR, 2017). These legal instruments explicitly mandate that responsibility for environmental protection rests squarely with the mining leaseholder.

Specifically, Rule 24(1) of MCDR, 2017, stipulates a critical planning requirement: "The holder of a mining lease shall submit a final mine closure plan to the competent authority for approval at least two years prior to the proposed closure of the mine." This provision ensures that closure is a planned, phased process, not an abrupt abandonment. Furthermore, Rule 26(1) of MCDR, 2017, cements the operator's duty, mandating that the leaseholder "shall have the responsibility to ensure that protective measures, including reclamation and rehabilitation works, are carried out in accordance with the approved mine closure plan." The FMCP, therefore, serves as the binding blueprint for action.

The purpose of the FMCP extends beyond mere physical stabilization; it encompasses the prevention of soil erosion, protection of local hydrology (e.g., through rainwater harvesting structures), and the regeneration of vegetation to restore ecological balance. The Indian Bureau of Mines (IBM) acts as the central authority overseeing and approving FMCPs, verifying both statutory compliance and technical adequacy before granting the FMCP Completion Certificate. The FMCP is duly approved by the IBM via the FMCP online portal under the Mining Tenement System developed by the IBM. This same portal also facilitates information regarding the Completion of the FMCP. Upon receipt of the duly approved FMCP Completion Certificate, the lessee must submit FORM D, a notice of abandonment, followed by receiving back the Bank Guarantee/Performance Security from the IBM.

Durgamanwadi Bauxite Mine

The Durgamanwadi Bauxite Mine, located in Radhanagari Taluka, Kolhapur District, was one of HIL's oldest mining leases, granted in 1968. By 2018, approximately half of the mined-out land—around 50%—had undergone reclamation and rehabilitation (R&R) efforts. Over several decades, the mine consistently supplied bauxite to the Belagavi Alumina Plant, supporting uninterrupted operations. However, due to statutory requirements, environmental concerns, and near exhaustion of mineral reserves on the plateaus, the mine was proposed to be closed.

The FMCP implementation adopted a comprehensive approach. Mined-out benches were reshaped and stabilized to prevent soil erosion and ensure safe slopes. Afforestation covered roughly 31% of the mined-out area, with over 7,500 saplings of native tree species planted, selected for their adaptability to lateritic plateau soils. Responding to the requests of local villagers, a significant portion of the reclaimed mined-out land,approximately 45%—was converted into grasslands to support cattle grazing. This involved seeding with suitable grass species to enhance pasture quality. Additional measures included trenching and fencing along the periphery of the mined-out zones to prevent soil runoff and unauthorized entry. Water harvesting pits were constructed at strategic low points to capture seasonal rainfall, promote groundwater recharge, and support vegetation growth.

Following verification of these site-specific interventions and confirmation that reclamation, afforestation, and water management met all regulatory standards, IBM formally approved the FMCP work and issued the FMCP Completion Certificate on 30th September 2025. Since then, HIL has actively monitored the site to ensure the successful establishment of vegetation and stabilization of the reclaimed terrain.

Dhangarwadi Bauxite Mine

The Dhangarwadi Bauxite Mine, located in Shahuwadi Taluka, Kolhapur District, was granted to Hindalco Industries Limited (HIL) in 2008 to support the raw material requirements of its Belagavi Alumina Refinery. Of the total lease area, approximately 85% was subjected to mining operations, while the remaining 15% was left undisturbed as virgin land. Prior to the implementation of the Final Mine Closure Plan (FMCP), reclamation and rehabilitation (R&R) efforts had already been undertaken on nearly 50% of the mined-out area. This left around 45% of the disturbed land available for further FMCP activities. With the bauxite reserves nearing depletion, HIL applied for FMCP activities. Approval was granted by the Government of Maharashtra (Mantralaya), followed by formal consent from the Indian Bureau of Mines (IBM) to proceed with mine closure and reclamation in compliance with statutory requirements.

The FMCP implementation at Dhangarwadi prioritized ecological restoration, slope stabilization, and sustainable land rehabilitation. Mined-out benches were reshaped and stabilized to ensure geotechnical safety and prevent erosion. Afforestation efforts were carried out over the remaining rehabilitable area, with approximately 11,155 native saplings planted, including species such as Awala, Jamun, Karanj, Bamboo, Chaffa, Phanas, Guava, Bakul, Cashew, and Lagerstroemia. These species were selected based on their adaptability to lateritic soil conditions and ecological value. To prevent soil erosion and support vegetation growth, trenching was undertaken along natural drainage lines, and vulnerable slopes were fenced to protect regenerating areas. Shrubs and bushes were planted on slopes to enhance stability and reduce runoff. Additionally, strategically placed water harvesting pits were excavated to capture monsoon runoff, promote groundwater recharge, and support afforestation during dry periods. Natural regrowth of vegetation in some parts of the mined-out area further complemented active restoration efforts.

Following the joint site inspection and verification of compliance with the Mineral Conservation and Development Rules (MCDR) 2017, IBM granted final approval and issued the FMCP Completion Certificate. This allowed HIL to formally surrender the lease, having fulfilled all environmental and statutory obligations while ensuring long-term ecological sustainability.

Table: List of Native Species Planted as a part of FMCP Implementation Works in Both Mines

Sl. No	Common Name (Local)	Common English Name	Scientific Name
1	Jamun	Malabar Plum / Black Plum	*Syzygium cumini (Syn: Eugenia Jambolana)*
2	Amba	Mango	*Mangifera indica*
3	Shisam	Indian Rosewood / Blackwood	*Dalbergia latifolia*
4	Awala	Indian Gooseberry	*Phyllanthus emblica*
5	Karanj	Indian Beech / Pongam Tree	*Pongamia pinnata*
6	Bamboo	Common Bamboo	*Bambusa vulgaris*
7	Chaffa	Frangipani / Temple Tree	*Plumeria rubra*
8	Phanas	Jackfruit	*Artocarpus heterophyllus*
9	Gauva	Guava	*Psidium guajava*
10	Bakul	Spanish Cherry / Bullet Wood	*Mimusops elengi*
11	Cashew	Cashew Nut	*Anacardium occidentale*
12	Lagerstroemia	Queen Crape Myrtle / Jarul	*Lagerstroemia speciosa*

Photograhs of reclamation works during FMCP like Planation/Trenching Fencing at Dhangarwadi Bauxite Mines

HILs Bauxite Sourcing Challenges

Over recent years, the Belagavi Alumina Refinery has faced significant challenges in securing a consistent supply of bauxite. These challenges stem from a combination of mineral exhaustion, statutory restrictions, and the expiry of key mining leases. Both the Durgamanwadi and Dhangarwadi mines have reached the end of their economically viable operational life, with large portions of their reserves already extracted and subject to closure under the Final Mine Closure Plan (FMCP). Consequently, a substantial part of the plant's historic raw material base is now under closure, creating an immediate risk of supply disruption.

This situation poses a critical operational challenge for the Belagavi plant, which directly employs approximately 2,000 workers and supports a broader supply chain. Any interruption in bauxite supply could negatively impact production schedules, aluminium output, export commitments, and regional employment.

Further compounding the challenge is the restriction under Section 6 of the Mineral Mines and Development and Regulation (MMDR) Act, which limits a single owner from holding mineral concessions exceeding 10 km² within a state. This statutory constraint restricts the expansion of existing leases, thereby limiting HIL's ability to extend current mining operations.

To mitigate these risks and ensure sustainable raw material availability, HIL has adopted a multi-pronged strategic approach:

- Participation in Mineral Block Auctions: HIL is actively engaging in upcoming auctions conducted by the Government of Maharashtra to secure new long-term mining leases. This strategy aims to diversify and stabilize its bauxite supply portfolio.
- However, due to non-Captive mining sources in Kolhapur, HIL is compelled/ forced to import bauxite from foreign countries and very long distant places, which results in substantial foreign exchange loss and increased operational costs. Furthermore, recent import restrictions by various countries have further intensified our supply challenges effecting the production of our Alumina Plant.

This comprehensive strategy reflects HIL's commitment to balancing industrial continuity, regulatory compliance, and environmental stewardship. Moreover, securing new mining blocks offers the potential to generate significant economic value—estimated between ₹2,500–3,000 crores—for the state and central exchequer, while creating employment opportunities that foster inclusive regional development.

Plea of Hindalco:

- ✓ **Exclusion of mineral bearing land** from "Eco Sensitive Areas (ESA)" of Western Ghat preferably entire bauxite bearing areas of Kolhapur District , so that sizable metallurgical grade bauxite mine/other mines can be auctioned by State Govt of Maharashtra.
- ✓ **Proactive Policywise support** from the State Government for resuming our Captive mines for ensuring Mineral Security for our Alumina Plant.
- ✓ Expediting **e-Auctioning** of new Bauxite Mining Blocks at Maharashtra to facilitate the Acquiring the new Bauxite blocks to our Belgaum Plant.
- ✓ Revisions to mining lease area limits under Section 6(1)(b) of the MMDR Act, 1957 for bauxite in Maharashtra:
    - **Mining Lease Limit:** Increase from **10 sq. km to 50 sq. km**.
    - **Prospecting License Limit:** Increase from **50 sq. km to 100 sq. km**
- ✓ This will facilitate **seamless industry participation**, align with the policy of **Atminirbhar Bharat** by the Central Government, and ensure the **long-term sustainability** of our **Alumina Plant**.
- ✓ This facility is the key asset to **Regional and National Economic growth**, and its stability will support numerous industries and employment sectors.

Conclusion

While Hindalco Industries Limited's (HIL) pursuit of new captive mine leases reflects a proactive and forward-looking approach to ensuring long-term raw material security amidst regulatory and ecological challenges, our ongoing FMCP implementation and lease surrender initiatives reaffirm HIL's unwavering commitment to environmental stewardship and responsible mining. The evolving landscape of bauxite sourcing presents a valuable opportunity to strengthen industry government collaboration. With progressive policy measures, streamlined lease frameworks, and a shared focus on sustainable mining under the vision of Atmanirbhar Bharat, India is well-positioned to achieve both resource security and ecological balance enabling continued industrial growth in harmony with the environment.

Unlocking India's Progress: Pathways to Growth, Innovation, and Sustainability

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India's Mining Legacy and Contemporary Excellence

India's mineral heritage represents one of humanity's oldest and most sophisticated resource extraction traditions, spanning from prehistoric flint quarrying operations during the 3rd century BCE to pioneering zinc distillation techniques developed at Zawar, Rajasthan around 1200 CE. The subcontinent's metallurgical innovations included early iron working by 1800 BCE and gold extraction methods documented in Kautilya's Arthashastra (300 BCE), establishing foundational practices that continue to influence modern mining operations.

The transition to commercial-scale operations began with the East India Company's coal mining initiatives in 1774 at the Raniganj Coalfield, which expanded from 1 million tonnes annually by 1853 to 18 million tonnes by 1920. Post-independence development accelerated through strategic policy evolution, including the Mineral and Metal Trading Corporation (MMTC) Act of 1948, economic liberalization in 1991, and the transformative National Mining Policy of 1993 that opened thirteen major minerals to private sector participation. The nationalization of coal in 1971-72 and 1973 further strengthened India's energy security foundation.

Record Production and Resource Supply

Building upon this rich heritage, India's mineral industry achieved unprecedented production milestones in FY 2024-25, with overall mineral production demonstrating robust growth across multiple categories. Iron ore production reached an all-time high of 289 million metric tonnes (MMT), marking a 4.3% increase from the previous year's record of 277 MMT. This achievement is particularly significant as iron ore accounts for 70% of total Mineral Conservation and Development Rules (MCDR) mineral production by value.

Coal production achieved historic levels at 1047.57 million tonnes in FY 2024-25, compared to 997.83 million tonnes in FY 2023-24, demonstrating a growth rate of 4.99%. Coal India Limited contributed 781.08 million tonnes, representing steady growth, while commercial and captive mining entities achieved remarkable expansion with production reaching 197.50 million tonnes, marking a substantial 28.11% increase from 154.16 million tonnes in the previous year.

Additional production achievements include manganese ore production surpassing previous records with an 11.8% increase from 3.4 MMT to 3.8 MMT, bauxite production growing by 2.9% from 24 MMT to 24.7 MMT, and lead concentrate output increasing by 3.1% from 381 thousand tonnes to 393 thousand tonnes. In the non-ferrous metals segment, primary aluminium production achieved new records, climbing from 41.6 lakh tonnes to 42 lakh tonnes, while refined copper output demonstrated robust growth of 12.6%, rising from 5.09 lakh tonnes to 5.73 lakh tonnes. These achievements underscore India's position in the global mineral scenario.

Economic and National Development Contribution

The record-breaking production achievements cements the mining and quarrying sector as a crucial driver of India's economic aspirations toward becoming a $5 trillion economy. The sector's Gross Value Added (GVA) at current prices reached ₹5,39,567 crore in FY 2024-25, representing 1.84% of total national GVA and demonstrating a growth of 2.6% over the previous year. The value of mineral production (excluding fuel, atomic, and minor minerals) for the period 2025-26 (April-July) is estimated at Rs. 51,143 crores, as against Rs 49,578 crore during the corresponding period of 2024-25.

This surge in production has translated into substantial fiscal benefits, District Mineral Foundations (DMF), established under the MMDR Amendment Act 2015, have collected over ₹1,03,242 crore since their inception, with projections indicating potential collections of ₹3,00,000 crores between 2025-2035. DMFs operate as non-profit trusts in 645 districts across 23 states, focusing on mining-affected communities' welfare. High priority work under DMFs (70% of funds) centres on education, drinking water supply, health, welfare of women and children, environment preservation, pollution control, and skill development. Various skill development programs under the National Skill Development Corporation continue to enhance workforce capabilities, addressing the sector's evolving technological requirements and supporting just transition initiatives for workers in transforming industries.

The mining sector provides substantial employment opportunities, employing approximately 1.25 crore people directly and indirectly, with a total value of production estimated at ₹1.40 lakh crore. The sector contributes approximately 2.5% to India's GDP and creates millions of direct and indirect jobs, making it essential for reducing the fiscal deficit and critical for socio-economic growth

Technological Advancement and Innovation

The socio-economic development in the mining industry is a direct outcome of the adoption of technological advancement and modernisation in all spheres of the sector. The sector has embraced comprehensive technological modernization through implementation of key technologies like in-pit crushing, facilitated by semi or fully mobile crushing plants, conveyorization of mines, electrification of mining operations thereby reducing diesel consumption and sourcing of electricity from renewable sources. The government's S&T-PRISM programme supports technological advancement in mining, mineral processing, metallurgy, and recycling sectors.

Advanced technologies transforming Indian mining operations include GPS and remote sensing in mineral surveying, real-time data analytics for operational optimization, AI-driven mineral grading systems, mechanized continuous miners, and drone-based topographic surveys are transforming Indian mining operations while enhancing productivity and bolster system reliability eve in adverse weather conditions. The industry wide mechanization has played a pivotal role in the mining field by reducing the time without compromising the assured quality as well as maintaining the threshold with environmental aspects.

Environmental Stewardship

Environmental management initiatives include air quality monitoring, water recycling systems, green belt creation, and comprehensive mine closure plans that integrate biodiversity restoration. Companies are implementing closed-loop water systems, renewable energy integration using solar, wind, and hydro power, and waste-to-resource initiatives that transform mine waste such as tailings, overburden, and slag into useful materials for construction, agriculture, or road building.

To ensure environmentally responsible and socially inclusive mining, India must align with globally recognized best practices that uphold sustainability at their core. The adoption of robust ESG frameworks is imperative—not only to mitigate operational and reputational risks, but also to safeguard local communities and reinforce India's long-term economic resilience. Strategic policy instruments such as the National Mineral Policy 2019 and the Sustainable Development Framework (SDF) have laid a strong foundation, promoting transparency, ecological stewardship, and social equity across the sector. With a clear commitment to decarbonization, India has set an ambitious target to reduce its mining-related carbon footprint by 30–40% by 2030 through sustainable innovation and systemic reform.

Policy Reforms and Strategy

Contemporary reforms encompass transparent auction processes, enhanced exploration policies, and expanded private sector participation to strengthen the sector's contribution to national development. These initiatives align with India's vision of Atmanirbhar Bharat while addressing the dual imperatives of economic growth and environmental stewardship. The government launched multiple tranches of critical mineral auctions throughout 2024-25, demonstrating commitment to transparent resource allocation. The sixth tranche in September 2025 included 23 comprising a diverse basket of minerals such as REE, Tungsten, Lithium, Tin, Graphite, Vanadium, Titanium, Cobalt, Zirconium, Gallium, Rock Phosphate, Potash, and Rare Metals. Legislative reforms included the Mineral (Auction) Amendment Rules 2024 and the Offshore Areas Mineral Conservation and Development Rules 2024. India's first offshore mineral blocks auction offering 13 offshore mineral blocks for composite licenses was held in November 2024.

The Union Cabinet approved the National Critical Mineral Mission (NCMM) on January 29, 2025, with an expenditure of ₹16,300 crore and expected investment of ₹18,000 crore by

Public Sector Undertakings over seven years from 2024-25 to 2030-31. The mission encompasses all stages of the value chain, including mineral exploration, mining, beneficiation, processing, and recovery from end-of-life products. Union Budget 2024-25 announced the elimination of customs duties on 25 critical minerals, expanded to 40 critical minerals in Budget 2025-26.

International Cooperation and Resource Security

To secure India's resource security, the Khanij Bidesh India Limited (KABIL) signed an Exploration and Development Agreement with CAMYEN of Argentina in January 2024 for exploration and mining of 5 lithium blocks. The Ministry signed a Memorandum of Understanding with the International Energy Agency (IEA) in November 2024 for cooperation in critical minerals. KABIL has established strategic partnerships with International Resources Holding RSC Ltd. (IRH) of UAE and Uranium One Group, a subsidiary of Russia's state-owned Rosatom, strengthening India's position in uranium and rare-earth supply chains. The company is actively pursuing overseas assets in Australia and Chile, with advanced discussions for lithium and cobalt mining opportunities.

These international engagements reflect India's strategic approach to securing critical mineral supplies while sharing technological expertise and best practices that emphasize environmental responsibility, ethical practices, and long-term resource management.

Framework for Sustainable Mining Operations

It is pertinent to highlight two foundational pillars that should underpin the framework for sustainable mining operations: the principles of a circular economy and the imperative of a just transition. A circular economy is a regenerative economic system designed to eliminate waste and keep products and materials in use for as long as possible, contrasting with the traditional linear model of "take-make-dispose". Its core principles include designing out waste and pollution, keeping products and materials in use through repair, reuse, and recycling, and regenerating natural systems. The goal is to decouple economic growth from resource consumption while fostering innovation, creating new jobs, and providing economic and environmental benefits through adoption of circular economy principles.

The Indian mining sector is increasingly embracing circular economy practices, with the potential to reduce mining waste by up to 50% by 2035. Zero waste mining aims to minimize waste generation and maximize resource efficiency through innovative practices, creating a circular economy within the sector. The government launched a ₹1,500 crore Critical Mineral Recycling Incentive Scheme in October 2025, targeting extraction of critical minerals from secondary sources such as e-waste, spent lithium-ion batteries, and industrial scrap. The scheme offers both capital expenditure (Capex) and operational expenditure (Opex) subsidies to incentivize private and public sector participation in establishing state-of-the-art recycling facilities.

Coal companies have implemented comprehensive circular economy models including eco-park creation, mine water utilization, plantation reclamation, processed overburden management, bottom ash utilization, and renewable energy promotion. The IEA notes that scaling up recycling could reduce new mining capacity needs by 25-40% for critical minerals by 2050, with copper and cobalt being prime candidates for this approach.

Next in line is Just Transition. Since the industrial revolution, fossil fuels have powered extraordinary growth and development, albeit with huge costs to our climate. As a direct result, we are today in a climate emergency. To avert catastrophe, we must now radically switch to a sustainable, net-zero future. This transition needs to happen fast, but it also has to happen in a fair and inclusive way. A structured approach to ensure that the economic and social transformation towards a green and sustainable economy is fair, inclusive, and leaves no one behind, particularly in sectors like energy transition. This is particularly important in the Indian context where aspiration for better living conditions is growing amid a contrasting call for reduction in carbon footprint.

India's just transition strategy should be congruent with the country's net zero target by 2070 and energy independence target by 2047. The coal mining sector, which employs around 300,000 permanent and 500,000 contract workers, requires careful planning as India transitions away from coal towards renewable energy. The Ministry of Coal has established a Sustainability & Just Transition Division to minimize adverse impacts of mining and establish sustainable environments around coal regions to improve ecosystem services. A phased approach is being adopted, initially focusing on old and unprofitable coal mines and power plants while developing comprehensive roadmaps for broader decarbonization. This structured approach ensures that the economic and social transformation towards a green and sustainable economy remains fair, inclusive, and leaves no one behind, particularly important in the Indian context where aspirations for better living conditions must be balanced with calls for carbon footprint reduction.

Energy Security and Industrial Growth Drivers

Coal remains crucial to India's energy security, contributing 55% to the national energy mix and fuelling over 73% of total power generation. Under the Atmanirbhar Bharat initiative, domestic raw coking coal production is projected to reach 140 MT by 2030, with current production at 66.821 million tonnes in FY 2023-24. The continued growth in iron ore production reflects robust demand from the steel industry, while growth in aluminium and copper production indicates strong economic activity across energy, infrastructure, construction, automotive, and machinery manufacturing sectors.

The sector's growth necessitates significant infrastructure development, including dedicated freight corridors, port modernization under the Sagarmala initiative, and inland container depot development. Mining expansion has catalysed the development of roads, railways, ports, and bulk material handling systems, creating multiplier effects in the economy and supporting regional development initiatives. The Mining Index indicated a 9% improvement in clearances timelines and reduction in approval bottlenecks, aided by single window digital portals and e-auction systems.

Future Challenges and Opportunities

While the sector demonstrates robust growth, challenges remain in balancing economic expansion with environmental protection and social welfare. The continued growth trajectory requires sustained investment in technology, infrastructure, and human capital development while maintaining ecological stewardship. Future strategies should focus on enhanced exploration capabilities, strengthened international partnerships for critical mineral security, improved community engagement mechanisms, and accelerated adoption of clean technologies. The transition towards circular economy practices and just transition frameworks will be crucial for ensuring the sector's long-term sustainability and social acceptability.

Conclusion

India's mineral industry in 2024-25 demonstrates remarkable achievements building upon millennia of mining heritage. With a GVA contribution of ₹5,39,567 crore and record-breaking production across key minerals, the sector remains fundamental to India's economic development aspirations. The successful implementation of policy reforms, transparent auction mechanisms, and sustainable mining practices positions the industry for continued growth while addressing social and environmental responsibilities.

From ancient flint quarrying in the Indus Valley to modern critical mineral exploration, India's mining journey reflects continuous innovation and adaptation. The sector's trajectory aligns with India's vision of becoming a $5 trillion economy through strategic resource utilization, technological innovation, and inclusive development. The integration of circular economy principles and just transition frameworks, combined with traditional wisdom and contemporary technology, positions India's mineral industry as a model for responsible resource development in the 21st century.

The adoption of these frameworks—circular economy for resource efficiency and just transition for social equity—will ensure that India's mineral industry continues to drive economic growth while maintaining ecological integrity and social harmony. Continued focus on exploration, international cooperation, sustainable practices, and stakeholder engagement will secure the mineral industry's pivotal role in India's economic transformation, creating a legacy of responsible mining that benefits current and future generations.

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Fly Ash & Bottom Ash Application in Underground Coal Mines as Stowing Material: Review with Case Studies

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1. Introduction

In underground coal mining, stowing is an important process used to control the movement of rocks above the mined-out area (strata control) and to reduce or prevent the land sinking on the surface (surface subsidence). For many years in India, river sand has been the most popular and widely used stowing material because it has excellent properties for these purposes. Hydraulic sand stowing (where sand is mixed with water and pumped underground) is simple and has many advantages: sand and water separate easily, water drains out quickly, less clogging in barricades, low water pressure on barricades, provides strong consolidation with minimum shrinkage. Also, river sand is considered as a hygroscopic material in nature and has peculiar properties like it stands on its own weight. However, river sand is now in short supply, so mining industry is searching for other cheap and easily available materials near to the coal mines. One potential alternative is fly ash and bottom ash — a waste product from the thermal power plants, created after burning pulverized coal. This waste causes an environmental problem and requires huge land areas on the surface for its disposal. In India: around 75% of electricity comes from the thermal power plants and 90% of these are coal-based (Fig.1). The coal used contains 30–50% ash (Pandian, 2004), producing very large amounts of fly ash. Currently, India produces about one billion tonnes of fly ash every year (Singh et al., 2005). The use of fly ash and bottom ash for mine stowing could help in two ways first in the power sector: Mine (often located near to power plants) can act as safe disposal site for fly ash and bottom ash. Second in Mining sector: Mines get low-cost filling material that improves safety and stability (without possessing harmful effects on the environment and humans too).

Additionally, trucks (dumpers) that deliver coal to power plants can carry fly ash and bottom ash back to the mines on their return trip thus reducing transportation costs. Although some believe fly ash stowing is less effective than sand stowing. However, reported research has shown that with proper techniques and mixing with some suitable waste materials from mine, fly ash and bottom ash can be used successfully. Reported studies (Karfakis et al., 1996) found that it can be used like other stowing materials such as sand or coal mine waste. If the maximum possible amount of fly ash and bottom ash is used for strata control in underground mines, it can reduce both: i) the problems caused by the shortage of sand & ii) the environmental issues arising out of from disposing large quantities of coal combustion by- products (CCBs).

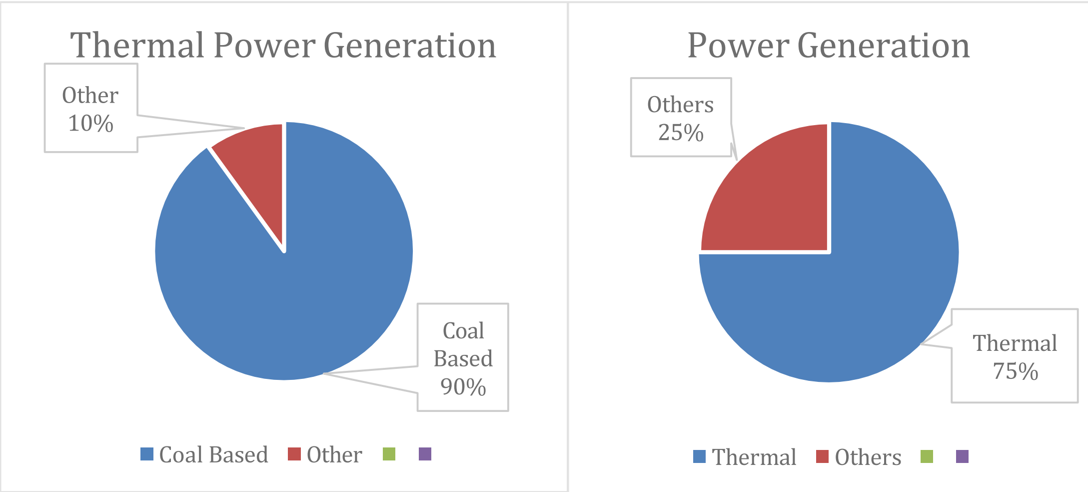

Fig. 1. Indian power generation. (Mishra, 2007)

2. Chemical Properties

The composition of fly ash depends on the type of coal being fired and is strongly influenced by factors such as the geology of the coal deposit, combustion conditions, and the efficiency of emission control systems. The minerals and organic matter presence in the coal largely govern the chemical composition of the ash produced during burning. Chemically, fly ash is generally comprised mainly of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3) and calcium oxide (CaO) (Openshaw et al., 1992). Smaller amounts of magnesium oxide (MgO), manganese oxide (MnO), phosphorus pentoxide (P_2O_5), potassium oxide (K_2O) and titanium dioxide (TiO_2) are also present. The main mineral phases found in fly ash also include: Aluminosilicate glass, Mullite ($Al_6Si_2O_{13}$), Quartz (SiO_2), Magnetite (Fe_3O_4), Anorthite/Albite ((Ca, Na) (Al, Si_4O_8), Anhydrite ($CaSO_4$), Ettringite ($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$), Opaline silica ($SiO_2$), Hematite ($Fe_2O_3$) and Lime (CaO). (Mishra, 2007).

Fly ash also differs depending on the coal type used. For example, lignite and sub-bituminous coals generally produce ash with higher calcium and magnesium content, but lower silica, iron and carbon compared to bituminous coal fly ash. (Mishra, 2007). Fig. 2 shows the chemical composition of fly ash for various coal types like Bituminous, Sub- bituminous and Lignite.

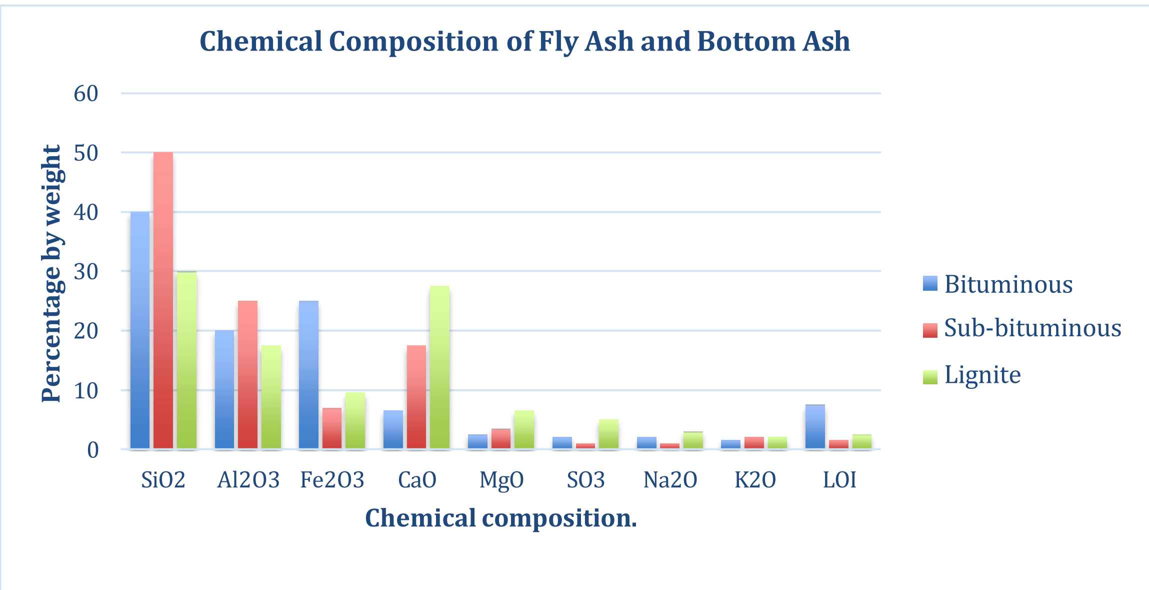

Fig. 2. Chemical compositions of fly ash (Data source: Mishra, 2007)

3. Physical Properties

Table 1 shows the physical properties of fly ash and Bottom ash. The physical properties of sand are also provided in the Table for the comparison since it is predominantly used for the purpose of stowing.

Table 1. Physical properties of fly- & -Bottom ash (Mohanty & Ram, 2022; Shaik et al., 2018)

Physical/Physico-mechanical Property	Fly ash	Sand
Specific Gravity	Indian Fly Ash: 1.9 – 2.2 Coal Ash (general): 1.6- 3.1 Sub-bituminous:~1.90 Bituminous (Fe-rich):~2.96	2.60 – 2.68.
Grain Size	<0.1 to >100µm (Indian Fly Ash) Arithmetic Mean Dia<10µm	Fine sand: 75 – 425 µm Medium sand:425-2000 µm Coarse sand:2000-4750µm
Strength Behavior (Shear Strength)	Internal friction angle:30–40^0	Angle of Internal Friction: 30–45^0
Hydraulic Conductivity (Permeability)	Fly Ash: 7.15×10^{-5} to 1.01×10^{-4} cm/s Bottom Ash: 1.34×10^{-4} to 2.01×10^{-4}cm/s	10^{-3} to 10^{-1} cm/s (High permeability)

Fly ash and sand differ significantly in their geotechnical properties as shown in Table 1. Fly ash has a lower and more variable specific gravity (1.6–3.1) compared to that sand (2.60– 2.68) and consists of much finer particles (<0.1 µm to >100 µm), whereas sand ranges from 75–4750 µm. Both materials show similar shear strength properties with internal friction angles in-between 30°–45°. However, fly ash has low hydraulic conductivity (7.15×10^{-5} to 1.01×10^{-4} cm/s), making it less permeable than sand (10^{-3} to 10^{-1} cm/s). These characteristics suggest that fly ash can serve as a lightweight, low-permeability alternative to sand in certain geotechnical applications, though thorough characterization is necessary before its use.

4. Case Studies

The Case studies of GDK 3 Incline, Ramagundam (SCCL); GDK 6A Incline, Ramagundam Area (SSCL); South Balanda (MCL); Kajora (ECL); Kathara (CCL); Medipalli OC (SCCL); Kaniba (MCL) were studied and summarized data is provided in Table 2.

Table 2. Fly- & bottom- ash as a stowing material in various mines. (Rao & Kumar, 2019)

Section	Fly Ash (1994 – GDK 3 Incline)	Bottom Ash (2005 – GDK 6A Incline)	Ash Utilization in OC Mines (Post-2005)
Location	GDK 3 Incline, Ramagundam (SCCL)	GDK 6A Incline, Ramagundam Area (SSCL)	South Balanda (MCL), Kajora (ECL), Kathara (CCL), Medipalli OC (SCCL), Kaniba (MCL)
Year	1994	2005	Post-2005
Ash Type	Fly ash	Bottom ash	Fly ash
Source of Ash	NTPC Ramagundam TPP	NTPC Ramagundam TPP	NTPC Talcher TPP & others
Objective	Assess fly ash as stowing material in underground coal mines	Assess bottom ash as stowing material (alternative to sand)	Reclamation of abandoned & operating opencast (OC) mines
Ash Quantity / Volume	~30,000 tonnes	~8,500 m³	~1 MTPA (South Balanda)
Ash:Water Ratio	–	1:0.7	–
Stowing Method	Hydraulic stowing (via boreholes)	Hydraulic stowing	Hydraulic ash slurry pipelines / Dry ash dumping
Flow Rate / Max Stowing Rate	–	~100 m³/h	–
Particle Size Distribution	–	99% >53 µm11% between +53–106 µm 88% >106 µm	–
Shrinkage Factor	–	<5%	–
Performance Observations	Fine ash escaped barricades; moisture issues; water seepage	High compaction; 2.5 m wall self-standing; negligible fines escape	Effective land reclamation; Green cover developed
Technical Challenges	Free flow hindered;barricade leakage; sump accumulation	None observed (experiment halted due to logistics)	Limited abandoned mines near TPPs.
Solutions Implemented	Vibrators, water jets, enlarged chutes, 8" pipes, flow meters	–	–
Results / Conclusions	Feasibility proven; some operational issues	Technically viable; low shrinkage; good compaction	Proven success in abandoned & operating OC mines; supports 100% ash utilization
Environmental Significance	–	Can help manage 20% of ash generated (bottom ash share)	Supports large-scale ash disposal, waste management, and environmental protection
Regulatory Approvals	DGMS & State Pollution Control Board	DGMS & State Pollution Control Board	State Pollution Control Board (SPCB) & DGMS permissions
Reason for Discontinuation	–	Logistical (organizing and planning)/transportation dispute	–

Over the past three decades, India has transitioned from using fly ash and bottom ash for underground mine stowing to large-scale reclamation of opencast (OC) mines also. In 1994, fly ash was trialed in GDK 3 Incline (SCCL), proving feasible but facing operational challenges. In 2005, bottom ash showed promising compaction and low shrinkage in GDK 6A Incline but was discontinued due to the logistical issues. Since 2005, fly ash has been effectively used for environmental reclamation in OC mines like South Balanda and Medipalli through hydraulic and dry dumping methods. These initiatives support 100% ash utilization and demonstrate strong potential for sustainable waste management and land rehabilitation.

The instrumentation monitored data during the underground coal mine stowing operation with fly-ash from Jitpur colliery is compiled and provided in Table 3.

Table 3. Instrumentation monitored data from Jitpur Colliery (Sharma et. al., 2020)

Instruments	**Installing Location**	**Before Stowing Condition**	**After Stowing Condition**
Load Cells	Longwall face (4 units, 25 m interval)	Initial setting load: 2.25–3.25 tons Gradual increase of 0.1–1.25 tons over 2 months Overall increase: insignificant	Two resets needed due to shifting before stowing Very little change in load after stowing
Convergence Indicators & Load Cells	Gate roads (50 m interval)	Convergence increased up to 25 mm in a month Rate: < 1 mm/day Floor: loose sand	1st point up to 13 mm in 2 weeks 2nd point: up to 14 mm in 2 weeks 3rd point: almost no convergence Rate: < 1 mm/day
Stress Meters	Chain pillar (Block-14 centre, 5ER level, ~250 m from face)	Initial stress:50 kg/cm² Max recorded: 82 kg/cm² Net increase: 32 kg/cm² in 1 month Gradual increasing trend	Initial stress: 4 kg/cm² Max recorded: 24 kg/cm² Net increase: 20 kg/cm² in 1.5 months Stepwise, irregular stress rise.

Fig. 1 shows the changes in load measured by a stress meter on the chain pillar of Block-14 before stowing. The data revealed a steady increase in load over time which suggested a growing buildup of the stress within the pillar. It started at about 55 kg/cm² on 1.7.2019 and steadily raised to around 82 kg/cm² by 30.7.2019. This trend indicated that the pillar faced rising stress due to the overburden or nearby excavation work before the bottom ash stowing. This presented data is vital for understanding how the chain pillar reacts to stress and highlights the importance of timely stowing to manage the load distribution and to avoid the structural failure

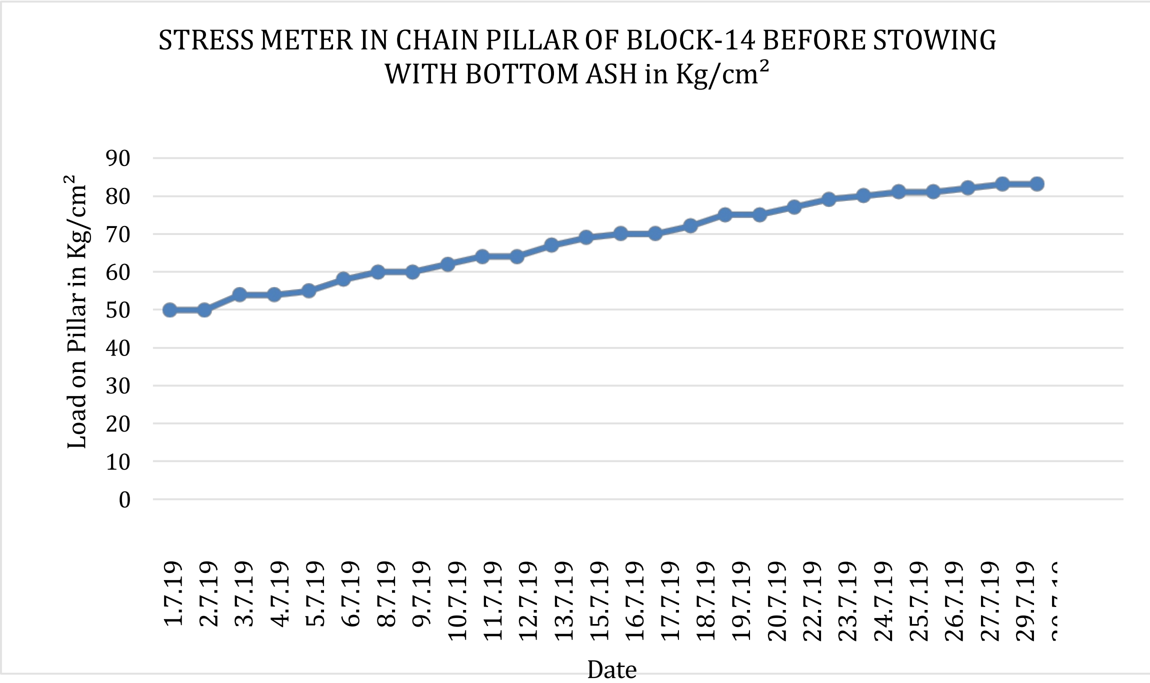

Fig. 1. Stress in Chain Pillar Before Stowing with Bottom Ash. (Sharma et. al., 2020)

Fig. 2 illustrates the load changes on the chain pillar in Block-14 after stowing. After the stowing operation with bottom ash (Fig. 2), the stress on the chain pillar significantly decreased and stabilized compared to that pre-stowing conditions as shown in Fig. 1. Initially, the load stayed relatively steady at around 5 kg/cm² until mid-November. Then, it gradually up reaching about 13 kg/cm² by 18.11.19. Then stress levels stabilized for a while before gradually increased again peaking at around 26 kg/cm² by 23.12.19.

The low and stable stress levels after stowing (Fig. 2), compared to the rising trend seen before stowing (Fig. 1), showed that bottom ash stowing effectively redistributed and reduced the stress concentrations within the chain pillar. This finding supports the role of stowing as an important ground control measure to improve upon pillar stability as well as overall mining environment of the panel undergoing depillaring with the fly-ash or bottom ash stowing.

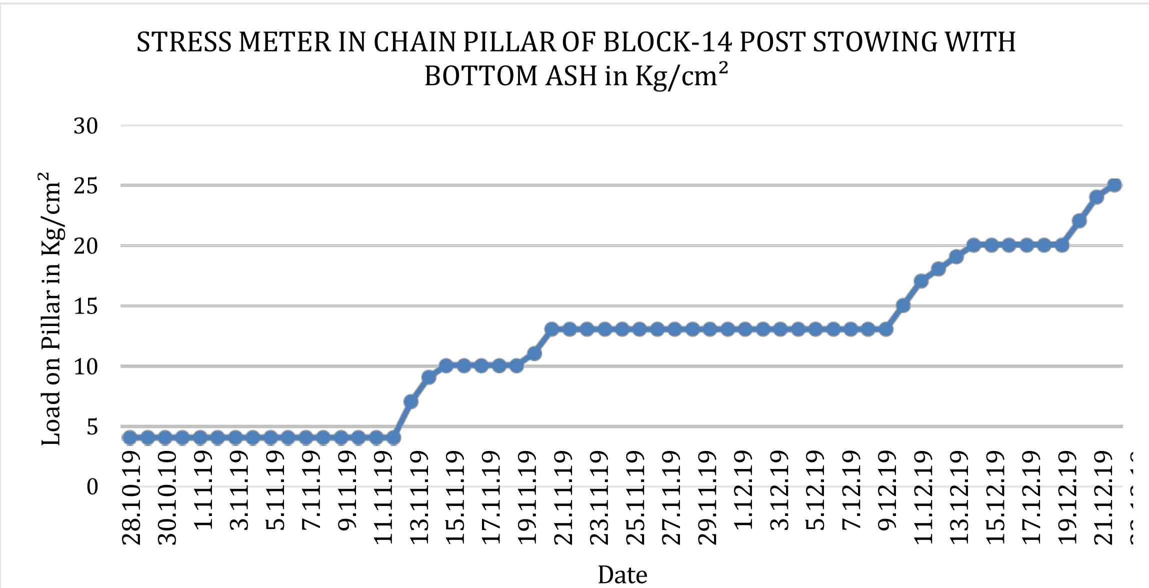

Fig. 2. Stress in Chain Pillar after stowing with Bottom Ash. (Sharma et. al., 2020)

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Use of Artificial Intelligence in Directional Drilling

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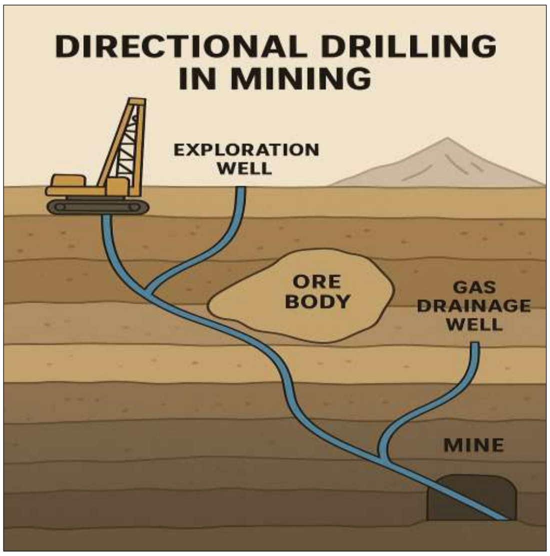
Directional Drilling

- Directional drilling in mining involves steering a drill bit along a non-vertical path to target ore bodies, relieve pressure, or gather data, while minimizing surface disturbance and improving precision.



APPLICATIONS

1. Exploration Drilling
    a) Access ore zones from a single collar by steering in multiple directions.
    b) Reach deep or structurally complex ore bodies (folds, faults, steep dips).
    c) Reduce number of surface drill pads, lowering environmental footprint.

2. Resource Evaluation
    a) Drilling fan patterns or mother holes with branch holes (wedging, navi-drills).
    b) Improves ore-body delineation and grade control.

3. Gas Drainage (Coal Mining)
    a) Directional boreholes drain methane from coal seams.
    b) Enhances safety by reducing explosion risk and enabling pre-drainage of gas.

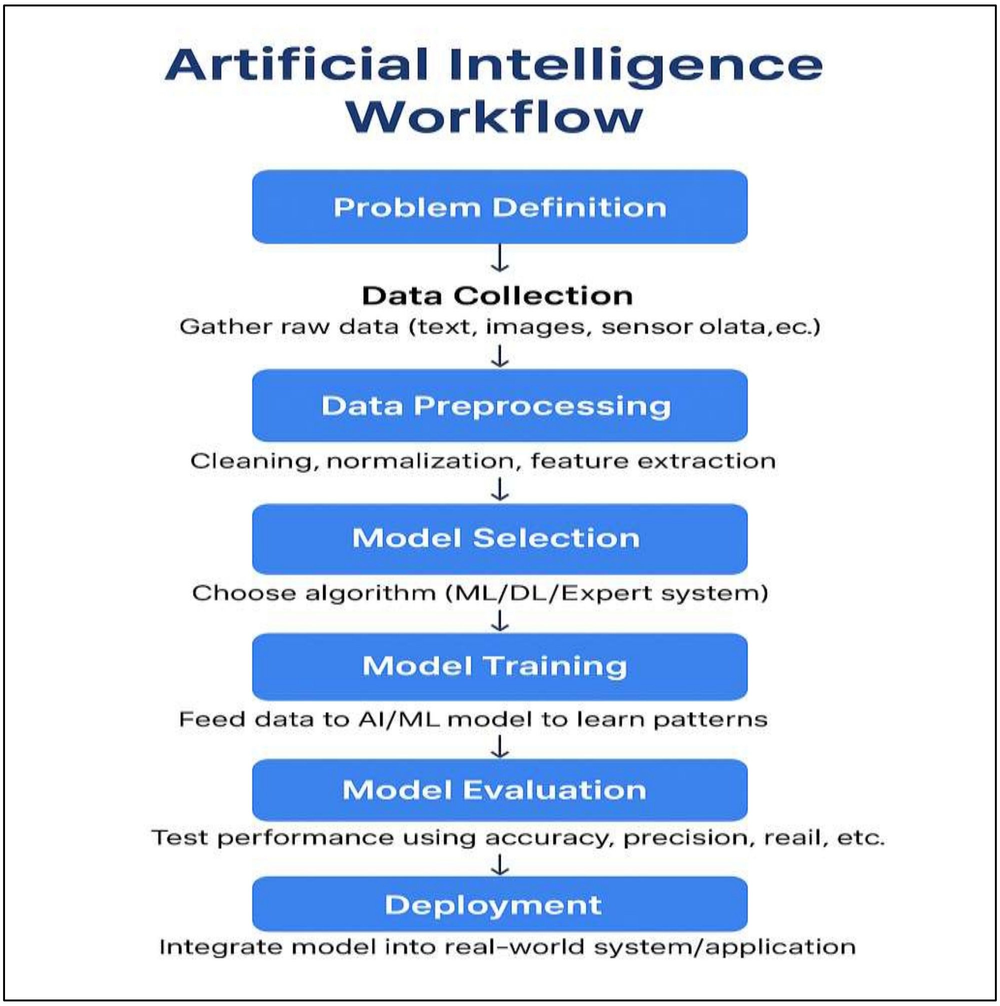
4. Water Management
    a) Drainage holes for dewatering aquifers or depressurizing rock masses.
    b) Reduce inrush hazards in underground mines.

5. Stope Design & Safety
    a) Probe holes to detect faults, cavities, water, or ore extensions.
    b) Better planning for underground excavation.

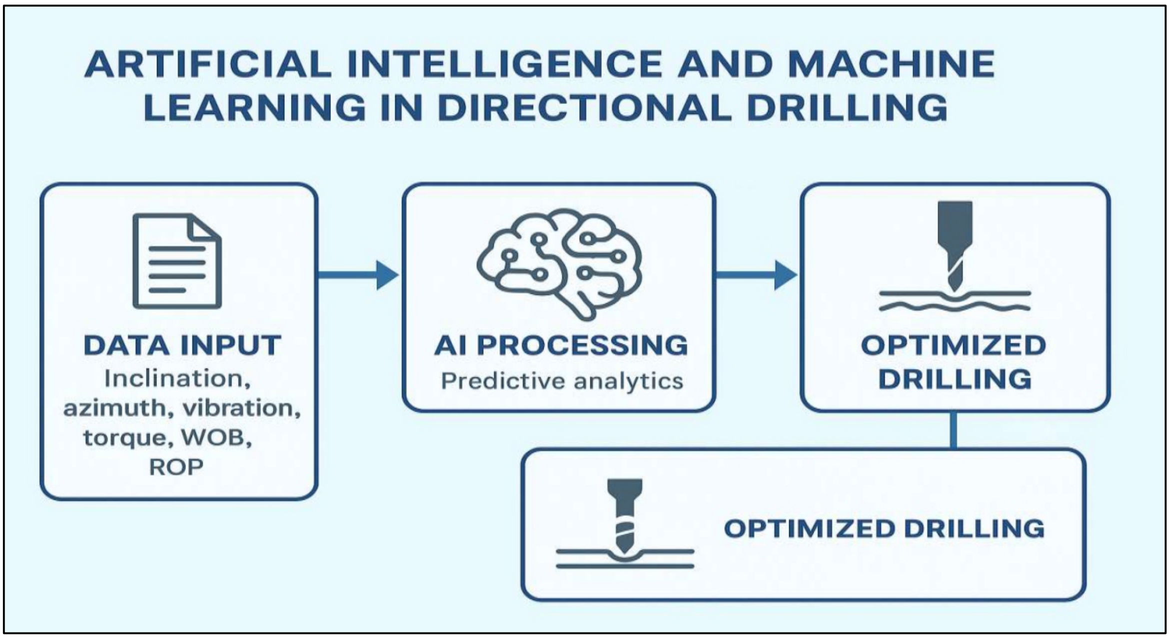
6. Surface-to-Underground Access
    a) Construct small-diameter service boreholes (for cables, ventilation, pipelines).
    b) Reduced need for costly shafts.

ARTIFICIAL INTELLIGENCE

1. It's a computed simulation of biological neural network
2. Constitutes of Individual fundamental processing units called neurons.
3. The neurons perform non-linear transformations of individual inputs fed to it in order to generate output.
4. This performed by training the network with certain set of data.
5. Validation of the results is performed by certain data sets.
6. This equips it to for decision making.



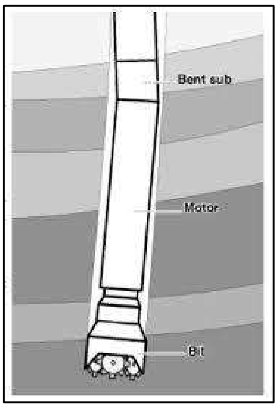
INTEGRATION OF AI INTO DIRECTIONAL DRILLING



THE PROPELLOR FOR DEVIATION

- Presently used technique is used as kick-off that changes direction of the drill rod.

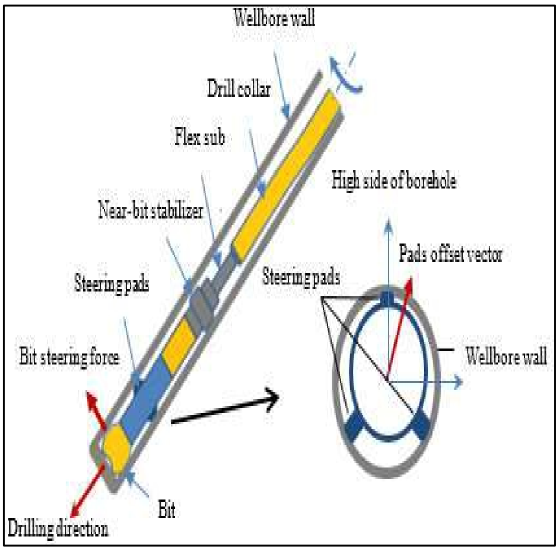
- ML can be used to process downhole sensor data (inclination, azimuth, vibration, torque) to adjust bit direction instantly



THE STEERING MECHANISM

- This may trigger the amount/pressure of hydraulic fluid of the steering pads that may in turn govern the deviation the drill rod may experience.

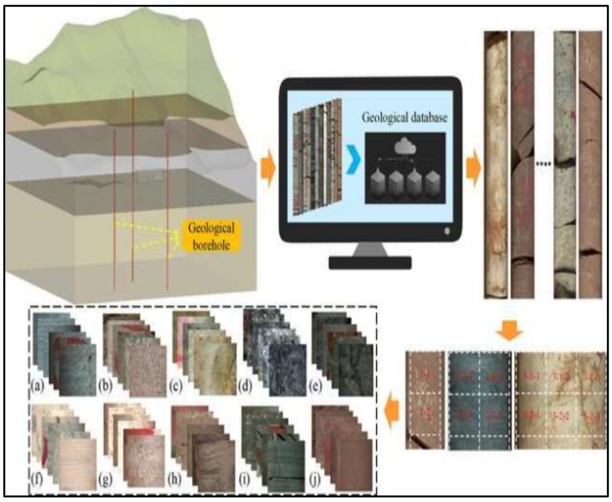
- Reinforcement learning continuously improve drilling paths



GOVERNANCE AS PER LITHOLOGY

- Presently, the lithograph is studied and through manual intervention and based upon extrapolation, drill rate of penetration, RPM, weight on bit is adjusted.

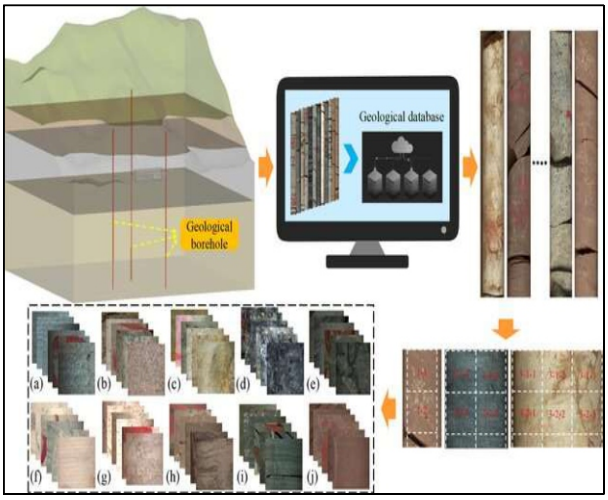
- ML algorithm analyze logging-while-drilling (LQD) and measurement while drilling data on real time basis adjust the above parameters



LITHOLOGY BASED DRILLING

- A continuous feedback loop between surface and the drill bit is required for path optimization like self-driving cars.

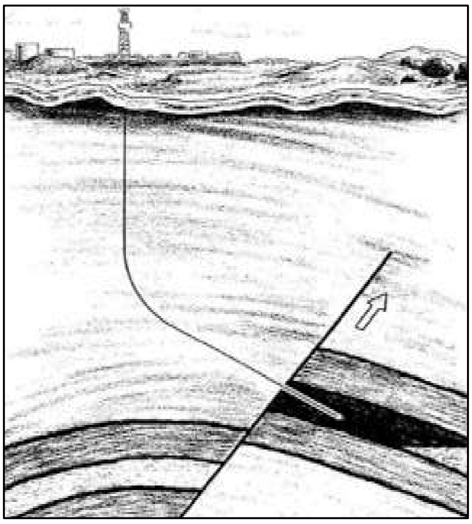
- This helps maximise drilling efficiency while reducing equipment wear.



ANOMALY IN THE PATHWAY

- Presence of geological disturbance leads to accidents that impact the construction time & cost

- Drill support engineers presently monitor the mud loggings to detect anomaly. Hence, it is a kind of post-mortem approach that may lead to drill failure.



PRE-EMPTIVE MEASURES

- Training the network using samples from previous accident use to analyse current behaviour

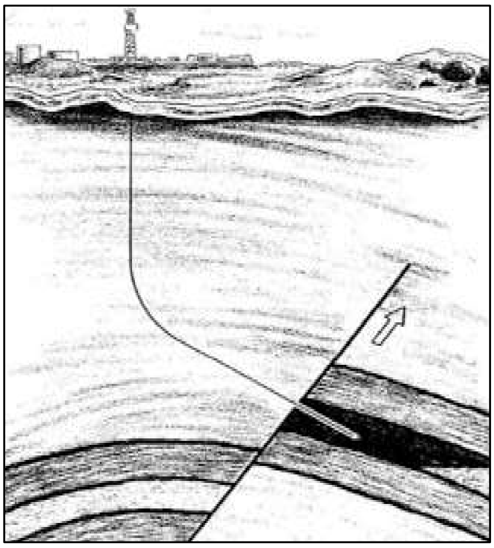
- As per the behaviour, the standpipie pressure, the rate & composition of mudflow may be changes accordingly so that the hole is negotiated and the casing is done as per the surrounding rock mass strength.

	Triping in	Tripping out	Drilling	Cleaning	Reaming
Stuck	18	11	10	0	1
Wash-outs	1	1	10	1	0
Breaks of drilling	1	2	4	6	0
Mud loss	2	2	6	0	1
Shale collars	0	0	9	0	0
Fluid shows	0	3	5	0	0
Total	22	19	44	7	2

Production Control Optimization

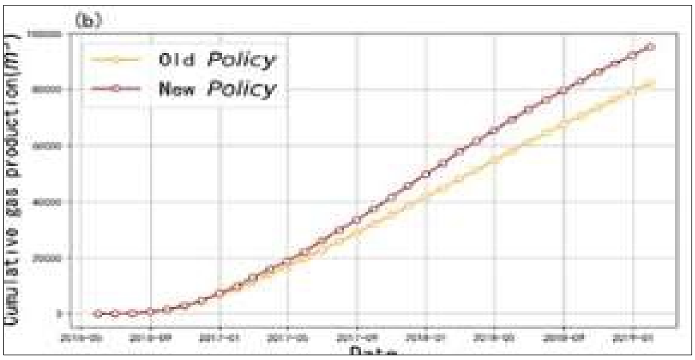
- Unreasonable drainage and bottom hole pressure drop may cause near wellbore permeability to drop, restricting the spread of pressure drop funnels

- Reinforcement learning through parameters like porosity, permeability, gas & water content, thickness, top depth and in-situ pressure of the coal seam is required.



BHP optimal control

- The forecasting will enable to maintain a pre-emptive data with regard to BHP reduction rate so that its optimal control can be undertaken and hence a wide fluctuation is not observed



Manganese and the Steel Ecosystem: MOIL's Blueprint for Resource Security and Capacity Augmentation

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Abstract

MOIL, a Miniratna Category-I Public Sector Enterprise under the Ministry of Steel, is the largest producer of manganese ore in India, playing a pivotal role in ensuring mineral security for the nation's vital steel and ferroalloy industries. MOIL consistently contributes approximately 50% of the total domestic production of manganese ore, primarily operating a mix of century-old underground and opencast mines across Maharashtra and Madhya Pradesh. This significant contribution is crucial for the steel sector, which relies heavily on manganese, and directly supports India's ambitious industrial growth targets, such as the National Steel Policy aiming for a 300 million tonne steel capacity by 2030.

MOIL's Blueprint for Resource Security and Capacity Augmentation," this paper details the company's strategic blueprint for maintaining market leadership and accelerating growth. It examines MOIL's robust operational performance and advancements in exploration to secure its resource base. Furthermore, the paper outlines an ambitious strategy for capacity expansion, which includes a planned Environmental Clearance (EC) roadmap, extensive mine mechanization, and key projects like shaft sinking. The final component of this blueprint involves MOIL's proactive engagement in global acquisition and technology tie-ups to ensure a diversified and technologically advanced future.

Key words: Drilling, Mine, Mechanisation / Automation, Mine Developer and Operator, Locomotives, LHD Machines / Electric Drills (Machinery)

1. Introduction

MOIL, a Miniratna Category-I Public Sector Enterprise of the Ministry of Steel, is recognized as the largest supplier of manganese ore in India. The company’s approximately 50% share of domestic production is essential for maintaining mineral security for the country's key steel and ferroalloy industries, thereby supporting India’s ambitious industrial plans, including the 300 million tonne steel capacity goal by 2030. MOIL operates a combination of heritage underground and contemporary opencast mines in Maharashtra and Madhya Pradesh. Beyond production, the company is guided by a commitment to sustainability, safety, and cost-effectiveness, aiming to build lasting stakeholder value through its environmentally sound resource development practices.

Beyond its critical output role, MOIL is increasingly recognised for its commitment to sustainable mining practices. The company has adopted a business philosophy anchored in sustainability, efficiency, and eco-friendliness, reflected in its official mission to create long-term stakeholder value through resource development in an "efficient, safe, cost-effective and eco-friendly manner."

2. Quarterly Performance Analysis (Q1, FY 2025-26)

MOIL demonstrated robust operational performance in the first quarter of FY 2025-26, particularly in core mining activities. Manganese Ore production increased by 7% year-over-year, reaching 5.02 lakh metric tonnes (MT). Exploration efforts saw a substantial 16% increase, with 34,900 meters drilled, representing the highest-ever Q1 exploration volume.

However, production of downstream value-added products, Electrolytic Manganese Dioxide (EMD) and Ferro Manganese (FMP), were scaled down by 13% and 12% respectively. This reduction was a strategic response to subdued market conditions and high inventory levels, allowing for efficient inventory management and factoring in a planned 7-day maintenance shutdown for FMP in May '25.

3. Resource Security and Exploration Focus

The strategy for resource security is focused on enhancing reserves within existing leaseholds. The total Reserve/Resource as on April 1, 2025, stands at 121.97 million MT, with 59.62 million tonnes added in the preceding five years.

The current exploration plan for FY 2025-26 targets 1,20,000 meters of drilling, with all activity strictly confined within leasehold areas. This disciplined approach ensures that capital expenditure is prioritized for legally secured and accessible reserves.

4. Capacity Expansion and Environmental Clearance Roadmap

MOIL is embarking on a significant expansion of its Environmental Clearance (EC) capacity to support the planned production growth. The total existing EC capacity of 26.79 lakh MT as of April 1, 2025, is targeted to increase by 19.26 lakh MT through ongoing applications across six key mines: Balaghat, Chikla, Dongri Buzurg, Gumgaon, Munsar, and Ukwa.

The EC grant timeline is aggressively scheduled, with 3.50 lakh MT capacity expected by Q3 FY 2025-26 and 15.76 lakh MT by Q4 FY 2025-26.

5. Mine Mechanization and Project Execution

A core component of the growth strategy is the extensive mechanization and automation of both underground and opencast mining operations.

5.1. Underground Mechanization

Mechanization is planned for Ukwa, Balaghat, Chikla, Munsar, Kandri, and Gumgaon Mines. The plan forecasts a cumulative requirement for additional machinery through FY 2029-30, including 41 Locomotives, 42 Load-Haul-Dump (LHD) machines, and 16 Electric Drills to support the targeted increase in production and development meters.

As a pilot, an underground belt conveyor system for ore loading is set for completion by September 1, 2025, to enhance material handling efficiency. Furthermore, scientific studies are underway with institutions like IIT-BHU, CIMFR, and VNIT-Nagpur to modify existing mining methods for improved safety and productivity.

5.2. Shaft Sinking Projects

The execution timelines for four major shaft sinking projects (Dongri Buzurg Production and Ventilation Shafts, Kandri 2nd Vertical Shaft, and Chikla 3rd Vertical Shaft) have been reassessed and reduced by four weeks to expedite capacity access. A significant focus is placed on promoting indigenization by proactively engaging potential Indian Joint Venture partners for deep shaft sinking technology.

5.3. Mine Developer and Operator (MDO) Engagement

To immediately boost production efficiency and leverage specialized expertise, MOIL is engaging MDOs for development, production, and hoisting at key levels within four mines: Ukwa, Balaghat, Chikla, and Munsar. The award of work is targeted for January 2026.

6. Global Acquisition and Technology Tie-ups

MOIL is actively pursuing international opportunities to secure supply of manganese and other critical minerals.

6.1. Overseas Mining Initiative

Crucially, MOIL's growth strategy extends beyond domestic borders, embracing a vision for global resource security. The company is actively pursuing overseas mining opportunities, with delegations visiting Gabon and South Africa, and engaging in acquisition/collaboration discussions for critical minerals like Copper (Cu) and Nickel (Ni) in Finland, and Vanadium assets in Australia and South Africa. Domestically, strategic MOUs with key PSUs like Hindustan Copper Limited (HCL) and a planned agreement with Indian Oil Limited (IOL) further solidify its collaborative approach to exploration and acquisition of critical minerals.

6.2. Technology Partnership

A Non-Disclosure Agreement (NDA) has been sent to Autlan for a potential technology tie-up. The partnership is envisioned to provide proprietary know-how, technical support, training, and ongoing process optimization for enhanced production and efficiency.

7. Summary

In summary, MOIL is transitioning from a traditional production giant to a future-ready, technologically advanced, and globally aware mining entity. By balancing aggressive production targets with a strong commitment to environmental compliance, operational mechanization, and strategic international and domestic resource acquisition, MOIL is not just ensuring the supply of manganese but is establishing a comprehensive blueprint for sustainable resource security and capacity augmentation to support India's long-term economic prosperity.

Underpinning this expansion is a commitment to sustainable mining practices, which the company views as an integral part of its business philosophy. MOIL's mission is explicitly focused on resource development in an "efficient, safe, cost-effective and eco-friendly manner".

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Flyrock in Surface Mine Blasting

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ABSTRACT: Flyrock has intrigued the mining fraternity in general and the blasters in particular, for times immemorial. Individual fragments that emerge out of the blast and travel uncertain distances than planned have had their share in accidents and fatalities in the mines, the worldover. The research on flyrock has seen a significant spike during the period 2010 to 2024. Most of the papers however have focussed on the prediction of flyrock distance with the help of artificial intelligent technques and machine learning methods. These publications have used a variety of variables in such predictions using a sizeable data from few particular mines. However, one important aspect, that majority of such publications have missed, is that flyrock is not a regular phenomenon and hence can not be predicted through variables which are more related to throw than flyrock. Other aspects of the flyrock distance prediction that have been missed out in such models are the multiple interactions involving blast design, the causative factors and the motion of flyrock in air, not to speak of confusing terminologies used in such publications. These considerations in conjunction complicate the predictive regime of flyrock distance. Instead, it is prudent to have a record of flyrock distances in a mine and dwell on the probabilities of the flyrock and evaluate the risks associated with the phenomenon. This in turn can help mines to define their danger zones or area security in scientific terms. An international effort to log flyrock and hence its probablities is anticipated to address the issue in totality. This paper presents a comprehesive account of the flyrock phenomenon, its prediction and the methods to evaluate the risk for fixing of danger zone on scientific basis. This work is based on the authors comprehesive work in the form of a book on flyrock.

1 INTRODUCTION

The purpose of blasting is to fracture the rock into smaller, manageable pieces that can be easily transported and processed. However, the energy released from the explosion is not fully utilized for breaking the rock. A portion of this energy is transferred to the surrounding rockmass in the form of throw, vibrations, air pressure, or as kinetic energy that propels rock fragments at high velocities called flyrock. The distance these travel is called the flyrock distance. The terms have been confused in literature to an unfair degree while mixing flyrock (a phenomenon) with flyrock distance (R_f, a measurable quantity). Not only does such misrepresentation exist in literature, but there is enough evidence of predictions that elude the basic premise of flyrock and tend to interpret flyrock purely in terms of blast design variables and is uncalled for (Raina, 2023).

What we are dealing with is an outlier and not a regular phenomenon that unlike throw of the material can be defined in terms of the blast design variables. Accordingly, there is a need to set the things right and develop a regime that focusses on the flyrock phenomenon and associated regimes to have a tangible solution for its predictions, if possible, and related control of flyrock distance.

Before focusing on the specific issues on the flyrock covered here, it is deemed fit to understand the contribution of CSIR-Central Institute of Mining and Fuel Research (CSIR-CIMFR), India, along with flyrock causes, prevention and control measures as exist in published literature.

2 CSIR-CIMFR CONTRIBUTIONS

Since the initial and classical work of (Lundborg, 1974) and up to 2004 there was very little or minimal research on flyrock. However, the consistent impetus to the research on flyrock was provided by our team at CSIR-CIMFR, India. Since then, there have been some significant contributions by our group (Figure 1) followed by lot of publications in the international domain (Figure 3).

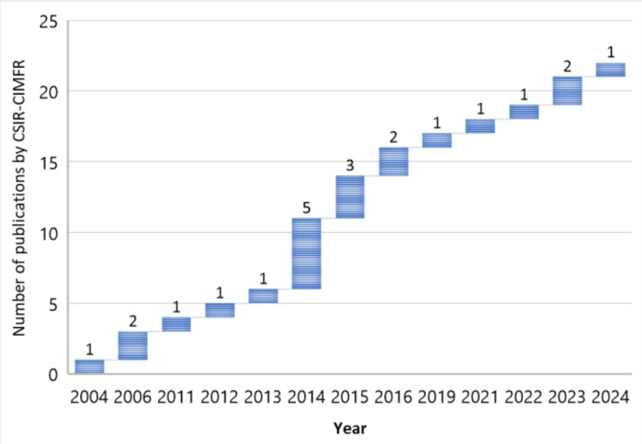

Figure 1: Number of publications on flyrock by CSIR-CIMFR between 2004 and 2024

The topics that have been covered in the research work range from basic research on flyrock, the modelling through empirical and numerical methods and other important aspects of flyrock (Figure 2).

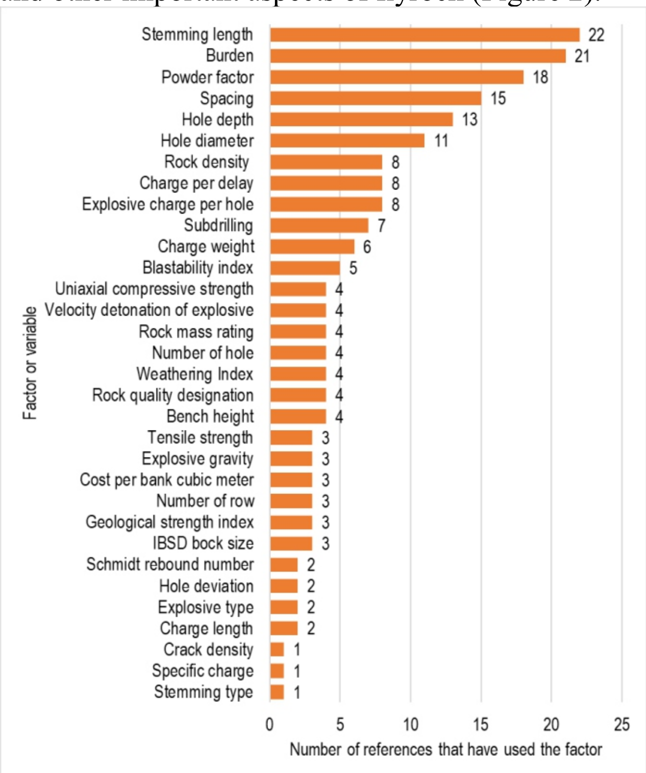

Figure 2: Topics covered in research conducted at CSIR-CIMFR on flyrock.

One of the significant contributions was defining the anomalies in rockmass or delay types that could lead to flyrock and incorporation of these into a factor of safety concept (Raina et al., 2006). However, these conditions have altogether been ignored in most of publications thereafter.

3 FACTORS CONTRIBUTING TO FLYROCK GENERATION

Several factors contribute to the generation of flyrock which have been classified in three groups, viz:

1. **The primary sources of flyrock:**
   The nature of the rock, including its strength, composition, and any natural fractures or faults, influences the behavior of the blast. Weak or highly fractured rocks are more prone to flyrock because they require less energy to be displaced (Bajpayee et al., 2004; van der Walt and Spiteri, 2020). However, due to quick release of the pressure in such formations, the pressures exerted on flyrock may not be to the tune of that in the case of strong and blocky formations.
   These factors include anomalous occurrences in the rockmass being blasted like presence of voids, cavities (particularly in limestone formations), fissures, weak beds, or presence of incompetent strata in a competent one.
2. **The damaged face conditions:**
   These involve damaged front free face, uneven face, and heavily broken top face rock, particularly due to previous blasts. This gives rise to uneven distribution of energy in the blastholes and forms a potential candidate for flyrock occurrence.
   A comprehensive account of such causative factors of flyrock can be found in (Raina, 2023, 2006).
3. **The blast design and implementation related factors**
   i. Explosive Charge and Placement: The amount and type of explosive used play a critical role in flyrock generation. Overcharging (using excessive explosive material) or improper placement of explosives within the drill holes can lead to the unwanted ejection of rock fragments.
   ii. Blast Design: Poor blast design, including incorrect spacing of drill holes, improper timing of the blast sequence, or failure to account for backbreak, can result in flyrock. Inadequate stemming (the material used to fill the top of the drill hole) can also cause explosives to eject rock particles rather than directing energy into fracturing the rock mass. It may be mentioned that stemming, as evidenced by many authors, plays a significant role and is a major causative factor in flyrock phenomenon,

but there is a lacunae on the front of type of stemming as is meagerly mentioned.

iii. Environmental Factors: Weather conditions, such as wind direction and speed, can affect the trajectory of flyrock. Similarly, the terrain surrounding the blast site can influence how rock fragments are projected.

4 PREDICTION OF FLYROCK

Prediction of flyrock has two aspects, viz.

i. The probability of flyrock.
ii. Distance of flyrock travel.

There is a considerable confusion in the publications in these two aspects as researchers have referred flyrock distance as flyrock, e.g., (Monjezi et al., 2011; Rezaei et al., 2011) which is not correct in its true definition. A need exists to straighten the understanding of the concepts in the regard to make distinction in definitions as deliberated in detail by Raina (2023). It is imperative to distinguish between flyrock that denotes its occurrence and flyrock distance that indicates its travel distance and should be used in predictions, not the former.

4.1 The probability of flyrock

The probability of flyrock involves how many flyrock(s) were produced in a blast or over a period in a mine or both. This has a connotation to the flyrock distance, particularly in terms of Blast Danger Zone (BDZ) but does not define the flyrock distance. The other aspect of this term refers to the fact, whether flyrock is produced in a blast or not, thus defining the its likelihood (Blair, 2022; Davies, 1995; Gibson and St George, 2001; Lundborg, 1979; Raina et al., 2004). Also, there can be multiple flyrock(s) from a single blast, that land at different places and deserve attention from the research fraternity.

4.2 Distance of travel of flyrock

Once the flyrock moves in the air and lands at a surface, the horizontal distance between the origin of flyrock and landing site is the flyrock distance and is the fundamental quantity for predictive models. It might not be out of place to mention that the physics of movement of a rock fragment, quite irregular in shape, comes into play and determines the travel distance, in addition to its initial velocity and launch angle (Stojadinović et al., 2011). The rebound on surface and topography of the area from which the flyrock is generated also have a strong bearing on the its travel distance that has generally been ignored or is implicit in R_f as the measurement methods adopted by researchers are not explicit.

5 PREDICTION OF FLYROCK DISTANCE

The flyrock distance prediction, wrongly mentioned as 'flyrock prediction' in most of the publications is a definitive and measurable quantity (although very difficult to ascertain) with manifold aspects involving the blast design, travel in air with related drag and Magnus effect, and rebound on the surface. The existing models have been strongly contested by some authors (Sevelka, 2023; Szendrei and Tose, 2022) for simple reason that the causative factors are not modelled in the predictions. The distance of flyrock travel is the distance between its origin and the final landing place. One of the imminent issues with flyrock distance prediction is that it is a vector quantity and the direction of projection is essential that is extremely probabilistic in nature despite of the important findings of Richards and Moore (2004).

Predicting flyrock is challenging due to the complex interactions between explosives, geological conditions, and blast design parameters. However, several techniques and models have been developed to predict the distance of flyrock. These methods can be broadly classified into empirical, analytical, and numerical approaches.

i. Empirical Methods: These methods rely on historical data and statistical analysis to estimate flyrock behavior.
   There are innumerable models that appear in published domain and is difficult to document here and can be consulted online or from Raina (2023). These models use several blast design variables like burden, spacing, specific charge, stemming and even maximum charge per delay (that is attuned rather to vibration prediction).
ii. Analytical Models: Analytical methods involve the use of physics-based equations to predict the velocity and trajectory of flyrock particles. These models consider the initial velocity of the rock fragments, the angle of projection, and the influence of gravity and air resistance. While analytical models can provide a theoretical estimation of flyrock, they often require simplifying assumptions that may not accurately reflect real-world conditions.
iii. Numerical Simulations: Advanced numerical modeling techniques, such as finite element analysis (FEA) and discrete element modeling (DEM), are increasingly being used to simulate the behavior of rock masses during blasting. These models can incorporate detailed geological and blast design parameters, providing a more accurate prediction of flyrock. However, numerical simulations require significant computational resources and expertise.
iv. Drone and Sensor Technology: Recent advancements in technology have introduced

the use of drones and sensors to monitor blasts in real time. These devices can track the trajectory of flyrock and provide data that can be used to improve prediction models. Drones equipped with high-speed cameras can capture the blast from multiple angles, allowing for detailed analysis of flyrock behavior. A concerted effort with this technology is expected to enhance the accuracy of R_f.

5.1 Conflicts in flyrock distance prediction

As brought out by various authors there are conflicts in causative and predictive factors when estimating flyrock distance in surface mining operations. These conflicts arise from the complex, interdependent nature of the variables involved in both generating and predicting flyrock. These involve:

a. Variability in Geological Conditions

Conflict: Geological factors, such as rock type, strength, fractures, and faults, significantly influence how energy from an explosion propagates. Causative factors like rock heterogeneity can lead to unpredictable outcomes, with flyrock behaving differently even in similar blasting conditions. Predictive models often assume certain homogeneities in the rock mass, simplifying the variability for calculation purposes. This mismatch between real-world geological variability and the assumptions made in predictive models can lead to inaccurate flyrock distance predictions.

Example: In a zone with weak, fractured rock, flyrock may travel farther due to easier rock displacement, but predictive models might not fully account for the degree of fracturing or weakness, leading to underestimation or overestimation of flyrock distance.

b. Explosive Energy Distribution

Conflict: The amount and placement of explosives are key causative factors in flyrock generation. However, the distribution of explosive energy is often uneven, particularly when the blast design is less than optimal (e.g., due to inadequate stemming or uneven charge loading). Predictive models typically rely on average values for explosive energy distribution and may assume an ideal, uniform energy release. Energy from a blast may be concentrated in certain areas, causing flyrock to travel farther than predicted.

Example: If a blast is overcharged or improperly stemmed, a portion of the energy might escape through the top of the blast hole, projecting rock farther than expected. Predictive models, which assume uniform energy containment, would not predict this extra flyrock.

c. Weather and Environmental Conditions

Conflict: Weather conditions such as wind speed, direction, and atmospheric pressure can influence the trajectory and distance of flyrock. Wind may cause rock fragments to travel farther in one direction or deflect them off their intended course. Most predictive models do not consider real-time weather conditions as part of their calculations, leading to discrepancies between predicted and actual flyrock distances.

Example: A predictive model might estimate a flyrock distance based on ideal or average atmospheric conditions. It is an established fact that the drag force increases as a square function of the velocity. Assume a fragment of area of 0.0625 m^2 (0.25 m by 0.25 m) with a density of 2500 kg/m^3; using a drag coefficient (average of 0.545), the drag force increases from 4.3 kN to 425.8 kN over a velocity of 10 to 100 m/s.

d. Blast Design and Timing

Conflict: A well-designed blast sequence considers factors like delay intervals between detonations, stemming quality, and hole patterns. If the actual blast deviates from the planned design due to human error, equipment malfunction, or environmental interference, flyrock may behave unpredictably. Predictive models rely heavily on the assumption that the blast design will be executed as planned, making them vulnerable to discrepancies if the actual execution differs.

Example: A delay misfire or improper initiation sequence can lead to uneven energy distribution, causing a localized overpressure in one area and throwing flyrock farther than predicted. Predictive models typically cannot account for such execution failures unless real-time monitoring is in place.

e. Empirical vs. Analytical Approaches

Conflict: Many predictive models (empirical or even ANN based) for flyrock distance rely on empirical data from past blasts under specific conditions. These empirical models use historical patterns to predict future behavior. However, this approach can conflict with causative factors when applied to blasts with different geological or operational settings, as the models may not generalize well beyond their initial conditions. In contrast, analytical models use theoretical equations but often simplify complex variables, potentially leading to inaccuracies when causative factors deviate from these simplifications.

Example: An empirical formula developed for flyrock prediction in limestone might not apply accurately to blasts in sandstone or granite. Likewise, analytical models may assume ideal stemming (length and type) or perfect energy transfer, ignoring practical issues like overbreak or uneven energy dissipation.

f. Scale of Operations

Conflict: The scale of the blast, including the size of the blast pattern and the amount of explosive used, can drastically change the behavior of flyrock. Small-scale operations may generate less flyrock than large-scale blasts due to differences in energy distribution and the amount of rock being displaced. Predictive models often apply scaling factors to account for the size of the blast, but these scaling factors may not fully capture the nuances of how causative factors interact at different scales.

Example: A small quarry operation using low-energy explosives might experience minimal flyrock, while a large mine using high-energy explosives could generate extensive flyrock, despite using similar prediction models. The conflict arises when scaling factors fail to account for the non-linear effects of larger blasts

In addition, the conflict between causative and predictive factors in flyrock distance prediction stems from the inherent complexity of the blasting process and understanding of the phenomenon in totality.

The causative factors of flyrock published in literature involve role of geology, stemming and improper loading of the blastholes, whereas, most of the predictive models ignore such conditions and deploy blast design variables for prediction.

Predictive tools, whether empirical, analytical, or numerical, must simplify real-world conditions to make predictions, but these simplifications can lead to discrepancies when the actual causative factors deviate from model assumptions.

Addressing these conflicts requires a combination of thorough site-specific data collection, the use of advanced technologies like real-time monitoring, and continuous adjustment of predictive models to account for changing conditions. This method will help to improve the accuracy of flyrock distance predictions, thus, reducing the risks associated with blasting operations.

6 CONTROL OF FLYROCK

Effective control of flyrock is essential for minimizing risks to personnel, equipment, and infrastructure. Several control measures can be implemented at different stages of the blasting process to reduce the likelihood of flyrock generation:

i. **Geology and face conditions**: The anomalies in the geology and the face conditions should be perfectly known to the blasters. It is imperative that site geologists provide their inputs in this regard and alert the blaster about the expected anomalies in the geology. The blaster should take care of the face conditions and presence of incompetent strata or voids in the formation.

ii. **Evolving production pattern**: One of the most effective ways to control flyrock is through proper blast design. This includes selecting the appropriate explosive type and charge size, optimizing drill hole spacing, and ensuring correct sequencing of the blast (Bauer, 2014; Kim and Kemeny, 2011). Proper stemming and the use of decking (placing inert material between explosive charges) can also help contain the explosive energy and reduce flyrock (Asl et al., 2018; Morgan, 1991; Schwengler et al., 2007).

iii. **Protective Barriers**: Physical barriers, such as blast mats, can be used to cover the blast site and contain flyrock (Noon, 2001). Blast mats are made from heavy-duty materials like rubber or steel chains and are placed over the blast area to absorb the energy of ejected rock fragments. Protective walls or berms can also be constructed around the blast site to shield nearby structures and personnel (Coy and Worsey, 2015; Wenger, 2021).

iv. **Controlled Blasting Techniques**: Techniques such as pre-splitting, buffer blasting, and smooth blasting can be used to control the direction and intensity of the blast, reducing the likelihood of flyrock (Mishra et al., 2017; Raina et al., 2016; Venkatesh et al., 2013). These methods involve creating a series of closely spaced drill holes to control the release of energy and direct it towards the desired area of fracture. However, muffling may not be feasible for large scale operations.

v. **Monitoring and Supervision**: Continuous monitoring of blast operations is critical for controlling flyrock. Blasting personnel should be trained to identify potential risks and take corrective actions when necessary. The use of high-speed cameras, vibration monitors, and air pressure sensors can provide real-time feedback on the effectiveness of the blast and help identify any deviations from the expected behavior

7 RISK ANALYSIS OF FLYROCK

Risk analysis is a crucial aspect of flyrock management in surface mining operations. The primary goal of risk analysis is to assess the potential hazards associated with flyrock and develop strategies to mitigate those risks (Blair, 2022; Davies, 1995; Masir et al., 2021; Raina et al., 2004; Zhou et al., 2002). A comprehensive risk analysis typically involves the following steps:

i. **Hazard Identification**: The first step in risk analysis is identifying the factors that contribute to flyrock generation. This includes examining the geological conditions, face conditions, blast design implementation, environmental factors, and operational practices that could lead to flyrock incidents.

ii. **Risk Assessment**: Once the hazards have been identified, the next step is to assess the likelihood and potential consequences of a flyrock incident. This involves estimating the probability of flyrock occurrence and evaluating the potential impact on personnel, equipment, and nearby structures. Risk assessment models, such as fault tree analysis (FTA) and event tree analysis (ETA), can be used to quantify the risks associated with flyrock.

iii. **Risk Mitigation**: Based on the results of the risk assessment, mitigation measures can be implemented to reduce the likelihood and severity of flyrock incidents. This may involve revising blast designs, improving training programs, or enhancing protective measures such as barriers and monitoring systems.

iv. **Emergency Response Planning**: In the event of a flyrock incident, it is essential to have an emergency response plan in place. This includes establishing evacuation procedures, ensuring that all personnel are equipped with the necessary safety gear, and providing clear communication channels to coordinate the response effort.

v. **Continuous Improvement**: Risk analysis should be an ongoing process, with regular reviews and updates based on new data and advancements in technology. Continuous monitoring of blasting operations, coupled with the analysis of past incidents, can help identify areas for improvement and ensure that flyrock risks are minimized over time.

8 FALACIES IN FLYROCK DISTANCE PREDICTION

At least 244 publications on various aspects of flyrock can be traced in Google Scholar (Figure 3) that have flyrock in title.

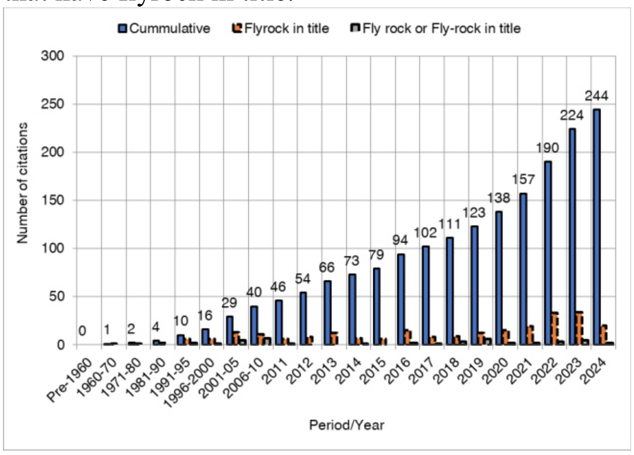

Figure 3: Number of publications on flyrock extracted from Google Scholar

Between 2021 and 2024, some 44 publications out of 109, have used different AI methods (Table 1) for flyrock distance prediction(s).

Table 1: Publications count with flyrock or fly-rock in title, AI based and methods used

Year	Publications (No.) with flyrock or fly-rock in title	Publications (No.) on AI in flyrock[#1]	Review papers	Illustrative citations
2024	20	8	1	(Bhatawdekar et al., 2021; Guo et al., 2021; Huang and Xue, 2022)
2023	34	12	0	
2022	33	9	1	
2021	19	14	2	
#1-Methods used: AI ML, ANFIS, ANFIS GH, ANN, DDM, DNN WO, EML, FFRA MCDM, Fuzzy ANN, GEP, HHO, LMR GEP, MCDM, ML, NN, PCA-CART, PSO, SPH, VM, SVR, Tree				

The count of publications (Table 1) is quite significant. The AI based prediction of flyrock distance (R_f) is however based mostly on blast design variables. A comprehensive list of such variables used in R_f prediction have been compiled in Figure 4 for the latest publications (2021-2024). It is difficult to include such comprehensive list of authors here. However, for the sake of simplicity the variables have been compiled to have an understanding about the issues in R_f prediction.

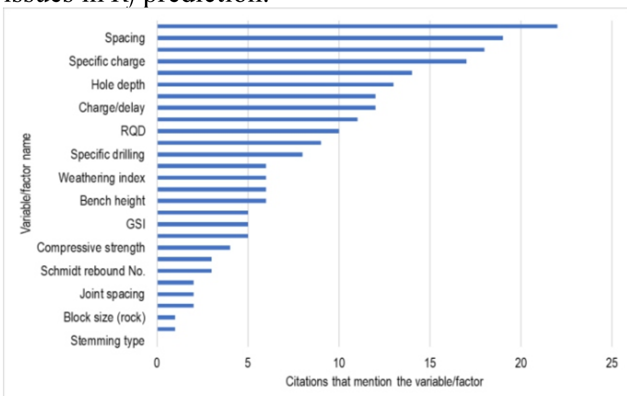

Figure 4: List of variables used in the predictive models using AI methods

Figure 4 demonstrates that the variables used in the R_f prediction belong to blast design category only. Also, most of these publications are limited to a data set from a few mines.

A comprehensive evaluation of causative factors and predictive factors (Raina, 2023) reveals that there are discrepancies in the logical assertions of such models as the variables used are not in tune with the causative variables. If blast design and rock factors are only to be considered then we need to resort to classical blast design formulation, where:

$B \propto d \dots 1$

$S \propto B \dots 2$

$l_s \propto B \dots 3$

$q = \frac{q_{hole}}{H_b \times B \times S} \dots 4$

$l_q \propto d \ldots 5$

Where, B is burden, S is spacing, l_s is stemming length, q is specific charge, l_q is the length of charge. The variables mentioned in Eq. 1 to 5 and others are simply related to the drill diameter (d). Use of such variables in isolation and factors like drill diameter, q in models make the equations redundant. This is one of the major concerns in such models. This means that all outcomes of a blast are related to the drill or explosive diameter and we are back to square one, i.e., the classical study (Lundborg, 1974).

The other issue is regarding their validity and high correlations coefficients that even assume values of 0.99 in many such publications. This leaves little room for uncertainty. If flyrock is generated by rock, explosive and applications conditions that do not constitute the blast design then such models leave little room for these as everything is explained by the blast design variables. However, logically, these variables can define regular outcome of blast like fragmentation, throw, vibration, air overpressure etc., not the flyrock in totality. Flyrock is an irregular phenomenon and can not be accounted by such measures. Hence, the fallacy, that needs to be addressed by the research community.

Instead, it is imperative to develop a regime that accounts for some of such anomalies as proposed by the author in 2015. Also, it is better to devise methods to monitor flyrock regularly and evaluate the probabilities and calculate the risk of a flyrock in different directions of a mine to define a scientific danger zone. A need exists for cooperation and collaboration for such work throughout the scientific and practicing engineers for developing such a database.

9 CONCLUSIONS

Flyrock is a significant hazard in surface mining operations, posing risks to both safety and productivity. Understanding the origin of flyrock, employing effective prediction techniques, and implementing control measures are essential for mitigating these risks. However, the approach to the prediction of flyrock distance has been approached in a fashion that does not seem to be logical.

A strong need exists to revisit the flyrock phenomenon, standardize terminologies, enhance focus on probabilities and associated risk and international cooperation between researchers for developing a sizeable database for evaluating probabilities and risk. It must be borne in mind that experimentation on flyrock is practically impossible as it involves generating the same and hence the consequences.

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Digital Transformation and Recent Breakthroughs in Mining: A Review of 25 Innovations (Classic + Recent Advances)

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Abstract

This paper reviews twenty-five significant innovations shaping modern mining, combining established technologies documented in historical compilations with recent advances from the last five years. Emphasis is placed on digital and robotics-driven solutions that improve safety, productivity, sustainability, and cost efficiency. The selected innovations include classic breakthroughs such as remote sensing, geostatistical 3D modelling, autonomous haulage, and ore sorting, plus novel contributions like self-bracing drilling robots (Stinger Robot), Robot-As-A-Sensor (RAAS) networks, AI-driven ambient noise tomography for exploration, and automated extraction of event logs from IoT streams (IoT Miner). The methodology involved thematic grouping (Automation, Sensing & Mapping, Data & Analytics, Environmental & Safety, and Operational Innovation) and prioritization based on novelty, industry impact, and IT integration. Findings indicate an accelerating convergence of robotics, AI, IoT and digital twins in mining — transforming single-machine automation into collaborative, data-driven mine systems. The paper concludes with recommendations for integrating these technologies responsibly, and suggestions for future research on system-level orchestration, cyber-physical security, and environmental optimization.

Keywords--*Mining innovation, robotics, digital twins, IoT, AI, autonomous mining, process mining, underground sensing*

1. Introduction

The traditional image of mining—one of brute force and heavy machinery—is quickly becoming a relic of the past. A new era is taking shape, driven by the transformative power of digitalization, robotics, and a critical focus on sustainability. For centuries, progress in the industry was measured by the size and strength of its equipment. Today, the most significant advances are happening digitally, as information technology and automation reshape operations to be safer, more efficient, and more environmentally conscious. This paper charts that evolution by synthesizing 25 pivotal innovations. By combining foundational, time-tested technologies with groundbreaking developments from the last five years, we present a modern narrative of mining's shift from mechanized extraction to intelligent, information-driven systems.

2. Methodology

To select the 25 innovations for this review, we developed a methodology that was both comprehensive and forward-looking. Our process began by building a foundational list of candidate technologies from well-regarded industry compilations, such as the *100 Innovations in the Mining Industry*. We then focused on the cutting edge, conducting a thorough literature search for research and reports published between **2019 and 2025** that demonstrated either true novelty or significant industrial uptake. Finally, to ensure our selection was balanced, we grouped the innovations into five key themes: **automation, sensing & mapping, data analytics, safety & environment, and operational transformations**. In making our final choices, we gave special priority to technologies that showcased a strong integration of IT and robotics, were verifiably recent, and were backed by referenced papers or public reports.

3. The 25 Innovations (grouped & listed)

Below are the 25 innovations selected for the paper. Innovations from the last ~5 years are marked with [NEW] and include a short description plus an authoritative link/paper where available.

A. Exploration & Geological Mapping Innovations

1. **Inversion Algorithm:** Inversion algorithms are mathematical tools used to convert geophysical measurements (like magnetic or seismic data) into subsurface property maps. They allow miners to visualize ore bodies or structures beneath the surface without direct drilling. These methods rely heavily on computational modeling and data processing — bridging geology with IT-based analytics[1], [2].
2. **Predictive Maps**: Predictive maps use AI and remote sensing data to identify potential mineralization zones before field exploration. Recent studies employ convolutional neural networks (CNNs) on satellite imagery (Landsat 8/9, ASTER) to detect subtle alteration patterns linked to ore deposits. These deep learning models outperform traditional methods by integrating geological, geochemical, and geophysical signals to produce high-resolution prospectivity maps. Enhances exploration efficiency and reduces drilling costs by pinpointing high-potential targets through automated, data-driven analysis [3].

3. **LiDAR (Light Detection and Ranging):** LiDAR uses laser pulses to create highly accurate 3D models of mine surfaces and underground workings. It supports mapping, slope stability studies, and volumetric measurements. With drone integration, LiDAR is now a vital tool in autonomous surveying systems [4].
4. **Low-Impact Seismics:** This technology employs lightweight seismic sources and advanced signal processing to explore subsurface geology while minimizing vibration and environmental disturbance. It is particularly useful for exploration near sensitive ecosystems or populated zones[5].
5. **Hyperspectral Imager:** Hyperspectral imaging captures hundreds of narrow spectral bands, allowing identification of minerals based on their unique spectral fingerprints. Used on satellites, drones, or field devices, it provides rapid, non-destructive mapping of ore deposits[6], [7].
6. **3D Geological Model:** 3D geological modeling integrates exploration data into three-dimensional representations of ore bodies and surrounding rock. It improves resource estimation, mine design, and risk assessment. Modern research demonstrates mesh-based model updating and deformation (Li et al. 2021, "Local Dynamic Updating …") as well as recent methods for modeling geological bodies with complex faulting (Gao et al. 2025) to improve accuracy and reduce uncertainty[8], [9], [10].
7. **GeoRadar:** Ground Penetrating Radar (GPR) uses electromagnetic waves to detect subsurface structures such as utilities, voids, and strata. Integration of AI, machine learning and advanced signal-processing (e.g., using Kalman filters, wavelet transforms, or neural networks) enhances anomaly interpretation accuracy, noise reduction, and detection of complex features. This makes GPR more reliable for void detection, ground stability monitoring, and locating buried infrastructure, especially in urban or sensitive environments[10].
8. **Ambient Noise Tomography:** Ambient Noise Tomography (ANT) uses passive seismic data recordings of background vibrations (from wind, ocean waves, traffic, etc.) — to image the subsurface without using active shock sources. By correlating signals across many sensors, ANT builds velocity models (often S-wave / surface wave) that reveal structure, cover thickness, and potential mineralization. The method is low impact, cost-efficient, and becoming more powerful as sensor tech, data analytics, and AI-based inversion / anomaly detection improve. It is

particularly useful for exploration in areas with sensitive environments or where conventional seismic or drilling is difficult or expensive[11], [12].

9. **Tele-Mining:** Tele-Mining enables remote control of equipment through digital networks and teleoperation systems. Operators can manage loaders, drills, or trucks from safe control centers, greatly enhancing safety and operational continuityte[13].
10. **RoboMap:** RoboMap combines autonomous robotic platforms with mapping sensors like LiDAR and cameras to automatically scan tunnels or stopes. It reduces human exposure to hazardous areas and produces accurate 3D maps for digital mine twins[14].
11. **Blasting Box / Electronic Detonators —** This innovation implements programmable delay detonators (electronic initiation systems) which allow precise timing control of blasts, improving fragmentation, reducing overbreak, and enhancing safety. Several studies demonstrate that modern electronic detonators reduce timing scatter to ±0.1 ms or better, leading to more predictable fragment size distributions and greater operational efficiency[15].
12. **Digital Twin (Integration of Data Systems):** Though not explicitly numbered in your list, the concept appears within integrated development and modeling. Digital twins create virtual replicas of mines, continuously updated with sensor data for simulation and optimization[16].
13. **Stinger Robot:** An advanced robotic system capable of stabilizing itself against irregular mine surfaces to perform autonomous drilling in confined tunnels. It minimizes human exposure in hazardous zones while improving drilling precision and productivity[17].
14. **Robot-As-A-Sensor (RAAS):** A multi-robot sensing architecture where mobile robots act as both data collectors and communication relays. This system enhances underground mapping, environmental monitoring, and hazard detection in areas unsafe for humans[18].

B. Processing, Transport & Production Optimization

15. **Truck Tracking (RAC):** Truck tracking systems use GPS, RFID, and telematics to monitor haul trucks, dumpers, and other mobile equipment in real time. These systems enable fleet managers to observe critical parameters like vehicle location, speed, loading/empty return times, and idling, feeding operational data into

analytics platforms to optimize routes, reduce fuel consumption, and improve safety. For instance, Agnihotri et al. (2003) demonstrated how GPS-based tracking in Indian mines helps analyze waiting, loading, empty, and full travel segments to boost productivity; more recently, Gladious et al. (2024) used GPS + load cell sensors to monitor both route and mineral load to reduce theft and inefficiencies. Vendor solution case studies like TechSolutions' SmartHaulage show RFID + GPS integration delivering real-time dashboards and route monitoring[19].

16. **Ore Grinding Monitoring:** Ore grinding monitoring systems employ vibration, power, acoustics, and liner thickness sensors mounted on grinding mills (ball, SAG, ROM) to continuously assess operational health. When coupled with AI/ML techniques—such as auto-encoding networks, disturbance detection, and predictive modeling—these systems can detect early warning signs of wear or anomalies (e.g. bearing faults, liner degradation), allowing maintenance to be scheduled proactively[3].
17. **Robotic Automation in Minig:** This study reviews the industrial advancements of robotic autonomous systems (RAS) in mining, focusing on real-world implementations in drilling, hauling, and earthmoving automation. It also evaluates performance assessment methods for robotic mining systems and outlines emerging research directions in intelligent mine automation[20].
18. **Sonar Flowmeter:** Sonar flowmeters use external acoustic sensors (non-invasive, mounted outside pipelines) to measure the volumetric flow of slurry, including solids content and entrained gases. They allow real-time monitoring without interrupting flow, reducing wear, maintenance, and error caused by abrasives or magnetic interference. Applications such as the SONARtrac installation at Minera Hierro Atacama show reliable flow and leak detection in long-distance pipelines, even under harsh slurry conditions[21].
19. **IoT Miner — Intelligent Event Log Extraction** [NEW]: A data-driven mining innovation that leverages AI to convert continuous IoT sensor streams into structured event logs. This enables real-time process optimization, predictive analytics, and efficiency improvements across mining operations[22].
20. **AI-driven Mineral Sorting & Ore Grade Prediction**: This application of machine learning directly impacts the efficiency of mineral processing. Using sensors like X-ray fluorescence (XRF) or hyperspectral cameras, these systems analyze rocks in real-time on a conveyor belt to **predict their mineral content or ore grade**. Based

on the AI's prediction, a high-speed mechanical system (often using jets of compressed air) sorts valuable ore from waste rock. This pre-concentration step ensures that energy-intensive grinding and processing plants are not wasted on barren mate[23].

C. Safety, Training & Environment

21. **VR & AR Training Simulators**: Driven by recent growth in immersive technologies, **Virtual Reality (VR) and Augmented Reality (AR)** are creating highly realistic, risk-free training environments. These simulators allow miners to practice operating heavy machinery, respond to emergency scenarios like fires or rockfalls, and learn complex site navigation without being exposed to physical danger. This enhances skill retention and significantly improves safety consciousness[24].
22. **Real-time Environmental Monitoring**: This innovation involves the deployment of extensive sensor networks to continuously track key environmental indicators. These systems provide live data on **air quality (dust and gas levels), water quality, and noise levels** around the mine site. Real-time monitoring enables immediate alerts when thresholds are breached, allowing for proactive management to ensure regulatory compliance and protect surrounding ecosystems[25].
23. **Tailings Dam Monitoring**: Following several major global incidents, there is a renewed and urgent focus on ensuring the stability of tailings storage facilities. The modern approach combines **drone-based surveys (visual, thermal, and LiDAR)** for surface inspection with a network of **in-situ geotechnical sensors** (like piezometers and inclinometers) embedded within the dam structure. This integrated system provides a comprehensive, real-time view of the dam's health, enabling early detection of potential failure risks[26].
24. **Autonomous Hazard Detection**: This technology uses **multi-sensor fusion** and AI to proactively identify dangers. Mobile robots or vehicles equipped with a suite of sensors—including cameras, LiDAR, and gas detectors—patrol mining environments. By intelligently combining these different data streams, the system can autonomously recognize complex hazards, such as subtle ground movements indicating geotechnical instability or the presence of a specific toxic gas, often faster and more reliably than human inspection[27].

25. **Zero-Emission & Low-Carbon Initiatives**: Representing a strategic shift towards sustainability, these initiatives focus on decarbonizing mine operations. This is primarily being pursued through pilot projects and the gradual replacement of diesel-powered fleets with **battery-electric vehicles (BEVs)** and emerging **hydrogen-powered equipment**. These efforts are critical steps toward developing the "mine of the future" with a vastly reduced or even net-zero carbon footprint [28].

4. Selected Recent Innovations

4.1 Stinger Robot — Self-Bracing Robotic Platform for Autonomous Drilling [NEW]

Specifically designed for drilling operations in confined and irregular underground environments. This compact, multi-legged robotic platform is capable of bracing itself against tunnel walls to achieve stability during drilling, eliminating the need for human presence in hazardous areas. As illustrated in **Fig. 1(a)**, the CAD model and exploded view show the internal worm gearbox configuration that enables its controlled bracing motion. The deployed setup, shown in **Fig. 1(b)**, demonstrates the robot's adaptive bracing configuration inside a test frame. Furthermore, the workspace visualization in **Fig. 1(c)** highlights the robot's operational reach under various stinger extensions. Utilizing force and torque feedback mechanisms integrated with closed-loop control systems, the robot can adapt dynamically to variable rock geometries and surface conditions while maintaining drilling precision. By enabling fully automated drilling in spaces that are inaccessible or unsafe for humans, the Stinger Robot broadens the operational scope of mechanized mining and contributes to improved safety, efficiency, and accuracy in underground development [17].

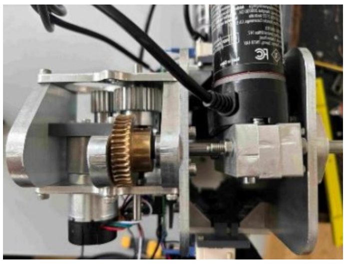

Fig. 1(a) CAD-model-and-exploded-view-of-the-worm-gearbox-used-in-the-Stinger-Robot-a-Assembled

Fig. 1(b) The-Stinger-Robot-deployed-inside-a-test-frame-demonstrating-its-bracing-configuration

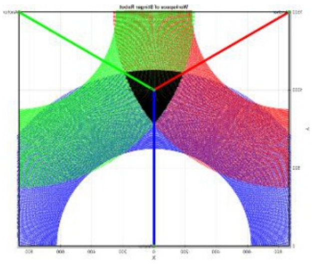

Fig. 1(c)Workspace of Stinger-Robot under-various-stinger-extension

4.2 IoT Miner — Intelligent Extraction of Event Logs from Sensor Data for Process Mining [NEW]

The IoT Miner represents a transformative innovation in the field of data-driven mining operations. It functions as an intelligent software pipeline that converts continuous IoT sensor streams—originating from loaders, haul trucks, and conveyor systems—into structured event logs suitable for process mining analysis. In **Fig. 2**, the IoT Miner pipeline integrates clustering algorithms, signal processing, and machine learning techniques to automatically identify operational boundaries and key production events within raw sensor data[22]. By combining clustering algorithms, signal processing, and machine learning techniques, IoT Miner automatically identifies operational boundaries and key production events within raw sensor data. This enables mining engineers and analysts to visualize process flows, detect inefficiencies, and discover performance bottlenecks without extensive manual data preparation. By bridging the gap between raw operational data and process analytics, IoT Miner provides a foundation for real-time optimization, predictive maintenance, and evidence-based decision-making in modern mining environments.

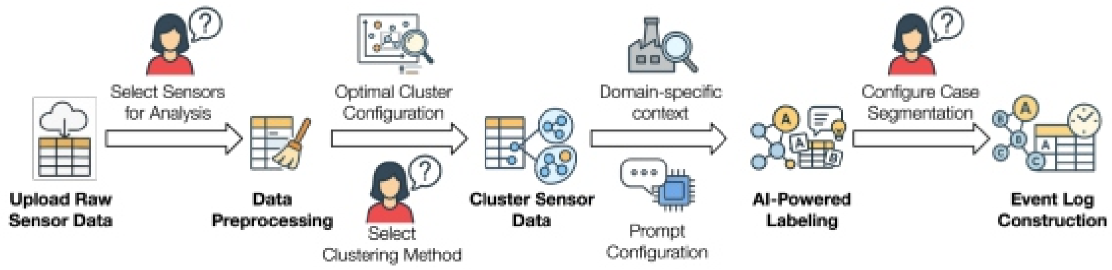

Fig. 2. IoT Miner Pipeline[22]

4.3 Robot-As-A-Sensor (RAAS) form a Sensing Networks [NEW]

A new paradigm for underground mining operations by transforming mobile robots into intelligent, networked sensing nodes. Rather than functioning as isolated units, these robots collectively form a dynamic sensing and communication network capable of real-time environmental and geotechnical monitoring. As illustrated in **Fig. 3**, each robot acts as both a data collector and a relay unit, capturing parameters such as temperature, gas concentration, vibration, and structural integrity while simultaneously transmitting data across the network [18]. Each robot acts as both a data collector and a relay unit, capturing parameters such as temperature, gas concentration, vibration, and structural integrity while simultaneously transmitting data across the network. This distributed system significantly enhances situational awareness and operational safety in deep or communication-degraded mine zones where fixed sensor networks are impractical. By integrating principles from wireless sensor networks (WSNs), Internet of Things (IoT), and edge computing, RAAS aligns with the emerging vision of Mining 5.0, emphasizing automation, collaboration, and sustainability. The RAAS model thus represents a critical step toward safer, more resilient, and data-driven mining ecosystems.

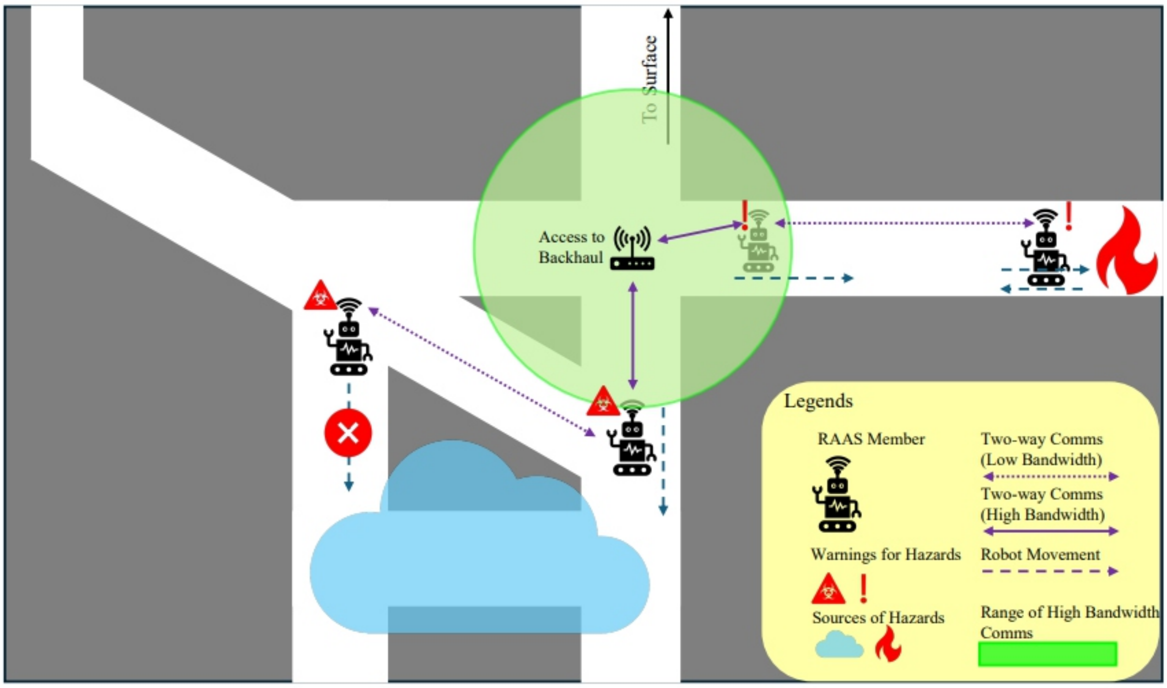

Fig. 3. A graphical illustration of Robot-As-A-Sensor for underground mine sites[18]

4.4 Ambient Noise Tomography (ANT) + AI for Mineral Exploration [NEW]

This approach integrates Ambient Noise Tomography (ANT) with Artificial Intelligence (AI) to accelerate mineral discovery—especially for critical resources like copper needed in the low-carbon transition. ANT offers high resolution, scalability, and low environmental impact, while AI refines large-scale geophysical data into precise deposit-scale predictions. As shown in **Fig. 4**, this hybrid approach, when applied to Australia's copper prospectivity model fine-tuned on the Hillside IOCG deposit, effectively delineates orebodies even with limited local data [11]. Using Australia's copper prospectivity model fine-tuned on the Hillside IOCG deposit, the method accurately outlines orebodies with minimal local data. Together, ANT and AI enable faster, data-driven mineral targeting, improving exploration efficiency and sustainability.

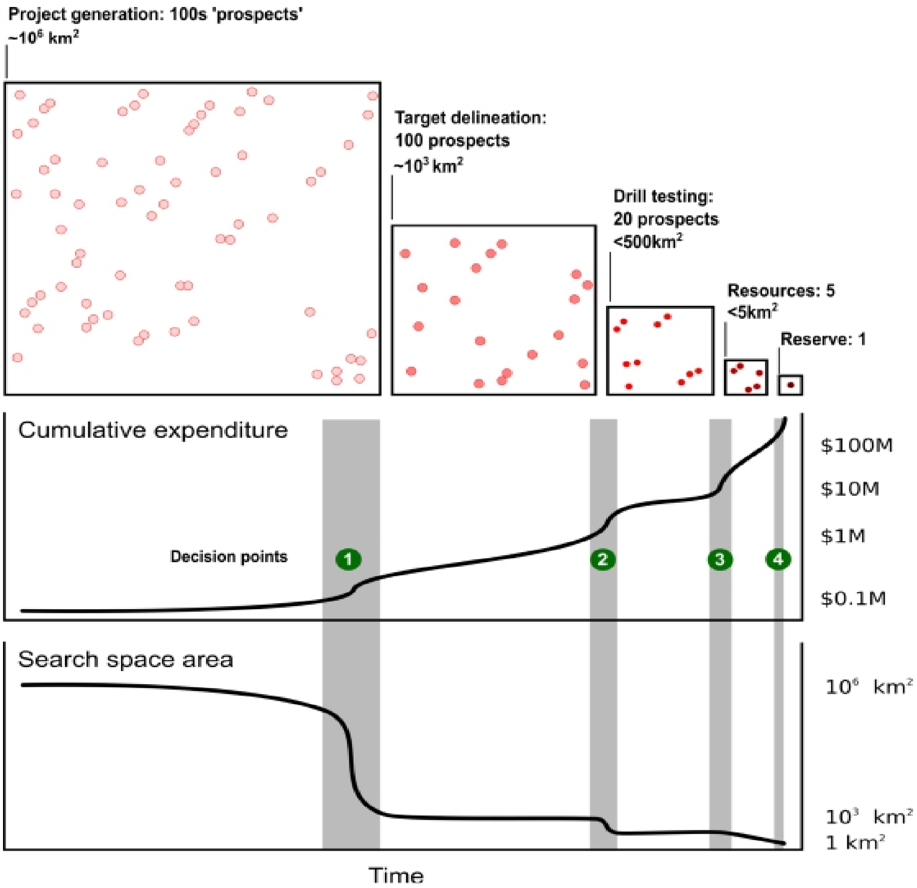

Fig. 4. The scale reduction process in mineral exploration towards mineral resource definition[11]

4.5 Surveys & Reviews of Robotic Automation in Mining [NEW — Survey]

With ongoing advancements in engineering and autonomous technologies, **Robotic Autonomous Systems (RAS)** are increasingly being deployed across the mining sector, offering the potential to replace humans in hazardous or repetitive tasks. Although RAS has significantly contributed to the development of intelligent mining machinery, a comprehensive survey of their industrial applications has been limited. This study bridges that gap by reviewing the **chronological progress of conventional mobile robotic platforms**—including drilling rigs, impact hammers, earthmoving equipment, and haulage trucks—emphasizing **real-world implementations** of mining automation. Furthermore, it evaluates **performance assessment methodologies** for **Robotic Autonomous Mining Systems (RAMS)** at both the individual and system levels, aiding in design validation before field deployment. As shown in **Fig. 5**, the development timeline of autonomous drilling rigs highlights the steady evolution of RAS technologies toward greater autonomy and operational safety [20].

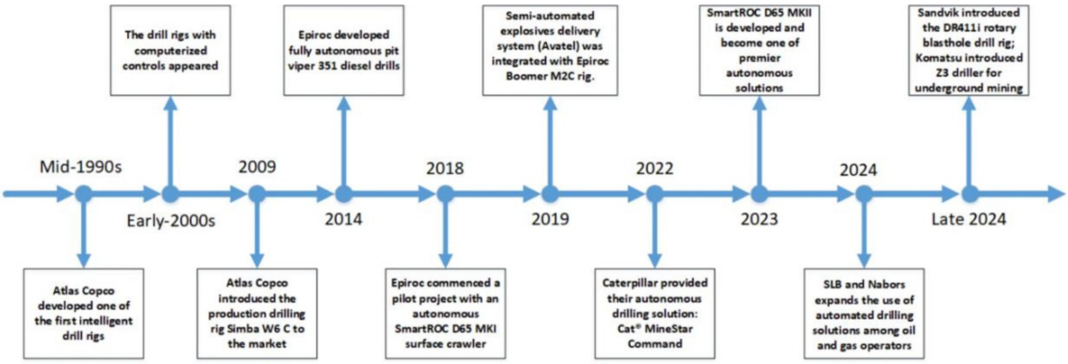

Fig. 5. The development timeline of autonomous drilling rigs

5. Discussion

Over the last five years, the mining industry has witnessed accelerated advancements in **robotic autonomy, sensor fusion, and AI-driven analytics**. Earlier innovation waves primarily focused on mechanization and single-machine automation, whereas the current trend emphasizes **systems-of-systems**, including collaborative autonomous platforms, mobile sensing networks, and digital twins that coordinate complex operations. This shift presents opportunities for IT professionals, creating demand for **software engineers, machine learning specialists, systems integrators, and cloud/edge architects**. However, key challenges remain, such as **cybersecurity risks, system reliability under harsh conditions, workforce reskilling, and integration with legacy infrastructure**.

6. Conclusion & Recommendations

This review highlights **25 key innovations** in mining, integrating both classical advancements and recent research from the past five years. The study confirms that **IT, robotics, and data analytics** are central to the ongoing transformation of the mining sector. For students and practitioners, priority focus areas include: (a) **process mining and IoT pipelines**, (b) **robotics and mobile sensing**, (c) **digital twin modeling**, and (d) **cyber-physical systems security**. Future research should address **socio-technical**

impacts, lifecycle carbon benefits, and the development of **standards for multi-vendor autonomous operations**, ensuring safer, more sustainable, and efficient mining practices.

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Review of Global Deep Mining Practices in High-Stress and Rockburst-Prone Mines

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Abstract

The mining in India is progressing towards greater depths, exceeding 1000m, where high in-situ stresses contribute to rockburst phenomena. These violent failures pose significant risks to personnel, equipment, and operational continuity. While rockburst is a well-documented challenge in deep mines across Canada, South Africa, and Scandinavia, a systematic study and documented case histories are notably absent in the Indian context. This paper presents a comprehensive review of global case studies to synthesize applied strategies for rockburst mitigation in deep hard rock mines. The study delves into the principles and applications of dynamic support systems, the role of advanced seismic monitoring networks, and proactive destressing techniques. By integrating findings from international best practices with an analysis of India's mining environment, this review aims to formulate a foundational framework for rockburst hazard assessment and control. The conclusions highlight the importance for adopting a multi-faceted strategy, combining robust mine design, real-time geomechanical instrumentation, and proactive ground control practices to ensure the safe and viable exploitation of India's deep-seated mineral resources.

Keywords: Rockburst, Deep Mining, High-Stress, Dynamic Support, Seismic Monitoring, Destress Blasting, Indian Metal Mines.

1.0 Introduction

The global pursuit of mineral resources has taken mining at increasingly higher depths. With the continuous advancement of mining technology and the increasing global demand driven by socio-economic growth, the exploitation of mineral resources has progressively extended to greater depths. Operations in Canada's Sudbury Basin, Sweden's Kiruna Mine, and South Africa's Witwatersrand Basin have historically exceeded depths of 2000 meters, helping in documenting the challenge of rockbursts, a phenomenon of sudden violent rock failure associated with seismic events (Malan et. Al. 2020). India's mining landscape is on a similar trajectory; with several metal mines approaching the 1000-meter mark, incidents of rock noise and rockbursts are beginning to be reported (Ghose et. al. 2007). This emerging reality signals an urgent need for proactive research and preparedness, moving beyond traditional empirical approaches to quantitatively driven rock mechanics.

As shallow mineral resources become depleted, the need for both metallic and non-metallic minerals has compelled the transition toward deep mining operations (Li and Murwanashyaka, 2019). However, as mining depth increases, the magnitude of in-situ ground stress also rises correspondingly (Kouame et al., 2017; Liu and Wang, 2018), as illustrated in Fig. 1. This escalation in ground stress leads to a higher probability and intensity of rockburst occurrences, posing significant challenges to the safety and efficiency of deep mining operations (He et al., 2012; Kaiser and Cai, 2012; Chen et al., 2012; Cai, 2016; Xia et al., 2017; Sengani and Zvarivadza, 2017; Kouame et al., 2017). Consequently, understanding the mechanisms, influencing factors, and control measures of rockburst has become a crucial aspect of modern deep underground mining research.

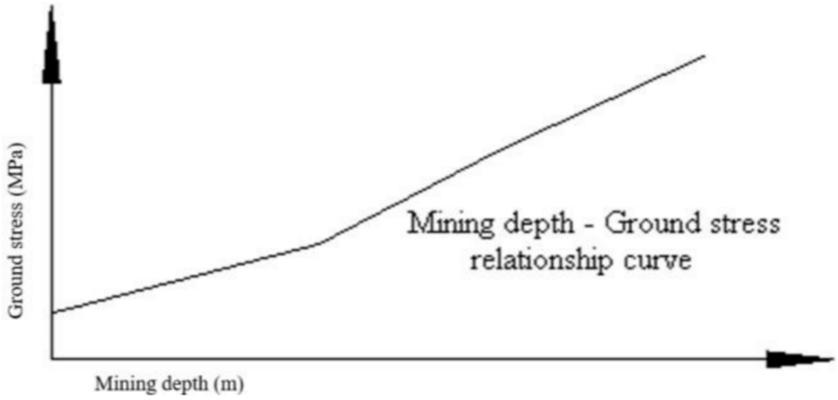

Figure 1: Relationship between mining depth and ground stress (Evariste Murwanashyaka, Xuefeng Li et. al.2019)

A rock burst is fundamentally a dynamic instability where the rock mass, unable to accommodate the mining-induced stress concentrations, fails violently, releasing stored strain energy in the form of kinetic energy (Kaiser et. al. 2010). This can result in the ejection of rock fragments at high velocities (1-7 m/s), causing fatalities, injuries, equipment damage, and severe production delays. The seminal work by Kaiser et al. defines it as "damage to an excavation that occurs in a sudden or violent manner and is associated with a seismic event" (M.Cai et. al. 1996). The hazard is multifaceted, comprising self-initiated strain bursts where the seismic source and damage coincide, and remotely triggered events where energy from a distant fault-slip or pillar collapse impacts an excavation (Kaiser et. al. 2012).

2.0 Rock burst mechanism and causes of rockburst

Rockbursts are **seismic events induced by the exploitation of deep mineral deposits**, characterized by the sudden, brittle failure of rock accompanied by the violent release of stored strain energy. These events occur when the rock mass is subjected to stresses exceeding its ultimate elastic limit, resulting in abrupt fracturing and severe damage within the excavation zone. According to Larsson (2004) and Kabwe and Wang (2015), a rockburst is an **excavation-induced seismic phenomenon** that causes structural damage to underground openings. According to various previous studies, rockburst mechanisms have been classified in several ways; however, the most widely recognized categories include strain burst, pillar burst, and fault-slip burst (Tang, 2000; Saraham, 2004; Leveillel et al., 2017), as summarized below.

The **strain burst** occurs in highly stressed ground near an excavation boundary. It involves the spalling or slabbing of the rock surface due to stress-induced brittle fracture. The driving mechanism is the excess of the rock's compressive strength by the tangential stress at the excavation boundary (Tang, 2000; Leveillel et al., 2017).

The **fault-slip burst** mechanism is primarily associated with shear instability in rock masses adjacent to geological structures such as faults, joints, and dykes. Mining-induced stress redistribution can trigger sudden fault rupture and displacement, resulting in intense seismic shaking and ground motion (Saraham, 2004; Leveillel et al., 2017).

The **pillar burst** occurs when excessive mining-induced stresses develop on load-bearing pillars, particularly in areas with high extraction ratios or large goaf zones. Once the pillar's strength is exceeded, sudden failure or spalling takes place, releasing a large amount of stored strain energy (Tang, 2000; Saraham, 2004).

2.1 Factors influencing rockburst

The severity of rockburst damage can generally be classified into minor, moderate, and major (or severe) levels, depending on factors such as the volume of displaced or failed rock, the extent of rock support damage, and the intensity of energy release, including impact or ejection velocity (Tang, 2000; Saraham, 2004). The damage severity is influenced not only by the intensity of the seismic event but also by a range of geological and mining parameters, including in-situ stress, rock mass quality, rock brittleness, effectiveness of support systems, local mine stiffness, geological structures, excavation geometry, and sequence of mining operations (Leveillel et al., 2017; Kaiser and Cai, 2012). To accurately assess rockburst damage potential, it is essential to consider the vulnerability of the excavation, which integrates both the characteristics of the rock mass and the mining environment.

2.1.1 Geological factors influencing rockburst

Lithology, structural geology, rock mass quality and stress field interactions determine the likelihood and intensity of rock bursts. Rocks composed of minerals such as quartz and feldspar generally display higher elastic modulus and uniaxial compressive strength, which is likely due to the grain boundary relation as well as the formation conditions of these rocks. These properties allow them to store more elastic energy, which, when released abruptly, results in violent rockburst events (Li et al., 2023; Zhang et al., 2025). Laboratory experiments on granite subtypes from the Ruihai gold mine further confirm that variations in microstructure have a major impact on the type of failure and the amount of energy released during compression testing (Li et al., 2023). These microstructures release the stress locally if there is a splay of microfractures, and hence, eventually, the rock strength is compromised. The nature of structural geological features such as faults, joints, folds, dykes, and bedding planes fundamentally governs stress distribution in the subsurface and thereby modulates the risk of dynamic failure events. Discontinuities, acting as either weaknesses or barriers within the rock mass, become sites for stress concentration and slip, triggering rock bursts when critical thresholds are surpassed. Detailed studies have identified that burst-prone regions commonly exhibit persistent, favourably oriented faults and joint sets, with large-scale discontinuities capable of involving substantial rock volumes in brittle failure events (Zhang et al., 2023; Wen et al., 2019).

The depth of mining operations and the prevailing tectonic conditions significantly influence both in-situ and mining-induced stress regimes. Empirical and modelling studies have established that increased mining depth correlates with greater vertical and horizontal stress concentrations, thereby intensifying the potential for dynamic instability. The stress field, superimposed with geological heterogeneity, delineates the most burst-prone zones. Microseismic monitoring data frequently reveal precursory events along major discontinuities, supporting the notion that rockbursts reflect the interplay between stress accumulation, structural orientation, and rock fabric (Zhang et al., 2024; Wen et al., 2019).

2.1.2 Seismicity factors influencing rockbursts

Rockbursts are closely linked to several geological and stress-related scenarios that generate mining-induced seismicity. Mining-induced seismicity is strongly influenced by geological and stress conditions, and several mechanisms of rockburst occurrence have been documented in deep mines worldwide. Fault reactivation is a common source of seismicity, where excavation-induced stress redistribution causes slip along pre-existing shear zones. For instance, reactivation of the Pretorius Fault in the TauTona Mine, South Africa, produced local seismic events with magnitudes up to Mw ≈ 2.0, resulting in ground damage near active workings. Similarly, high in-situ stresses at great depths (>2-3 km) are responsible for static overstress and brittle failure of rock masses, leading to energetic seismic events typically ranging from ML 1 to 3.5, as observed in the Mponeng, TauTona, and Kloof gold mines (Durrheim et al., 2007). The competent and brittle lithologies, such as quartzite and massive sandstone, favour sudden energy release, making them more prone to violent rockbursts. At Mponeng Mine, seismic monitoring has shown higher energy release (Mw 1.5-2.5) in the quartzite footwall compared to weaker shale horizons.

Furthermore, lithological contacts, dykes, and stiffness contrasts act as stress concentrators that localise failure. Studies at Creighton and Kidd Creek Mines in the Sudbury Basin have revealed that dykes and shear zones often coincide with seismic clusters of Mw 1-3. In addition, pillar or remnant collapse, also known as pillar bursts, occurs when overstressed support pillars exceed their strength, releasing stored elastic energy suddenly. Canadian hard-rock mines such as Kidd and Creighton have documented pillar bursts with magnitudes up to Mw 2.8, often accompanied by strong ground motions.

In deep coal mines, longwall extraction induces periodic stress redistribution in the roof and floor strata. This results in seismic tremors or “bumps,” with magnitudes typically between ML 1 and 2.5, as reported from the Upper Silesian Coal Basin in Poland. Another mechanism, remote dynamic triggering, occurs when seismic waves from a large mining-induced event or regional earthquake induce secondary failures in already stressed zones. Such dynamically triggered strainbursts (up to Mw 2.0) have been reported in South African gold mines. Finally, hydromechanical effects, such as sudden pore-pressure changes or gas migration, can reduce effective stress and initiate slip or collapse. Hydro-coupled triggering has been observed in the TauTona Mine, where changes in subsurface gas and fluid pressure were correlated with increased seismic activity.

4.0 Geotechnical rockburst mitigations

Mining operations at depths of more than 1,000m below the surface present highly challenging geotechnical conditions. Elevated stress regimes, seismic disturbances, and time-dependent rock deformation make mining more complex and significantly raise the risk of serious failures, including rockbursts, roof falls, and pillar instability. A thorough understanding of these geotechnical factors is therefore essential to maintain safety, optimize productivity, and ensure the overall economic sustainability of deep mining projects. Implementation of monitoring systems is an important part of mining, especially in high-stress conditions. These systems measure the response of the rock mass to the formation of the excavation and may also be used to calibrate geotechnical models. The main aim of any rock mechanical monitoring is to provide a safe working environment for mine personnel.In the context of rockburst risk management, practical control measures with the hazard control framework shown in Fig. 2 is categorized into three types: **strategic**, **tactical**, and **administrative** controls. These are arranged according to the **hierarchy of controls**, from the most effective to the least effective methods (Ming Cai et.al. 2024).

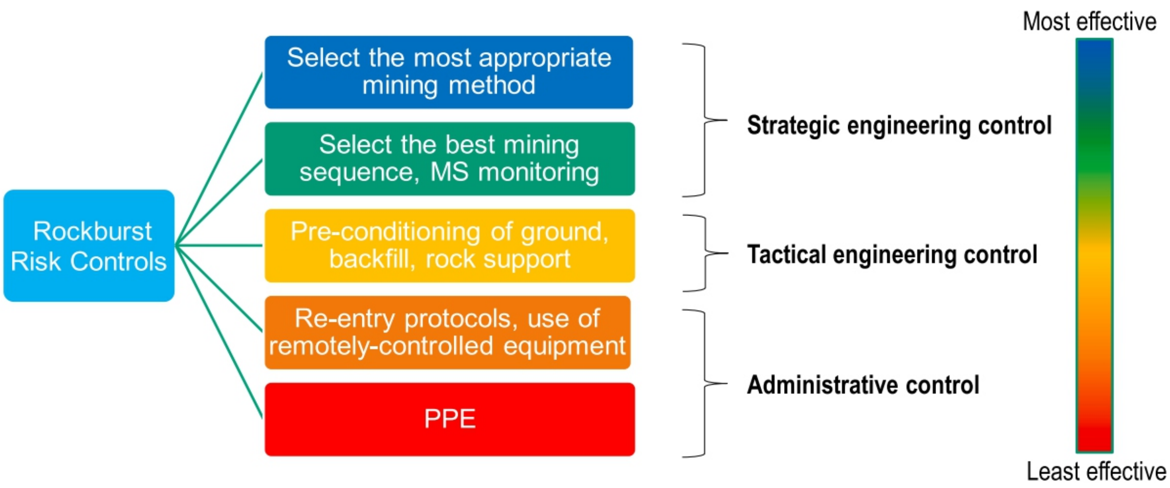

Figure 2 : Rock bursts risk control (Ming Cai et.al. 2024)

Rock mass monitoring at various mines has evolved progressively with changing mining conditions. Initially at Pyhäsalmi mine (Finland), yielding pillars were monitored using extensometers and three-dimensional stress gauges, which provided data for back-analysis. Once subsidence along the ore–waste rock contact was detected, extensometers were additionally deployed to measure displacement at this interface. Fixed-point surveying was also introduced to track contact subsidence. In 2002, a microseismic monitoring system was installed to detect and locate zones of rock yielding. Furthermore, visual damage mapping has been employed to identify rockfalls and other hazards, as well as to support back-analysis and validate data from other monitoring techniques (bergstrom et.al.2014). In geotechnical applications, seismic monitoring serves as a valuable tool to refine the understanding of the relationship between in-situ stress conditions and rock mass strength. This information can then be applied to improve geotechnical designs and optimize mining sequences. The greatest advantage is realized when seismic monitoring is introduced proactively, enabling adjustments to mine designs and layouts before seismic activity escalates to a level that disrupts operations (bergstrom et. al.2014). Moreover, according to Saraham (2004), stress control methods in rockburst prevention encompass ground preconditioning, alternative mining methods, and rock support systems.

One significant advancement for rockburst mitigation is the adoption of the **longwall mining method** in deep hard rock mines susceptible to rockbursts. This method facilitates increased mineral recovery while also minimizing stress concentrations due to its streamlined layout. Consequently, it offers a safer alternative to the traditional room-and-pillar mining approach, with a lower likelihood of inducing rockbursts (Salamon, 1993).

In South African gold mines, the use of large **stabilizing pillars** has proven effective in reducing the convergence of mined-out zones. This approach has contributed to a noticeable decrease in both seismic activity and the frequency of rockbursts (Ortlepp, 1984; Lenhardt, W. A. (1992)).

Destress Blasting and Preconditioning

Destress blasting introduces controlled damage in rock to release stored energy. South African mines pioneered destress holes drilled along the hanging wall or pillars and charged with ANFO; fracturing transfers peak stress away from the production face. Destress blasts are sometimes combined with preconditioning (large-diameter holes, hydraulic fracturing, water infusion) to weaken strong ore pillars. The psychological benefit of de-stress blasting for workers has been noted knowing that stress has been relieved improves confidence (T. Zvarivadza et. al. 2025)

Displacement block model

A displacement block model provides a clear visualization of subsidence and the extent of movement across different areas. It is generated using fixed survey point data along with maximum displacement readings from installed contact extensometers. To improve accuracy and expand coverage, surveys were conducted across all accessible levels of development. The model can be updated quickly on a monthly basis with new survey data. It shows strong correlation with visual inspections and is a valuable tool for identifying geotechnical risk zones as well as for planning and scheduling ground support.

Damage mapping

Regular inspections of all excavations to identify damage, rockfalls, and other hazards are a fundamental duty of care for every individual and form an essential part of daily workplace practices when accessing and performing tasks. These inspections should be integrated into a structured system that ensures the entire workforce is properly trained to detect rockfalls and other forms of underground damage.

Conclusions

The transition toward deep mining has created new geotechnical challenges, among which rock bursts represent one of the most critical and complex hazards. As mining operations advance beyond 1000 meters in depth such as those in India's emerging deep metal mines the combined effects of elevated in-situ stress, brittle rock behaviour, and geological heterogeneities increasingly amplify the risk of dynamic failure. Global experiences from operations in South Africa, Canada, and Sweden highlight that the phenomenon of rock burst is not only a function of depth but also a product of the interaction between geological structures, rock mass characteristics, and mining-induced stress redistribution. The integration of geotechnical monitoring and hazard control frameworks has proven to be one of the most effective approaches in mitigating rock burst risk. Seismic and displacement monitoring, as demonstrated at the Pyhäsalmi Mine, allows for early detection of stress accumulation and structural instability, thereby supporting predictive and adaptive mine design. The use of displacement block models and damage mapping further enhances situational awareness, enabling engineers to correlate visual observations with quantitative data and to prioritize ground control interventions. Such proactive and data-driven methodologies mark a critical shift from reactive responses toward preventive rockburst management. The real world experience from international and Indian mines show us that no single measure can completely eliminate rockburst risk. Instead, the integration of continuous monitoring, optimized mine design, and adaptive control measures provides the most reliable defense. The advancement of modern rock mechanics tools, combined with real-time seismic data interpretation and microstructural analysis of rock behaviour, paves the way for safer, more sustainable deep mining.

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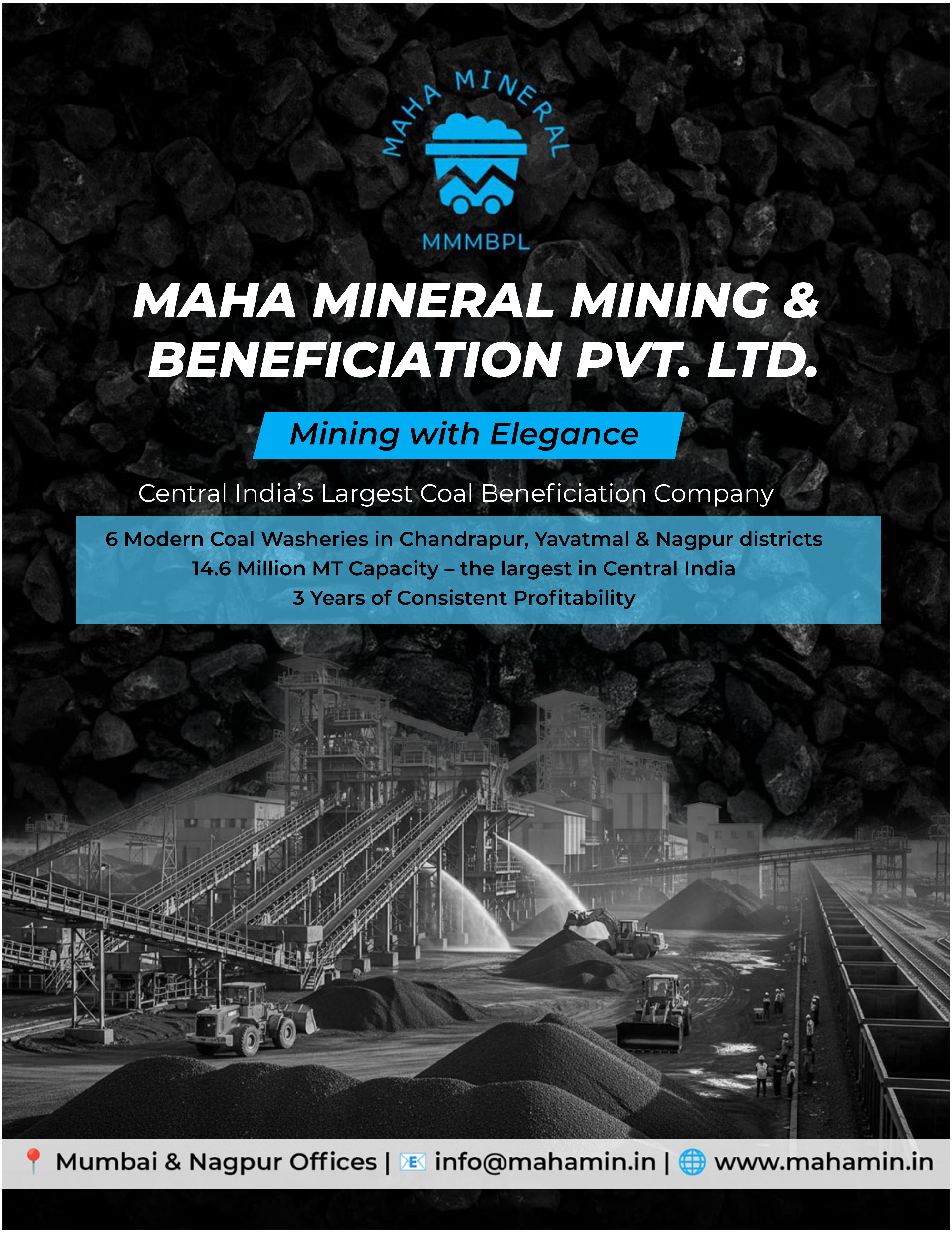
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