सीएसआईआर–केन्द्रीय खनन एवं ईंधन अनुसंधान संस्थान
(वैज्ञानिक तथा औद्योगिक अनुसंधान परिषद्)
विज्ञान एवं प्रौद्योगिकी मंत्रालय, भारत सरकार
बरवा रोड, धनबाद – 826 001, झारखण्ड, भारत
CSIR-Central Institute of Mining and Fuel Research

डॉ. प्रदीप कुमार सिंह
एफएएससी, एफएनएएससी
निदेशक
Dr. Pradeep K Singh
FASc, FNASc
Director

(Council of Scientific & Industrial Research)
Ministry of Science & Technology, Govt. of India
Barwa Road, Dhanbad - 826 001, Jharkhand, India

Message

It is a matter of great pleasure that Indian Mining and Engineering Journal entered into 60th year of its publication in 2021. It is quiet exciting to know that the journal is bringing out a Special Volume (e-Journal) on this auspicious occasion. This e-Journal will be a knowledge enrichment source across the domain of mining professionals.

In the last 60 years, the mineral based industries have attained greater heights with technological advancement and coal production increased by 15 times since independence. CSIR-Central Institute of Mining and Fuel Research is a major stakeholder in mining and mineral related business and knowledge portfolio. The institute provides R&D inputs for the entire coal-energy chain from mining to consumption. The laboratory also strives to develop mineral based industries to fulfil the raw material demand of the country. The institute is well equipped with the instrumental facilities to provide technological solutions to reach the targeted production for country's energy security and growth with high standards of safety, economy and cleaner environment. Presently, CSIR-CIMFR is extending the scientific & Technical support to many. coal and mineral based industries. The footprints of CSIR-CIMFR can even be found in other allied sectors such as strategic and other important sectors like Atomic Energy, Defence (Border Roads Organisation), Railways, Hydro-electric Projects, Archaeology, City planning (Navi Mumbai International Airport) etc.

I hope that the publications in e-journal will certainly be helpful to the mining community enriching the knowledge with the latest technological innovations in the sector.

I congratulate the publisher and editors for the successful journey of 60 years and wish the Editorial Board Members all the success for the upcoming e-journal

PKSingh 24.03.2021
(Pradeep K Singh)

HQ:Dhanbad-Tel.:+91-326-2296023,2296006(O) **Fax:**+91-326-2296025 **EPABX:**+91-326-2296012/6013/6027t6029
e-mail : director@cimfr.nic.in, drpksingh@cimfr.nic.in, pradeep.cimfr@yahoo.com **Digwadih Campus : Tel.:** +91 -326 -2381111
ResearchCentres:Bilaspur: Tel.: +91-7752-271450 **Nagpur:Unit.I - Tel.**'. +91-712-2510604, **Unit . II .Tel,:** 2510390
Ranchi : Tel.: +91-9430799534, 9430799540 **Roorkee : Tel.:** +91-1332-275998
Website : www.cimfr.nic.in

THE INDIAN MINING & ENGINEERING JOURNAL

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

www.theimejournal.com

VOLUME 60: Number 03 **MARCH 2021** ISSN 0019-5944

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

IME PUBLICATIONS

Corresspondance Address
The IM& E Journal 1457, Fishery Tank Road, Chintamaniswar, Laxmisagarpatna, Bhubaneswar - 751006, Odisha **Mobile:** +919861008387
Mail: indianminingjournal61@hotmail.com
Branch office:Near TV Tower, JODA, Dt. Keonjhar 758034
Phone: 06767-273173

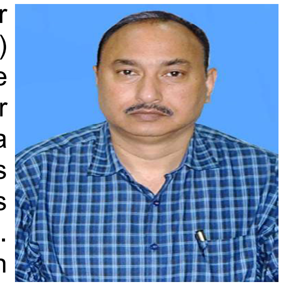
CELEBRATING 60 YEARS The Indian Mining & Engineering Journal

Contents

Technical Papers

The IME Journal Readers' Forum
Regd. Office : IMEJournal, Laxmisagarpatna, Bhubaneswar 751 006
E-mail : indianminingjournal61@hotmail.com Mobile: +919861008387

Persons in the News



Shri J.P Gupta joined as Director Technical (Project and Planning) BCCL on 01.04.2021. Currently, he is also serving as Director Technical (P&P) ECL. Shri Gupta has a vast experience of 37 years in coal mining technology and has served CIL in different capacities. Upon reaching Koyla Bhawan on 01.04.2021, Sri Gupta congratulated the medical fraternity of Central Hospital BCCL for their outstanding efforts in conducting the Covid-19 vaccination drive for employees, outsourced workers and citizens of Dhanbad.

Shri Subhash Kumar presently Director (Finance), Oil and Natural Gas Corporation (ONGC), has taken additional charge as Chairman and Managing Director (CMD)- ONGC. Shri Kumar has been appointed to the post by the President of India. Prior to joining as Director (Finance), ONGC, Shri Kumar served a brief stint with Petronet LNG Limited where he joined as Director (Finance) in August 2017. Shri Kumar is Fellow Member of ICMAI and also Associate Member of ICSI. He is an alumni of Panjab University, Chandigarh, where he obtained his Bachelors Degree and Master Degree in Commerce with Gold Medal.

Shri Kumar joined ONGC in 1985 as Finance & Accounts Officer (F&AO). After initially working in Jammu and Dehradun, he had a long stint at ONGC Videsh, the overseas arm of ONGC. During his tenure with ONGC Videsh, Mr Kumar was associated with key acquisitions and expansion of company's footprint from single asset company in 2001 into a company with global presence in 17 countries with 37 assets. He played a key role in evaluation and acquisition of many Assests abroad by ONGC Videsh.

He worked as Head Business Development, finance & Budget and also as Head Treasury Planning & Portfolio Management Group at ONGC Videsh from April 2010 to March 2015. He then west on to serve as Chief Financial Officer of Mansarovar Energy Colombia Limited, a 50:50 joint venture of ONGC Videsh and Sinopec of China, from

September 2006 to March 2010. Shri Kumar joined back. ONGC as Chief Commercial & Head Treasury of ONGC in July, 2016 where he played a key role in evaluation, negotiation, and concluding outstanding issues pertaining to the organization.

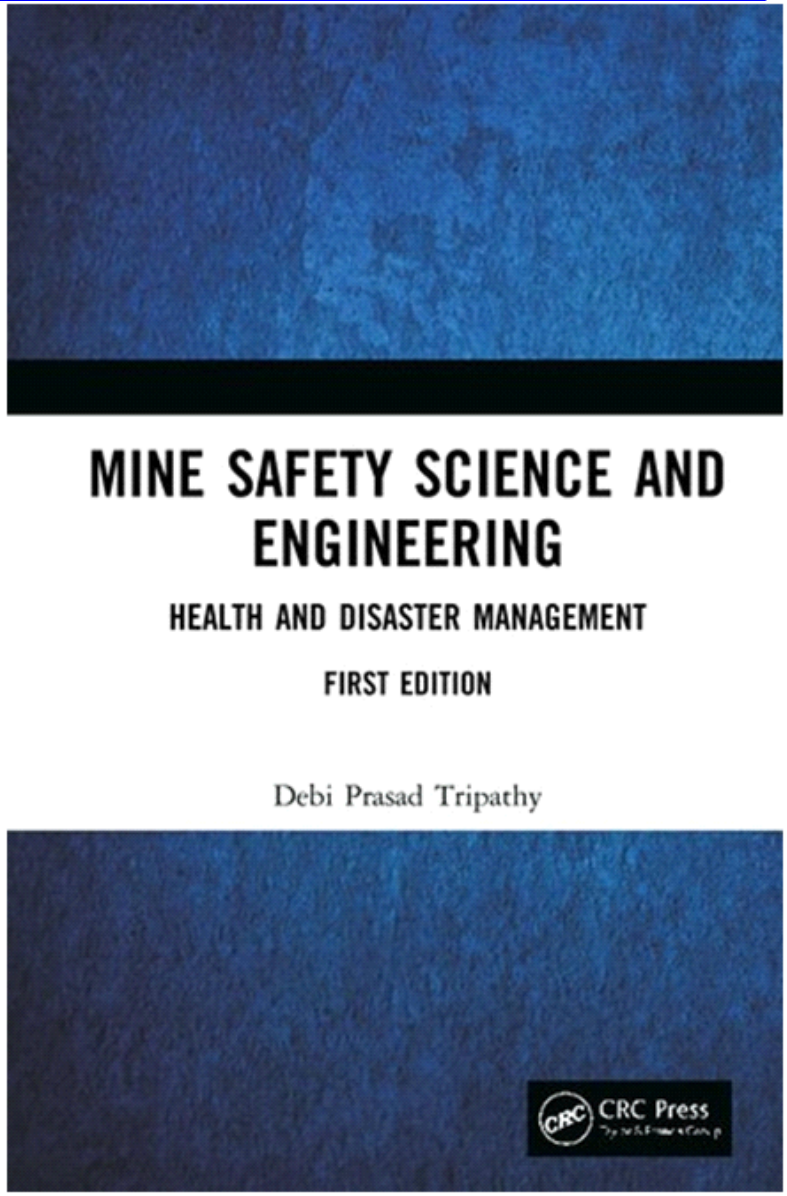
Shri Pradosh Kumar Basu presently Chief Financial Officer, ONGC Petro Additions Limited (OPaL), has been appointed as Director (Finance) in National Aluminium Company Limited (NALCO) for a period of five years from the date of his assumption of charge of the post.

Shri Kiran Patil has assumed the role of Managing Director at Wonder Cement on March 15, after the superannuation of the previous MD, Jagdish Chandra Toshniwal,". Shri Patil is a Mechanical Engineer from PDA College of Engineering, Gulbarga University, and also has a Master's in Finance from Sikkim Manipal University. With over 35 years of experience, Shri Patil is a veteran in the cement industry and is well known for his innovation-driven approach and project management skills. He also has exposure across different geographies like the Philippines and Vietnam, apart from the Indian market.Shri Patil would be operating out of the company's headquarters in Udaipur, Rajasthan. Shri Patil has worked as the Chief Manufacturing Officer (CMO) with ACC Ltd, based out of Mumbai. He has previously worked with Ultratech Cement, Lafarge India and Tata Steel.

Dr Prabhakar Sangurmath Former Geologist MECL and Former Executive Director of HGML, joined board of Directors of HGML. An eminent geologists was recipient of National Mineral Award, and several national awards. He has 35 years experience in identifying viable gold(Primary & Secondary) and base metals mineral properties for exploration, mining(Underground & Open-pit), Processing i.e. Planning, Execution, Documentation, Feasibility, related R&D activities and Project Management.

Book Review

Mine Safety Science and Engineering Health and Disaster Management by Prof D.P.Tripathi, Hardback £140.00 eBook £40.49, ISBN 9781138061491, Published September 9, 2019 by CRC Press, 424 Pages 120 B/W Illustrations



In Mining Engineering operations, mines act as sources of constant danger and risk to the miners and may result in disasters unless mining is done with safety legislations and practices in place. Mine safety engineers promote and enforce mine safety and health by complying with the established safety standards, policies, guidelines and regulations. These innovative and practical methods for ensuring safe mining operations are discussed in this book including technological advancements in the field. It will prove useful as reference for engineering and safety professionals working in the mining industry, regulators, researchers, and students in the field of mining engineering.

The 13 Chapters included Basics of Mine Safety Engineering, Safety Issues in Opencast and Underground Mines, Behavioural-Based Safety, Safety Culture in Mining Industry, cident Statistics, Analysis and Prevention in Coal and Non-Coal , Safety Risk Assessment and Management, Safety Audit & Standardization, Occupational Health and Safety in Mines ,Safety Education and Training, Innovations in Mine Safety Engineering, Disaster Management, Mine Rescue,First Aid and Ambulance Work and an Appendix on Safety nomenclature.

Professor Debi Prasad Tripathy is Professor in the Department of Mining Engineering at National Institute of Technology, Rourkela. He obtained his B.E.(Mining Engg.) from VNIT, Nagpur; M. Tech. from I.T., BHU; and Ph.D. from ISM, Dhanbad.

His areas of teaching and research interests are: Mine Environment and Safety Engineering, Environmental Management (Air & Noise), Mine Management, Mine Planning, and Computer Applications in Mining Industry.

COAL NEWS

CIL SIGNS CONTRACT WITH M/S. URALMASHPLANT, RUSSIA

CIL has signed a contract with M/s. Uralmashplant JSC, Russia - for the supply, installation and commissioning of five electrical walking draglines. All the five electrical walking draglines will be commissioned in Northern Coalfields Ltd. While four draglines will be commissioned in Bina open cast project, one will be commissioned in Jayant open cast project of Northern Coalfields Ltd.

Shri. Binay Dayal, Director - Technical, CIL signed the contract on behalf of Coal India Ltd and Mr. Yan V. Senter signed on behalf of M/s. Uralmashplant JSC, Russia.

Shri. Pramod Agrawal, Chairman, CIL, Shri. Sanjiv Soni, Director - Finance, CIL and Shri. S. N. Tiwary, Director - Marketing & Personnel & IR, CIL were present on the occasion.CIL SIGNS CONTRACT WITH M/S. URALMASHPLANT, RUSSIA

CIL has signed a contract with M/s. Uralmashplant JSC, Russia - for the supply, installation and commissioning of five electrical walking draglines. All the five electrical walking draglines will be commissioned in Northern Coalfields Ltd. While four draglines will be commissioned in Bina open cast project, one will be commissioned in Jayant open cast project of Northern Coalfields Ltd.

Shri. Binay Dayal, Director - Technical, CIL signed the contract on behalf of Coal India Ltd and Mr. Yan V. Senter signed on behalf of M/s. Uralmashplant JSC, Russia.

Shri. Pramod Agrawal, Chairman, CIL, Shri. Sanjiv Soni, Director - Finance, CIL and Shri. S. N. Tiwary, Director - Marketing & Personnel & IR, CIL were present on the occasion.

COAL INDIA ANNUAL PRODUCTION DROPS FOR SECOND STRAIGHT YEAR

CIL said it provided additional coal supply in the country during 2020-21, which prompted customers to opt 90 million tonnes of domestic coal instead of importing it from abroad. At the end of COVID-19-hit 2020-21, Coal India Ltd (CIL) silver lining, amid output and offtake challenges, came in the form of curbing coal imports to the tune of 90 million tonnes (MT), the public sector undertaking said in a statement. Also, beating the previous estimates, the state-owned coal major booked an all-time high of 124 MT in its e-auctions.

Sustaining its growth trajectory throughout the fiscal, over burden removal (OBR) logged 17 per cent growth easing the way for faster future production, the statement said. OB is the extraneous material that overlays the coal seam, removal (OBR) of which makes the dry fuel's production easier. "In the absence of our import substitution measures through a host of concessions and benefits, the customers would have had no alternative than to source coal from imports. In that, it was a productive and timely move," the company said. The company opened a new window exclusively for coal importers in October last year.

CIL allowed its subsidiaries to sign memorandum of understandings (MoUs) with 17 power plants linked to them to substitute their imports with its own coal, for blending.Additional coal was allocated to central and state power generation companies (gencos), under flexi-utilisation, enabling them avert coal imports. Annual contracted quantity (ACQ) for power plants was enhanced to 100 per cent of normative requirement from 90 per cent. Increased quantities of coal was offered to non-regulated sectors against fuel supply agreements (FSAs) up to 100 per cent of ACQ. Trigger level for the power sector was elevated from 75 per cent to 80 per cent. Increased bookings in auctions were a major booster in import substitution efforts. While these actions cumulatively helped the power sector opt for domestic coal to the tune of 42 MT, non-regulated sector (NRS) picked up bulk of the rest.

CIL set a new high in booking 124 MT of coal under five e-auction windows in 2020-21 eclipsing the previous record of 113.6 MT achieved in 2016-17. Compared with 66 MT booked in 2019-20, CIL logged a strong 88 per cent growth in auction bookings. In absolute terms, the increase is 58 MT. CIL produced 596.2 MT of coal ending 2020-21 against 602.1 MT produced in 2019-20, while the offtake was 573.8 MT compared to 581.4 MT. "Despite our best efforts, there was marginal contraction in output and offtake by per cent and 1.3 per cent, respectively, on a year-on-year comparison due to coronavirus-led lack of demand," the company said. Primarily what hurt CIL's supplies was reduced coal lifting by the power sector and a steep 31 per cent fall in road transport despite our best efforts for conversion from road to rail during the pandemic-induced lockdown. Coordinated efforts with railways witnessed loading from CIL's own sources go up 11 per cent on a year-on-year basis. "The shrinkage in supplies could have been more had not for the spate of actions and sops offered to our customers," the company said.

The lack of demand also led to a stockpile of 99 MT at CIL pitheads. Further production would have resulted in stocks building up even higher. On the positive side with the expected demand revival during summer months of the first quarter, the company has sufficient buffer to meet any surge and the stocks would be reduced substantially. CIL accounts for over 80 per cent of the domestic coal output.

COAL INDIA LIKELY TO POST MARGINAL PRODUCTION DEGROWTH IN FY21

Coal India is likely to post marginal contraction of its output for the year 2020-21 by 5-6 million tonne in 2020-21 as its production will below the 600 million mark, sources said on Sunday. In 2019-20, the miner produced 602 million tonne down from 606.9 million in 2018-19 when it registered its highest production. It will be the second year in a row when the miner will register degrowth. The miner had projected a 660 million tonne production target and by mid-year the company had been expecting to attain 630-640 million tonne of output. "Till March 27, the production was 585 million tonne and 11 million tonne is expected to be added in the remaining days of the month. So, total production could be between 596- 597 million tonne," sources told. Offtake for the year is expected to be around 577 million tonne.

Inventory with Coal India stood at around 77.8 million tonne as of February-end, up from 66.8 million tonne at the end of January 2021. Domestic power plants are well stocked with coal supplies. Coal stocks at power plants stood at 31.9 million tonne at the end of February, enough to last 17 days. This has resulted in a fall in coal offtake for the third straight month. Coal offtake fell by 7 per cent year on year during February 2021.

ADANI ENTERPRISES SIGNS PACT WITH MAHAGENCO FOR OPERATION OF COAL MINE IN CHHATTISGARH

Adani Enterprises Ltd. along with its wholly-owned subsidiary Gare Palma II Collieries Pvt Ltd (GPIICPL) has signed a pact with Maharashtra State Power Generation Co Ltd (MAHAGENCO) for development and operation of Gare Palma Sector II coal mine. The coal ministry had allocated the coal mine in Raigarh district of Chhattisgarh to MAHAGENCO in 2015, Adani Enterprises said. "Adani Enterprises Limited along with its wholly-owned subsidiary company, Gare Palma II Collieries Pvt Ltd. has signed a coal mining agreement with MAHAGENCO for development and operation of Gare Palma Sector II coal mine," the filing said.

The coal block was allotted for development, operation and captive consumption of coal to its end use thermal power plants located at Koradi, Chandrapur 8- Parli. As per the approved mining plan, the peak rated capacity of mine is 23.6 million tonnes per annum with total mineable reserve of 553.177 MT for opencast mine. MAHAGENCO had floated a tender for selection of mine developer and operator for development and operation of Gare Palma II coal mine in March 2016. After a reverse auction, Adani Enterprises Ltd emerged as L-1 bidder. The contract period will be for 34 years, including for mine development and final mine closure.

MINING NEWS

VEDANTA TO SET UP A NEW COPPER SMELTER WITH AN INVESTMENT OF RS 10,000 CRORE IN A COASTAL STATE, SUBMITS EOI

Vedanta Ltd. is planning to set up a new copper smelter with an investment of around Rs 10,000 crore in partnership with the state government said the company through an expression on interest (EoI). “We are looking to partner with state governments for setting up a copper smelter in a coastal region in India,” the company said in its EoI statement.

The company said that the copper smelter of 500-kilo tonne per annum (KTPA) will require a footprint of around 1000 acres in proximity to port along with logistics connectivity with conveyor/corridor of rail and road to handle 5 mtpa material movement on both in-bound and out-bound side the EoI statement said.

India’s copper requirements are set to grow exponentially in the coming years. Having ample supplies of copper is critical to ensuring successful implementation of new-gen technologies such as electric vehicles, rapid automated transport and clean energy, said the company’s spokesperson in a reply to the queries sent. “We are therefore actively on the lookout for a suitable partner state to help take forward the vision of an Atmanirbhar Bharat through a copper manufacturing plant, the operational and environmental parameters of which are comparable to the best in the world," the company's spokesperson said.

This comes after the company's copper unit in Tuticorin, Tamilnadu, Sterlite Copper has been shut for the past 3 years after the Madras High Court in its 815-page order, in August 2020 ordered the company to shut down due to environmental violations. Residents from villages around Sterlite, along with social and environmental activists, staged protests against the copper plant on pollution allegations, in 2018. The Vedanta Sterlite Copper Smelting factory in Tamil Nadu's Thoothukudi was pulled up by the Tamil Nadu Pollution Control Board (TNPCB) for polluting air and water.

On May 24, 2018, the company faced massive backlash from the public following which the Tamil Nadu state government ordered a complete closure of the plant citing violations of Section 33A of the Water (Prevention and Control of Pollution) Act and Section 31A of the Air (Prevention and Control of Pollution) Act. On May 22nd, the 100th day of protests in the district around 13 people lost their lives and over a hundred of them were injured when the police opened fire on the protestors citing self-defence as the reason.

Founder and Chairman of Vedanta Ltd, Anil Agarwal in January 2021 said that the company is looking to develop a $10 billion investment fund by submitting expressions of interests on Government companies that are up for sale and will focus on completing the due diligence, and bringing in the best management team to run the companies acquired. "We will be looking to develop this $10 billion fund and participating via EoIs, that does not mean we are going to win…We are going to spend money to do due diligence, if it falls in our category we will go ahead and bid via this fund," said Agarwal. When operational, Sterlite Copper was meeting nearly 40% of India's demand for the metal and the country was a net exporter. However, the shutdown of Sterlite Copper has turned India into an importer in the last two years, the company said. "Post closure, India has become a net importer of copper for the first time in 18 years, with copper imports growing 3X while exports have plunged by 90%. We are continuing to explore all legal avenues towards achieving a sustainable solution to the closure," said Vedanta's spokesperson.

STRENGTH MEETS CONFIDENCE' - AMBUJA CEMENT'S STRATEGY FOR VALUE CREATION

Ambuja Cement released its first Integrated Annual Report for the year 2020. Themed 'Strength meets Confidence', the report combines company performance with disclosures of both, Annual and Sustainability Reports - creating a unified Integrated Report for a comprehensive articulation of its value-creation approach. As one of India's leading cement manufacturers, Ambuja Cement is progressing on its Sustainable Development Ambition 2030 with a sharper focus on climate and energy, building a circular economy, conserving resources and nature, and driving meaningful change in the lives of communities and the larger stakeholder fraternity.

India's aspiration of achieving a 5 trillion-dollar economy in the near future entails an inclusive yet diverse growth that would raise the quality of lives of millions of people, conserve natural resources, deploy capital prudently and drive the climate agenda very strongly. As one of India's leading core sector players, with focus on responsible manufacturing, we see a larger role for ourselves in this operating environment. As Chairman N S Sekhsaria rightly observed, "COVID-19 had posed a temporary pause in economic activity, and we are already seeing the green shoots of recovery. The government's mega push on affordable housing and infrastructure will further widen the opportunity horizon for us, as the Indian economy gradually regains its pre-COVID momentum. We have the capability and the commitment to help build the India of tomorrow."

Ambuja's priority during the difficult months of the pandemic was to ensure business continuity, said Ambuja Cement's MD & CEO Neeraj Akhoury. "We realigned our focus and channelised our energies around three core areas – health, cost and cash. Despite a temporary delay caused by the lockdown, we were quick to resume the construction of our upcoming plant at Marwar Mundwa in Rajasthan and expect to commence operations in 2021." Ambuja's market positioning as well as both, ongoing and future expansion plans, will ensure increase in market share. "Our continued focus on value-added products and premiumisation will also ensure that we remain a preferred brand in the retail market," added Mr Akhoury.

Despite challenges, the Operating EBITDA for the year grew from Rs.2,149 crores in 2019 to Rs.2,647 crores, while PAT strengthened from Rs.1,529 crores in 2019 to Rs.1,790 crores in 2020. Operating EBITDA margin for the year stood at 23.7%, against 18.9% in 2019 while PAT margin grew to 16% in 2020, against 14%in 2019. The company has also invested Rs.525 crores towards Waste Heat Recovery Systems (WHRS) for enhanced use of green energy and optimisation of operating cost. The

Company's focus remains on individual home builders across existing and new markets. "We are stepping up innovation to offer durable solutions to individual home builders in home construction. Our growing presence in suburban and rural regions, along with strategically located grinding units, enables us to service these markets better and faster. Additionally, our upcoming capacities will help us carve out a larger piece of the market pie" added Chairman N S Sekhsaria. During the year, the company also launched Ambuja Kawach, an environmentally friendly product that helps reducing carbon emissions by 33% during production. The product was launched virtually across different markets reaching out to ~5,000 dealers and selling 53,611 tonnes in 2020.

ULTRATECH CEMENT PREPAYS RS 5,000 CR LOAN

UltraTech Cement said it has prepaid its long-term loans of Rs 5,000 crore. The loan repayment has been done through free cash flows that the company has generated over the last few quarters despite the pandemic, the Aditya Birla Group firm said in a statement. However, the company did not share the deadline by which the long-term loans were to be prepaid. "We are pleased to inform you that the company, during the last week, has prepaid its long-term loans amounting to Rs 5,000 crore," said UltraTech. This is in line with the company's endeavour to maintain optimal capital structure, it added.

"The loan repayments have been done through free cash flows that the company has generated over the last few quarters despite the challenging circumstances and severe business interruptions during the first quarter of the current fiscal year," it added. UltraTech Cement reported a revenue of Rs 40,649.17 crore in 2019-20 and is the largest manufacturer of grey cement, ready mix concrete (RMC) and white cement in India. With a consolidated capacity of 116.8 million tonne per annum (MTPA), it is the third-largest cement producer in the world, excluding China.

SHREE CEMENT'S NEW CEMENT GRINDING UNIT IN ODISHA COMMENCES COMMERCIAL PRODUCTION

Shree Cement said its new cement grinding unit in Odisha with a manufacturing capacity of 3 million tonnes per annum (mtpa) has commenced commercial production. The company has commenced commercial production at its new cement grinding unit having capacity of 3.0 MTPA set-up at Athagarh Tehsil in Cuttack District of Odisha, Shree Cement said in a regulatory filing. Shree Cement had posted over two-fold jump in consolidated net profit to Rs 631.58 crore for the third quarter ended December 31, 2020, as against a net profit of Rs 311.83 crore in October-December period a year ago. Shares of Shree Cement Ltd were trading 1.41 per cent lower at Rs 27,334.55 apiece on BSE.

SAIL CLOCKS BEST QUARTERLY SALES AT 4.27 MT DURING JAN-MAR QTR

Steel Authority of India Limited clocked its best-ever quarterly sales at 4.27 million tonnes (MT) during the March quarter of the last fiscal year, up 14 per cent over the year-ago period. The domestic steel giant's crude steel production too increased by 6 per cent during the quarter to 4.55 MT. "(SAIL), the Maharatna PSU, has recorded its best-ever quarterly performance in both production and sales during Q4 FY'21," the company said in a statement. The company had clocked 3.74 MT sales and 4.31 MT crude steel output during the January-March quarter of fiscal 2019-20. About annual figures, the company said despite the volatility in the market during the year, the determined efforts by the company to improve its volumes saw it clock its best-ever annual sales at 14.87 MT, a growth of 4.4 per cent over 14.23 MT during FY'20," the company said.

SAIL chief Soma Mondal said, "After the difficult market conditions during the initial months of the financial year, the company adopted a focussed approach on improving its volumes, improving operational efficiencies, operating the facilities at optimum levels, de-leveraging its balance sheet, reducing its inventory levels, etc. The multi-pronged strategy has helped us top the performances during the month, quarter as well as the year." The team effort by SAIL employees helped in seizing the opportunity offered by the pick-up in the economic activities in the country especially the steel-intensive sectors like infrastructure, construction, automobiles, etc, she added. In line with its focus on reducing the borrowings, the company has reduced its gross debts by around Rs 16,150 crore to stand at Rs 35,330 crore (provisional) as on March 31, 2021 vis-a-vis Rs 51,481 crore as on March 31, 2020.

CEMENT INDUSTRY EXPECTED TO GROW 13% BY VOLUME IN FY22: CRISIL RATINGS

The cement industry is set to hit a decadal high volume growth of 13 per cent in the next fiscal, helped by an expected revival in demand from the infrastructure and urban housing sectors, according to Crisil Ratings. The increased sales volume will counterweigh the impact of rising power and fuel costs on cash accruals and will keep the credit outlook of cement makers stable, the rating agency said. "While volume growth will rebound, higher cost of sales would weigh on cement profitability next fiscal," it said. Rising prices of raw materials such as diesel, pet coke or coal, and polypropylene bags may push up cost by Rs 150-200 per tonne, it said adding that freight, power and fuel constitute almost 55 per cent of the total cost of sales of cement.

"Increasing share of infrastructure and urban housing means a higher proportion of sales will be from the cost-conscious non-trade channels. That would translate to marginally lower net realisation for cement companies," the agency said. Commenting on the report, Crisil Ratings Director Nitesh Jain said demand from the hinterland, which was a saviour for the cement industry in the pandemic impacted FY21, should sustain on the back of higher rural incomes. "Higher spends on infrastructure development would be in line with the 26 per cent increase in budgetary allocation for infrastructure in the Union Budget 2021-22. That, coupled with pent-up demand in urban housing, will drive volume growth," he said.

Operating profits could moderate by Rs 200-250 per tonne next fiscal due to higher cost and lower net realisation, said Crisil Research Director Isha Chaudhary. However, cash accruals won't be affected as higher volumes will offset the impact of lower profit margins, she added. "Higher cash accruals will keep the net debt to EBITDA ratio salutary at 1.4-1.5 times next fiscal, despite an increase in capital expenditure," Chaudhary said.

While talking about the pandemic impacted FY21 for the cement industry, the report said it would have a volume decline of up to 2 per cent. "The swift recovery after a 31 per cent contraction in the first quarter this fiscal should limit the volume decline to just 1-2 per cent for the full fiscal," it said. Companies had slowed down Capex and chose to conserve cash amid demand disruption. Besides, ample liquidity and strong balance sheets have cushioned the impact of the pandemic on the credit profiles of cement companies. "Incremental rural demand has offset the slump in urban housing and infrastructure. The demand rebound should spur expansion plans and the CAPEX run rate could return to the Rs 12,000-14,000 crore annual run rate from next fiscal," it said.

The report also added that timely release of funds for key housing and infrastructure projects as announced in the budget for the next fiscal will be crucial for the anticipated demand growth. Moreover, any resurgence of COVID-19 cases could derail economic recovery and will therefore bear watching, Crisil added.

JSW STEEL COMPLETES ACQUISITION OF WELSPUN'S PLATES AND COIL MILL BUSINESS

JSW Steel completed buying the plates & coil mill business of Welspun for a sum of Rs 848.5 crore under a business transfer agreement. "It may kindly be noted that Laptev (a JSW Group company) has assigned all its rights and obligations under the BTA to JSW Steel Limited. Accordingly, the Plates and Coil Mill Division (PCMD)is transferred to JSW Steel Limited from March 31, 2021," said Welspun. The transfer was completed on March 31st and the consideration amount will be paid on a deferred basis subject to Welspun fulfilling certain regulatory approvals and payment milestones as provided under the business transfer agreement, the company said. In March 2019, Welspun Corp announced a value unlocking exercise Rs. 940 crore through the divestment of its Plate and Coil Mill Division (PCMD) and its 43 MW Power Division.

Turnover of the PCMD is around Rs. 1,230 crores comprising 16.90% of the Consolidated Revenues as of 31st March 2018 after which it was considered as a discontinued business. The Turnover of the PCMD Business is Rs 539.8 crore for Financial Year ending March 31, 2020. " The PCMD Business will be of strategic importance for JSW to expand its value added and special products portfolio, particularly plate mill plates in which JSW has so far not been present," JSW Steel said.JSW Steel also announced starting production of hot-rolled plates from its Dolvi works plant in Maharashtra. "JSW Steel has commenced production of Hot-rolled plates from the new 5 million tonne per annum hot strip mill facility at its Dolvi Works," the company said.

This comes at a time when the steel prices have touched record levels of Rs 57,000 to Rs 60,000 a tonne on the back of surging global prices and a better than expected domestic demand. Morgan Stanley in its recent sector report said that the current cycle has an element of similarity to both the prior upcycles (after the global financial crisis 2009 and supply-side reforms during 2016-18). "We see a sharp rebound in steel demand globally in 2021, supported by a V-Shaped economic recovery," the report said.

The company is also planning to double Dolvi Works capacity to 10 million tonne per annum by the end of Q1 of FY22. In order to take Dolvi's capacity from 5 mtpa to 10 mtpa, some upstream and downstream facilities were planned with 4.5 mtpa of Blast furnace with a 5 mtpa of Steel Melt Shop and a 5 mtpa of hot strip mill and an 8 mtpa of pellet plant. Now the 5 mtpa downstream facility of the hot-strip mill is up and running and is producing hot-rolled plates now.

The company recently completed the acquisition of Bhushan Power and Steel Ltd by transferring Rs 19,350 crore to a Punjab National Bank (PNB) and bringing the three-and-a-half-year-old resolution process to an end, paving way for the Sajjan Jindal-led company to enter the mineral-rich eastern India, which has so far been the dominated by state-owned SAIL and Tata Steel. The current steelmaking capacity of JSW Steel is around 18 MTPA and after expansion in Vijayanagar, Dolvi and Salem along with the BPSL acquisition, the capacity is likely to go up to 27 MTPA, making the company the largest steel producer overtaking Tata Steel which has 20.6 MTPA capacity.

FORM IV

Statement about ownership and other particulars of The Indian Mining & Engineering Journal to be published under Rule 8 of the Registration (Central) Rules 1965

1.	Periodicity of the publication	:	Monthly
2.	Printer's Name	:	Mrs. Pradhan Anita
3.	Whether Citizen of India	:	Yes
	Address	:	Laxmisagarpatna, Bhubaneswar - 751 006
4.	Editor's Name	:	S.K.Mahanta
	Whether citizen of India	:	Yes
	Address	:	Laxmisagarpatna, Bhubaneswar - 751 006
5.	Name and address of individuals who own the newspaper and partner or shareholders holding more than one percent of the total capital	:	Mrs. Pradhan Anita Mr. A Sahoo Laxmisagarpatna Bhubaneswar - 751 006

I, Pradhan Anita, hereby declare that the particulars given above are true to the best of my knowledge and belief, March, 2021.

Publisher

The Indian Mining & Engineering Journal, Vol. 60, No.03, March 2021, pp.12-16
Printed in India, @ IME Publications, ISSN 0019-5944

The Application of Non-destructive Tests (NDT) towards Evaluation of Rock Bolting Support System: Review with Indian Perspective

M. N. Bagde*

ABSTRACT

The study of the rock bolting support system towards its efficacy and effectiveness in mining and civil excavations or for stabilization purposes including mining and civil slopes is very important from the safety point of view. Recent developments undertook in the area of non-destructive tests (NDT) are being used widely for the said purpose. Its successful application particularly in the areas with abnormal in-situ stress region in the case of deep mining as well as where support found ineffective is being reported. According to the findings reported the NDT system used is able to provide pre-warning towards any instability or anomalies present in the rock mass. Also, the real-time bolt support quality and its monitoring is possible towards effective support design as well as bolting parameters optimization etc. Herewith, brief review on the applications of the NDT system with results reported towards rock bolt characterization and its applicability with reference to the Indian mining industry is discussed and presented.

Keywords—NDT, rock bolting, roof failure, efficacy, pre-warning, real time monitoring

INTRODUCTION

It is well known that as we go deeper, mining excavations and particularly roadways which are most commonly supported by roof bolts often face severe strata-control problems. The mostly problems reported are support failure leading to roof failure, due to the high *in-situ* stress regime, soft and jointed rock mass structure, abnormal tectonic stress and rock burst conditions, and intense mining disturbances because of complex geological structure etc. In such cases ensuring the stability of the surrounding rock mass and the mining environment as a whole is very challenging task. Also, in most of the cases it is observed that roof bolt or support system along with rock mass often collapsed even before the actual excavation started or finished completely. The various researchers' applied the NDT technology and equipment to study the support system efficacy, bolt length and grout binding and its effectiveness including other quality parameters. In recent, Zhang et al., (2017) developed the NDT based equipment and successfully applied it in field to provide pre-warning technology for support system optimization in the case of deep coal mining roadways. Beard and Lowe (2003) developed a portable NDT instrument based on the principle of guided ultrasonic waves using the pulse-echo test to evaluate the condition of the rock bolts. They are able to determine the bolt length, and major defects such as necking, deformation, and loss of resin encapsulation etc. Ivanovic and Neilson (2013) used non- destructive dynamic test to study rock bolts installed in a concrete block to determine the effective bolt length and damage condition of the bolting system. However, their system is based on the impulse load (GRANIT-Ground Anchorage Testing System) and also a periodic (swept sine) using a magneto-strictive shaker. The both excitation methods are able to provide the similar responses which allowed estimation of the effective length of the bolt. The findings from the experimental along with the numerical modelling studies combined together, provided a frequency range which could be related to obtain the effective bolt length. From the presented brief review, it is found that NDT technology and equipments are being used towards rock bolt support system monitoring very effectively and it is non-destructive in nature when compared to the traditional pull-out tests. In this paper brief summarised applications of NDT equipments and technology towards the rock bolt monitoring is being discussed.

SUPPORT SYSTEM – BRIEF STATUS

It is well known that during the installation of roof bolts or any other support system (Fig. 1), its performance is mostly depends on the installation equipment and tools, surrounding rock mass conditions, and also operators' skills and may be including other technical and geo-technical parameters. The efficacy of the bolt system installed is directly influenced by the drill hole depth, the hole condition and its deviation, the resin/cement

*CSIR-Central Institute of Mining & Fuel Research, Nagpur Research Center
*Corresponding Author: mnbagde@gmail.com

cartridges is not mixed properly or cement slurry or cement/resin capsules are unable to fill completely or due to its shrinkages with time etc. The problems faced in the field generally are, the bolt end hangs from the roof due to the larger bolt length when compared to depth of the hole. Again, providing the adequate pre- tension to the bolts by torque or any other method is very difficult process and occasionally during this process the bolt fails or slips. Also, on most of the occasions the initial anchoring force of the bolt is not sufficient enough and again with time it shrinks, leading to failure of the anchored roof area. The bolting technology uses plastic covered resin cartridges to reinforce the bolt and should allow proper mixing of the resin components during the installation process. Otherwise "gloving" - refers to the plastic cartridge of a resin capsule partially, encasing the length of bolt, typically with a combination of mixed and unmixed resin filler and catalyst remaining within the cartridge. This gloved and unmixed portion found to reduce the effective anchor length and thus severely affects its ability to reinforce the roof strata to its fullest capacity. After the completion of bolt installation once the excavation is over, the surrounding rock mass starts to deform, thus the axial bolt load gradually increases until it becomes relatively stable. However, during the further excavation of mine roadway or retreat mining/depillaring, the axial bolt load increases suddenly. This is due to the dynamic type loading conditions encountered which reduce the bolt load capacity causing first support failure followed with roof collapse. Mark et al., (2002) on the basis of the roof sagging or stress build-up zones have classified the bolt failure in three types: (i) the head or plate failure, (ii) the rod break either in tension or in combination with bending, (iii) grout fail means no better rock mass-bolt interaction. It is always difficult to observe the behaviour of the installed roof bolting system within a given time frame by naked

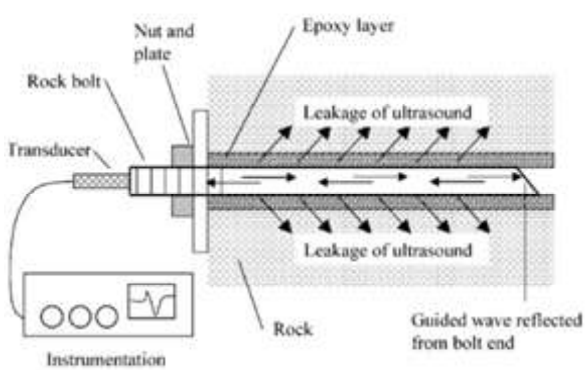


Fig. 1: The schematic showing rock bolt installation and NDT system (Beard & Lowe, 2003)

eye and thus we fail to detect and take necessary timely control measures to prevent the accidents caused by the support system failure. The above issues discussed are generally found to influence directly the stability of the mining environment and the safety of the men and machineries' and on most of the time the secondary cost involved, which may be huge.

SUPPORT SYSTEM EFFICACY EVALUATION WITH NDT

The number of non-destructive testing techniques and equipments are developed for various industrial and field applications. They are mostly: ultrasonic methods, guided ultrasonic methods, acoustic emission, electromagnetic techniques, impulse based by means of a pneumatic or solenoid device e.g. GRANIT- Ground Anchorage Testing System etc. On the other hand conventional type of pull-out test which is mostly the destructive to assure quality control is generally as reported applicable to anchored or friction bolts. In addition to this, non-destructive ultrasonic or other type testing methods are presently in development stage, not fully tested or understood in the field yet or not been widely used elsewhere as well as in our country. Though, it is under development stage only at the present, however, its application worldwide shows encouraging results.

A. Bolt support quality

For a newly installed bolt, generally the parameters to be determined are the full-length and anchorage length. These parameters mostly needed to determine the supporting area as well as the stability of the bolt support installed. Simultaneously, the bolt pre-tension is examined to determine if it meets the designed and desired values. After bolt installation, the main aim is to monitor the change in magnitude of the axial bolt load in real time during the various mining excavation phases. In such cases, the monitoring of axial bolt load helps to evaluate whether the bolt support system is in good working condition or not.

Zhang et al., (2017) and his research team have carried out good applied studies involving analysis of the propagation characteristics of the elastic waves travelling along the axial direction of the bolt. The new kind of NDT technique and equipment is independently developed by them. The elastic wave reflection and diffusion characteristics at the interface between the free, anchorage and the bolt end are successfully obtained by them. According to them, this technique is found useful to detect the bonded as well un-bonded bolt length. Again, it is possible to monitor the status of the axial bolt load in real time in deep coal mine roadways. From the analysis of the data, the advanced detection technology towards the bolt support quality and performance analysis is developed. The developed system is successful in ensuring the safety and to predict the un- stable zone. Fig. 2 shows such two engineering cases of bolt characteristic length and real-time bolt load performance using NDT equipment developed by Zhang et al. (2017) and his team.

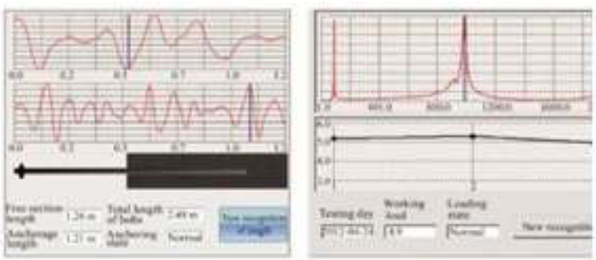


Fig. 2: The bolt length characteristics and real- time bolt load monitoring (Zhang et al., 2017)

B. Prediction of un-stable zone

In general, roadways in the case of deep coal mining, from the development to depillaring stages, will go through three phases: i) initial support stage, ii) pre-mining stage, and finally, iii) mining disturbance stage. Through the analysis of the existing results of bolt load evolution in deep roadways and *in- situ* test results, the working status characteristics of bolts in the mine roadways during the different mining stages is well illustrated by Zhang et al., (2017) as provided in Fig. 3.

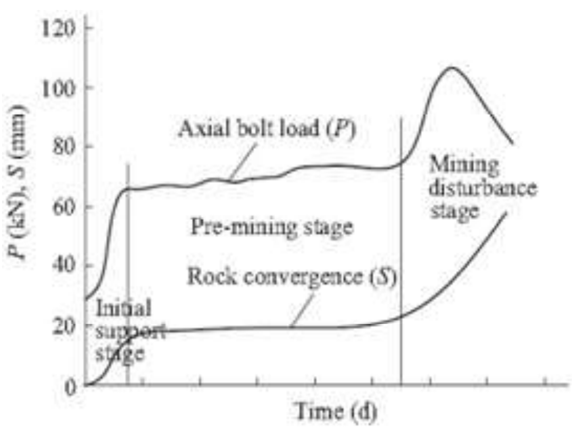


Fig. 3: The working status characteristics of bolts at different mining stages (Zhang et al., 2017)

According to the observations made by them, when the roadway is mined out over to 25 m, the surrounding rock mass mostly remains in equilibrium state, which is also called the pre-mining stage, where, the deformation rate is found to be much lower compared to the initial support stage. The axial bolt load mostly fluctuates during this phase, however, mostly found to show rising trend. Generally, from their reported findings, the axial bolt load is found to be at about 50% of its yield load (Ps). However, when the roadways are excavated over to 50 m, stresses build up in the surrounding rock mass at the working face found to be abnormal. In such cases, the axial bolt load found to be in the range of 80–120 kN - roughly 80% of the yield load. However, in the case of complex geological conditions and some cases, where the axial bolt load as reported by them is found to exceeds the yield load causing bolt rod splitting or fracture. It is found that there exists a good relationship between real time axial bolt load observed and the entire process of deformation, failure, and collapse of roadways in the mining panels. Thus, the real-time monitoring results of axial bolt load could be helpful towards the evaluation and judging the stability of the surrounding rock mass by means of pre-warning technology based on the NDT observations.

According to the NDT monitoring results of axial bolt load at the belt-entry of another panel in Chinese mine with relatively the complex mining structure as compared to the above presented case, the average safety factor of the axial bolt load is 3.4 and the minimum safety factor is at 1.9. The safety factor in this case is: the ratio of ultimate bolt yield load to its real- time axial load observed. Considering this viewpoint and specific disturbed geological conditions, it is found that the bolt design parameters in this particular roadway are at the conservative side. However, when the state of surrounding rock deformation is monitored in front of the working face and the fore-pole support is conducted well by adjusting the zone of fore-pole support flexibly, the anchor bolt support in this roadway is found to be reliable during the all mining stages. For example, the surrounding rock mass is comprised of poor, loose and broken adjoining to the B6 and B7 test bolts. The axial bolt load observed in this zone is minimal as compared with the adjacent bolts (Fig. 4). The nearest distance of these two bolts from the face was only 10 m. However, Fig. 4 shows that rock deformation near the B6 and B7 bolts is not so alarming, even though they are influenced by the mining disturbances. From these two view points, it is observed that the bolt support in this roadway found to be excessive during the pre-mining or during the mining disturbance stage.

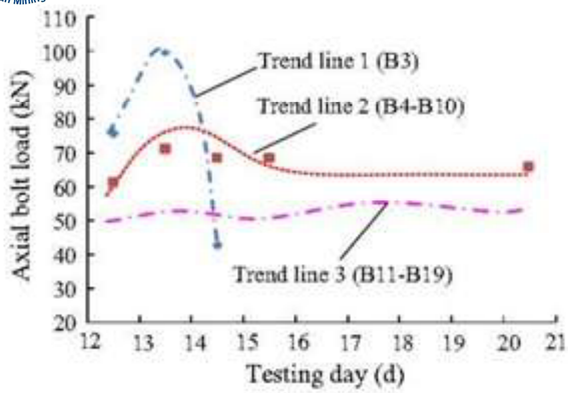


Fig. 4: The axial bolt load trend along the working face advancement (Zhang et al., 2017)

According to the monitored results of axial bolt load and surrounding rock deformation during the mining disturbance stage, significant findings are divided into five cases by Zhang et al., (2017): (i) the axial bolt load increases while the surrounding rock deforms slowly, (ii) the axial bolt load increases while the surrounding rock deforms rapidly, (iii) the axial bolt load remains constant while the surrounding rock deforms slowly; (iv) the axial bolt load remains constant while the surrounding rock deforms rapidly, and (v) the axial bolt load decreases while the surrounding rock deforms rapidly. In the case of first three, it needs to be judged whether the axial bolt load has exceeded 80% of its yield load or not. If not, the surrounding rock of the roadway is in a stable state and if yes, pre-warning needs to be made or additional reinforcement support measures need to be taken. In the last two cases, the surrounding rock of the roadway is in unstable state and additional support measures are needed.

CONCLUSIONS WITH INDIAN PERSPECTIVE

Indian mining industry, particularly, underground coal mines will be facing daunting challenges ahead due to the increase in working depth, complex *in-situ* stress problems, problematic geological structure, rock burst including other strata control problems etc. Also, mechanization is being planned at the large level means huge investment in skilled technical manpower and automation machineries etc. Its success mostly will depend on introduction of latest roof bolting support technology as well as towards its monitoring in real time through the combination of instrumentation and observations etc. It is already reported that almost up to 40-60% of fatal accidents reported annually in Indian mining industry are caused by the roof/side fall and or roof bolt failure due to their in-ability to sustain the load caused by the mining. The support system monitoring for its efficacy by the latest available techniques like NDT type equipments and technology will be certainly beneficial towards achieving cent- percent success rate of roof failure prevention and or due to the support system, if any. Also, the secondary cost involved towards failed roof management by providing the additional roof bolts is not acceptable considering the Indian mining industries sustainability and survival when compared to the competitive world-wide mining industry. The need of the hour is the introduction of the modern and latest innovative techniques is being used worldwide in Indian mining industry in the area of roof bolting and support technology, tools to monitor it effectively like NDT types and instrumentation for strata monitoring etc.

REFERENCES

- Beard M. D. and Lowe M.J.S. (2003). Non- destructive testing of rock bolts using guided ultrasonic waves. International Journal of Rock Mechanics & Mining Sciences. 40, 527–536.
- Bigby D. N., Arthur J. (2001). Improved rock bolting safety world wide through recent UK instrumentation and testing RTD. In Proceedings of international symposium on roof bolting in mining, Aachen, Germany, p.463–480.
- Campbell R., Mould R. J. (2005). Impacts of gloving and un-mixed resin in fully encapsulated roof bolts on geotechnical design assumptions and strata control. I J Coal Geology. 64, 116–25.
- Compton C. and Oyler D. (2005). Investigation of fully grouted roof bolts installed under in-situ conditions. In Proceedings of 24th international conference on ground control in mining, Peng S. et al., (Editors). Morgantown, p. 302–12.
- Hyett A., Bawden W., Reichard R. (1992). The effect of rock mass confinement on the bond strength of fully grouted cable bolts. Int J Rock Mech Min Sci Geomech Abstr. 29, 503–24.
- Ivanoviæ A. and Neilson R. D. (2013). Non- destructive testing of rock bolts for estimating total bolt length. International Journal of Rock Mechanics & Mining Sciences. 64, 36–43.
- Ivanoviæ A., Neilson R. D. (2008). Influence of anchor head on dynamic response. Proceed ings of ICE, Engineering and Computational Mechanics. 161,27–34.
- Ivanoviæ A., Neilson R. D. (2008). Influence of geometry and material properties on the axial vibration of a rock bolt. Int Journal of Rock Mechanics and Mining Sciences. 45, 941–51.
- Ivanoviæ A., Neilson R. D. (2009). Modelling of

debonding along the fixed anchor length. International Journal of Rock Mechanics and Mining Sciences. 46 (4), 699–707.

- Ivanoviæ A., Neilson R. D., Rodger A. A. (2001). Lumped parameter modelling of single tendon ground anchorage systems. ICE Geotechnical Engineering.149 (2), 103–13.
- Ivanoviæ A., Neilson R. D., Rodger A. A. (2002). Influence of pre-stress on the dynamic response of ground anchorages. Journal of Geotechnical and Geoenvironmental Engineering ASCE. 128(3), 237–49.
- Kang Y. S. Liu Q. S., Gong G. Q., Wang H. C. (2014). Application of a combined support system to the weak floor reinforcement in deep underground coal mine. Int J Rock Mech Min Sci. 71, 143–50.
- Kejriwal B. (2002). Safety in mines – a survey of accident, their causes and Preventions. Lovely Prakashan, Dhanbad.
- Li J. P. (2003). Several issues concerning security and reliability of bolting support in coal heading. Coal Technol. 22(10), 59–60.
- Li Y. M., Shi J. J., Jia A. L., Ma N. J. (2005). Main technical analysis on bolt initial anchor-hold in coal tunnel. Coal Min Technol.10(4), 45–8.
- Maiti J. and Khanzode V. V. (2009). Development of a relative risk model for roof and side fall fatal accidents in underground coal mines in India. Safety Science. 47, 1068-76.
- Mark C., Compton C. S., Oyler D. C., Dolinar D.R. (2002). Anchorage pull testing for fully grouted roof bolts. In Proceedings of 21st international ground control in mining conference. Morgantown, WV, USA; 6–8 August, p.105–113.
- Neilson R. D., Ivanovi A., Starkey A. J., Rodger A. A. (2007). Design and dynamic analysis of a pneumatic impulse generating device for the non- destructive testing of ground anchorages. Mech Syst Signal Process. 21(6), 2523–45.
- Neilson R. D., Ivanoviæ A., Starkey A. J., Rodger A. A. (2007). Design and dynamic analysis of a pneumatic impulse generating device for the non- destructive testing of ground anchorages. Mechanical Systems and Signal Processing. 21, 2523–45.
- Neilson R. D., Ivanoviæ A., Starkey A.J., Rodger A.A. (2004). Quality control in rock bolt installation. In Proceedings of the fifth conference on quality reliability and maintenance. Oxford,UK, 1–2 April, p.79–82.
- Peng S. S. (2015). Topical areas of research needs in ground control-a state of the art review on coal mine ground control. Int J Min Sci Technol.5(1),1– 6.
- Robert J. L., Brachet-Rolland M. (1982). Survey of structures by using acoustic emission monitoring. IABSE (International Association For Bridge and Structural Engineering) Symposium, Washington DC, maintenance, repair and rehabilitation of bridges, final report, IABSE reports. 39, 33–38.
- Shen B. T. (2014). Coal mine roadway stability in soft rock: a case study. Rock Mech Rock Eng. 47(6), 2225–38.
- Thurner H. F. (1979). Non destructive test method for rock bolts. In Proceedings of fourth international Cong. Rock mechanics, Montreux, Switzerland, Vol. 3, p. 254–255.
- Van der Merwe J. N. (2001). In situ investigation in to the causes of falls of roof in South African collieries. In Proceedings of the 20th international conference on ground control in mining. Morgantown, WV, USA, 7–9 August, p.105–118.
- Villaescusa E., Varden R., Hassell R. (2008). Quantifying the performance of resin anchored rock bolts in the Australian underground hard rock mining industry. International Journal of Rock Mechanics and Mining Sciences. 30, 94–102.
- Windsor C. R. and Thompson A. G. (1992). Reinforcement design for jointed rock masses. In Proceedings of 33rd US symposium on rock mechanics, Santa Fe. Rotterdam, Balkema, p. 521– 30.
- Wittenberg D., Ruppel U. (2000). Quality management for grouted rock bolts. In Proceedings of the 19th Int conference on ground control in mining, Morgantown, WV, p.249–254.
- Xie D. G. (2008). Quality control and monitoring of roadway bolt construction. Coal Technol. 27(6),122–3.
- Xue D. C., Wu Y., Zhang K.(2013). Experimental study and application on non-destructive testing of axial bolt load in coal mine. J Min Safety Eng. 30(3), 375–9.
- Xue D. C., Wu Y., Zhang K.(2013). Experimental study and application on non-destructive testing of axial bolt load in coal mine. J Min Safety Eng. 30(3), 375–9.
- Yang X. X., Jing H.W., Chen K. F., Wang W. L. (2013). Study on influence law of in-situ stress in deep underground rocks on the size of failure zone in roadway. J Min Safety Eng. 30(4), 495–500.
- Zhang H. , Miao X., Zhang G., Wu Y., Chen Y. (2017). Non-destructive testing and pre-warning analysis on the quality of bolt support in deep roadways of mining districts. International Journal of Mining Science and Technology. 27, 989-998.
- Zhang K., Zhang G., Hou R., Wu Y., Zhang H. Q. (2015). Stress evolution in roadway rock bolts during mining in a fully mechanized longwall face, and an evaluation of rock bolt support design. Rock Mech Rock Eng. 48(1),333–44.
- Zhu C. Y., Wang J., Zhang W. G., Wu B. Q. (2002). Pre-stressed anchor bolt support design and deformation monitoring of roadways in coal mine. Coal Mine Support. 2, 26–9.

The Indian Mining & Engineering Journal, Vol. 60, No.03, March 2021, pp.17-20
Printed in India, @ IME Publications, ISSN 0019-5944

Numerical Simulation of Cemented Paste Backfill using an Improvised Strain Softening/Hardening Material Model

P.K. Binjhade* J.L. Porathur* S. Sekhar* P. Bagde* D.N.Sharma*

ABSTRACT

In recent times, use of Cement Paste Backfill (CPB) has become common for backfilling operation in underground metalliferous mining. In India and around the world it is widely used as it is more effective ground support and enables faster backfilling. Physico-mechanical characteristics of the CPB have been determined by various researchers using laboratory testing. These properties can be incorporated in the numerical modelling softwares to enable more accurate mine modeling and stope design. In this paper an attempt has been made to simulate stress-strain characteristics of CPB. This simulation has been carried out with the help of FLAC^{3D} software. To simulate the characteristics of CPB as obtained in the previous experimental studies, some modification has been introduced in the conventional strain-softening/hardening constitutive model of FLAC^{3D}. Conventional Strain-softening material model has provision for incorporating the post-failure behavior only in one form based on the plastic strain. The improvised simulation program allows different post-failure characteristics to be assigned to each element according to the confining stress of the material. The results obtained from the software are in conformity with the laboratory tested data. This newly developed material model can be applied to simulate materials such as cemented backfills, rock mass, shotcrete, concrete, etc.

Keywords—Cemented paste backfill, strain softening, strain hardening, FLAC 3D, mining.

INTRODUCTION

There are many challenges in underground mining of deep seated ore deposits such as mine safety, ground support, environmental restrictions, optimum ore recovery, economic operation, etc (Mchaina et al., 2001). To meet some of these challenges Cemented Paste Backfill (CPB) is used in underground stoping. CPB is a mixture of mill tailings, hydraulic binder and water. The use of paste backfill is currently practiced in many modern mines throughout the world (Grabinsky et al., 2014). To design underground stoping in tandem with CPB with fair amount accuracy, it is important to use suitable material model in numerical simulation codes.

In this paper numerical simulation of the mechanical behaviour of CPB has been carried out by using FLAC3D software. FLAC3D uses Finite Difference Method for numerical modelling. The commonly used material model in FLAC3D is Mohr-Coulomb model. In which the material is treated as purely plastic and will not reflect the softening or hardening behaviour of the material. In strain- softening/ hardening model, material parameters like cohesion, friction angle, dilatancy angle can be varied with plastic strain. The yield criterion, potential function, plastic flow rules, stress correction are same as in the Mohr coulomb model (Li et al., 2019; Zhang et al., 2013).

The strain-stress behaviour of CPB is strongly influenced by the confinement. The increase in confining pressure leads to a change in the mode of failure, the post-failure stiffness and an increase in the post-failure strength (Fall et al., 2007). To simulate the mechanical behaviour of CPB, we have used modified strain softening modelling using different cohesion post-failure characteristics for different confining stresses.

POST-FAILURE CHARACTERISTICS OF CPB

A. Under Uniaxial Compression

Regardless of the CPB types, up to stress level of approximately 30-40% of the peak stress, the CPB shows an elastic behaviour. Near the peak region, as the stress increases the deformation curves of CPB shows its first visible non liner behaviour. In the descending branch the stress level decreases rapidly with increasing deformation. Shape of the stress strain curve is largely influenced by peak strength (Fall et al., 2007).

B. Under Tri-axial Compression

The peak stress and the stiffness of CPB are dependent on the confinement. At zero or low confinement, the stress-

**CSIR-Central Institute of Mining and Fuel Research, Nagpur Research Centre, Nagpur, (Maharashtra)*
**Corresponding Author: johnlouip@gmail.com*

strain curve show better defined and sharper peaks. The increase in the confinement causes a change in mode of failure at the peak stress. Peak stress increases with increase in confinement (Belem et al., 2000; Chen et al., 2017; Fall et al., 2007; Kaklis et al., 2018). At greater confinement the CPB material has got hardening behavior after the post-peak level.

properties are assumed to remain constant. Here the users can deûne the cohesion, friction and dilation as piecewise-linear functions with respect to the plastic shear strain. A piecewise- linear softening law for the tensile strength can also be prescribed in terms of the plastic tensile strain. The code measures the total plastic shear and tensile strains by incrementing the hardening parameters at each timestep, and causes the model properties to conform to the user-deûned function of the post-failure behavior of a material (Manual, FLAC3D, 2010).

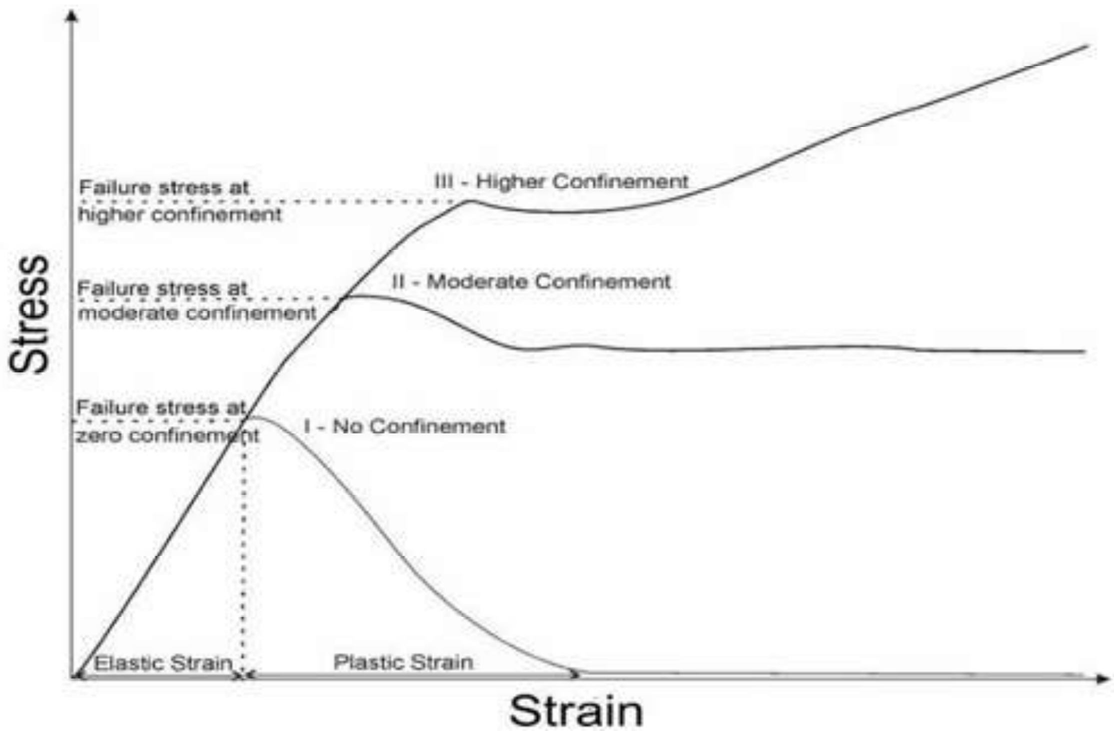


Fig. 1: Stress-Strain characteristics of Cemented Paste Backfill

NUMERICAL SIMULATION

The numerical modelling is carried out using the finite difference method. The application software used is FLAC3D by Itasca Consultancy Group, USA. To represent the material, strain softening mechanical model is used.

A. Improvised Strain Softening/Hardening Model

Conventional strain softening/hardening model is based on the FLAC 3D Mohr- Coulomb model with non-associated shear and associated tension ûow rules. The difference, however, lies in the possibility that the cohesion, friction, dilation and tensile strength may harden or soften after the onset of plastic yield. In the Mohr-Coulomb model, those the limitation of the conventional strain softening/hardening model is that it can use only one function for each variable as one table. To overcome this FISH programming language in FLAC3D has been utilized and three different characteristics of cohesion is supplied to the material according to the confining stress, which is the minimum principal stress of each element (ó3). The cohesion characteristics used is shown in Table 1.

A cylindrical grid corresponding to ISRM standard compressive test core specimen of L/D ratio of 2.5, with length 13.5 cm and diameter 5.4 cm has been created. To represent the behaviour of material under different confinements, normal stress is applied at the circumference of the specimen simulating a tri- axially stressed state. Multiple cohesion post- failure characteristics were assigned accordingly. The methodology adopted is represented as a flowchart as shown in the Figure 2.

The numerical simulation is carried out for three different confining conditions, such as 0 MPa (unconfined), 0.5 MPa and 1 MPa.

RESULTS AND DISCUSSIONS

Initially numerical simulation without any confining stress is carried out. The specimen was only subjected to uni-axial compression. It is performed in a simulated servo-controlled testing scenario by incrementing the platens at a fixed axial velocity. Initially it shows elastic behaviour and strain increases linearly with the increasing stress level. After the peak stress is reached, it shows non-linear behavior. The elements can be seen failed/yielded in tension as well as shear. The curve shows the softening of the material strain. The non-linear post failure characteristics is in according with the previous experimental works (Belem 2007, Chen 2017) of researchers. The result of the numerical simulation is shown in the Figure 3.

Second numerical simulation has been carried out at a moderate confining stress of 0.5 MPa. It shows elastic behaviour initially and as the peak stress level reached it shows the non- linear behaviour. With the confinement the peak stress increased. After the peak stress level it shows a dip in the stress as most of the elements goes into yield in shear and thereafter behaves like a perfectly plastic material and show the characteristics similar to Mohr- Coulomb material. The resulting stress-strain characteristic is shown in Figure 4.

At a higher confinement of 1 MPa the peak stress (transition from elastic to plastic behaviour) is further increased. After the failure/yielding the stress increases with increasing plastic strain displaying shows hardening behaviour of the material.

Table 1: Cohesion characteristics corresponding to plastic strain

Plastic strain	Low confinement cohesion (MPa)	Moderate confinement cohesion(MPa)	Higher confinement cohesion(MPa)
0	0.61	0.61	0.61
0.02	0.45	0.61	0.61
0.04	0.3	0.61	0.7
0.08	0	0.61	0.8
0.5	0	0.61	1.2

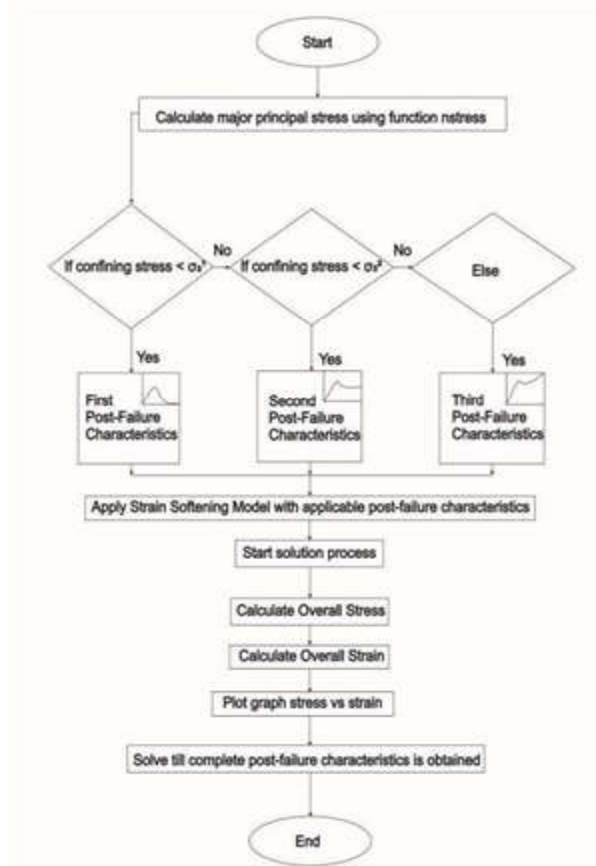


Fig. 2: Flowchart of the methodology

The result has been shown in the Figure 5. During uniaxial state several elements can be seen yielding in tension. However at higher confinement, the elements yield mostly in shear alone.

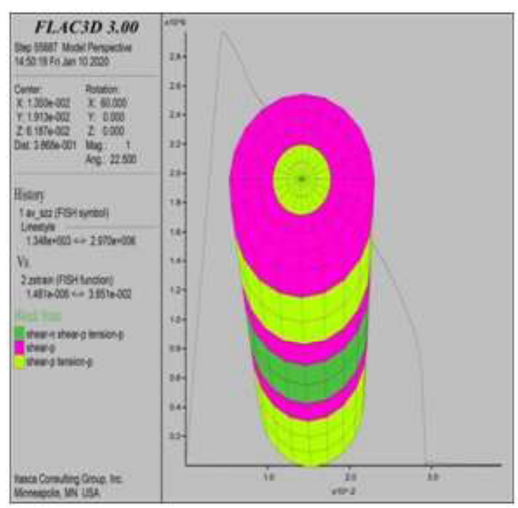


Fig. 3: Stress-Strain characteristics of CPB without confinement

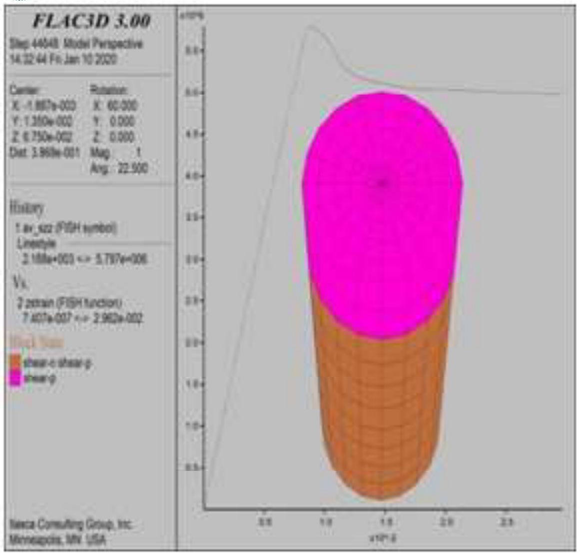


Fig. 4: Stress-Strain characteristics of CPB under confining stress of 0.5 MPa

The results show that the numerical simulation of CPB using the Strain Softening model with modifications is able to represent its characteristics more appropriately for various confining stresses. The results are in line with the previous experimental investigations carried out by some researchers of CPB cylindrical specimen in a servo-controlled environment at various confinement levels. This numerical simulation method can also be applied for numerical modelling of similar materials such as cemented backfills, rock mass, shotcrete, concrete, etc.

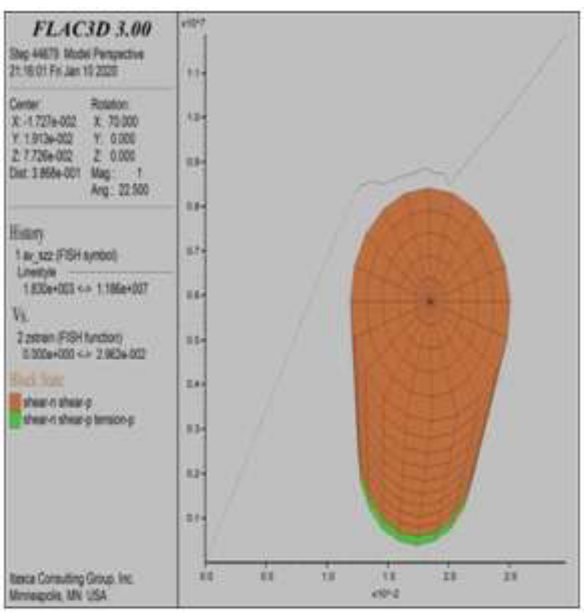


Fig. 5: Stress-Strain characteristics of CPB under confining stress of 1 MPa

REFERENCES

Belem, T., Benzaazoua, M., & Bussière, B. (2000). Mechanical behaviour of cemented paste backfill. Proceedings of 53rd Candadian Geotechnical Conference, 1(February 2016), 373–380. http://web2.uqat.ca/gnm1002/Cours#8_mecanique desremblais (geotech)/PaperConfCanadianGeotech2000.pdf.

Chen, Q. song, Zhang, Q. li, Fourie, A., Chen, X., & Qi, C. chong. (2017). Experimental investigation on the strength characteristics of cement paste backfill in a similar stope model and its mechanism. Construction and Building Materials, 154, 34–43. https://doi.org/10.1016/j.conbuildmat.2017.07.142.

Fall, M., Belem, T., Samb, S., & Benzaazoua, M. (2007). Experimental characterization of the stress- strain behaviour of cemented paste backfill in compression. Journal of Materials Science, 42(11), 3914–3922. https://doi.org/10.1007/s10853-006-0403-2.

Grabinsky, M., Simon, D., Thompson, B., Bawden, W., & Veenstra, R. (2014). Interpretation of as- placed cemented paste backfill properties from three mines. 351–363. https://doi.org/10.36487/acg_rep/1404_28_grabins ky.

Kaklis, K. N., Agioutantis, Z. G., Mavrigiannakis, S. P., & Nomikos, P. P. (2018). A multi-stage triaxial test for cemented paste backfill. 52nd U.S. Rock Mechanics/Geomechanics Symposium.

Li, G., Ma, F., Liu, G., Zhao, H., & Guo, J. (2019). A strain-softening constitutive model of heterogeneous rock mass considering statistical damage and its application in numerical modeling of deep roadways. Sustainability (Switzerland), 11(8), 1–19. https://doi.org/10.3390/su11082399.

Manual, Flac3d, O. (2010). 1 Constitutive Models/ : Theory and Implementation. Options, 1–192.

Mchaina, D. M., Januszewski, S., & Hallam, R. L. (2001). Development of an environmental impact and mitigation assessment program for a tailings storage facility stability upgrade. International Journal of Surface Mining, Reclamation and Environment, 15(2), 123–140. https://doi.org/10.1076/ijsm.15.2.123.3415.

Zhang, K., Cao, P., & Bao, R. (2013). Progressive failure analysis of slope with strain-softening behaviour based on strength reduction method. Journal of Zhejiang University: Science A, 14(2), 101–109. https://doi.org/10.1631/jzus.A1200121.

The Indian Mining & Engineering Journal, Vol. 60, No.03, March 2021, pp.21-30
Printed in India, @ IME Publications, ISSN 0019-5944

Change Analysis in Land Use Land Cover Due to Surface Mining in Jharia Coalfield Through Landsat Time Series Data

A. S.Siddiqui* M. K.Jain*

ABSTRACT

Mining and reclamation are the essential drivers for land use land cover changes (LULC) in Jharia coalfield. The accurate mapping of changes in a time interval helps to examine the impact of mining on the surrounding area's ecology. In this research, Landsat imagery from 1999, 2009, and 2015 was used to map land cover changes for Jharia coalfield. The Landsat data used was L1T standard data product, this data is radiometrically calibrated and orthorectified. An unsupervised ISODATA clustering method along with matrix union function was used to map the land cover of mining areas and to view the changes in LULC for Jharia coalfield. The results show that from 1999 to 2009, in between this ten-year interval the mining sector expanded by 81.72%, and the reclamation by 8.46%, whereas in between the five-year interval from 2009 to 2015 the increase in mining was 14.20% while 8.92% area of mining turned to vegetative reclaimed mines. The overall classification accuracy of all the satellite imagery is above 90%, which signifies that the ISODATA classification techniques produce better results of classification. This study of change analysis will be effective in quantifying the changes and will provide the supporting platform for decision making in the environmental management plans for mining.

Keywords— Land Use Land Cover Change (LULC), ISODATA classification, landsat imagery, reclamation, change detection, mining

INTRODUCTION

Consumption of coal as a source of energy among fossil fuel is highest. Coal fulfills the primary energy demands for human consumption and is still an economical source among alternative energy sources. Starting from mining to consumption and ultimately disposal, coal releases numerous pollutants in the air, water, and soil (Travis et al., 2011). Topographical changes during the mining process are invariant and these changes in land cover shrinking the natural ecosystem (Simmons et al., 2008). Therefore, land use land cover (LULC) change recognition is a key factor in the dynamic investigation of coal mining and its impact on ecosystems. The locations and "from-to" types of LULC changes can add valuable information for the environmental change (Bindschadler et al., 2010). Hence, remote sensing is a strong tool for studying changes in the land-use pattern by relating time-sequential satellite data (Prakash &Gupta et al., 1998).

Remotely sensed data are adequate for generating and updating land-use maps feasibly (Rozenstein & Karnieli et al., 2011). A newer research illustrates that the Landsat Thematic Mapper (TM) images with the 30 meters spatial resolution are suitable for classification of a broad range of landscapes (B´egu´e et al. 2018; Alrababah & Alhamad 2006; Koutsias & Karteris 2003; Manandhar et al. 2009; Senf et al. 2015) Since 23 July 1972, till date Landsat program is constantly producing imagery by its Landsat satellite series (1-8). Starting from the early Landsat series: Landsat-1, Landsat-2, and Landsat-3 were carrying a single multispectral sensor known as Multispectral Scanner (MSS), pursued by the second Landsat series, which were carrying two satellite Landsat-4 and Landsat-5 equipped with two multispectral sensors: MSS and Thematic Mapper (TM) (Satellites & sensors 2018). The third Landsat series had Landsat-6 and Landsat-7 satellite with a multispectral sensor known as the Enhanced Thematic Mapper Plus (ETM+) and finally, the Landsat Data Continuity Mission (LDCM) is the next-generation Landsat satellite which is a Landsat-8 with Operational Land Imager (OLI) sensor and a thermal sensor (Barsi et al., 2014). Current, only two satellites are active Landsat-7 and Landsat-8, out of which Landsat-7 data are no further in service since 31 May 2003 for land-use mapping; as its Scan Line Corrector (SLC) in the ETM+ instrument failed (Bakr et al. 2010; Hansen et al. 2014). The Landsat time-series data yield an opportunity to map a land cover and to examine variations in topography due to the mining. The mapping of mines and reclaimed mines has major importance for interpreting the long-term complexity of mining on ecosystems (Simmons et al., 2008). Even though diverse remote sensing data are available for Land-use mapping, but because of lower cost, higher frequency,

*Department of Environmental Science and Engineering. Indian Institute of Technology (ISM)-Dhanbad, Jharkhand, India
*Corresponding Author: manishjkm@gmail.com

and extensive historical data collection in its archives Landsat data is still being used in the land-use mapping. In an early analysis, several methods have reported change detection applying multi- temporal remote sensing data, including image algebra, image transformation, and image classification based methods. The classification techniques such as K-means, Maximum Likelihood Classification (MLC), minimum distance to means, artificial neural network (ANN), decision tree, support vector machine (SVM) have been applied in the LULC change detection analysis. (Lillesand et al., 2014; Pal & Mather 2003; Sabins 2007; Richards & Richards 1999; Verbeke et al., 2004; Lawrence et al., 2004; Meyer & BL Turner 1994; Demirel et al., 2011). The detailed study of those methods and techniques can be found elsewhere (Lu & Weng et al., 2007).

In this research, an Unsupervised ISODATA classification technique applied to generate the LULC map, with the support of featured dataset (Principal Components (PCs), Tasselled Cap transformed bands, and Normalized Difference Vegetation Index (NDVI)), which give a unique spectral value of each class, and helps to reclassify the clusters generated after classification into their respective classes. The difference between this study and the previous one is that in this study, errors in classification because of the algorithm get reduced by reclassifying the mismatched classes based upon the analyst prior knowledge of the study area, and information received from the feature dataset. This will help to interpret the classes for the LULC map. The purposes of this work were: (1) To prepare LULC maps using the ISODATA classification method of different time periods. (2) Accuracy assessment of classified images. (3) Land cover changes analysis “from-to” of classified images. This research work will help planners and decision-makers to make environmental management plans.

MATERIALS AND METHODS

A. Study Area

The study area Jharia coalfield is situated in Dhanbad region of Jharkhand State, India. coalfield is demarcated by latitudes 23°35´N- 23°55´N and longitudes 86°05´E- 86°30´E, stretching in a range of 460 sq km in the Damodar river valley with an average elevation of 220 meters above mean sea level Fig.1. Structural and geological information concerning Jharia coalfield can be found elsewhere (Verma et al., 1979). Mining activities in Jharia coalfield have continued since 1874, which escalated in 1925. The government nationalized the mines in 1971. Jharia coalfield is one of the important repositories of prime coking coal reserves in India (Chatterjee 2006) it is the largest producers of bituminous coal in India. This coal has wide applications in industries like thermal power, steel, cement, etc., incorporating domestic purposes. During the coal mining process, many pollutants discharge into the atmosphere, apart from these an unplanned mining in the past have created drastic changes in its topology which causes subsidence and mine fires. Coal mine fires in Jharia coalfield that have been occurring from the earliest days of mining are also a major cause of land degradation (Sinha 1986). In the year 1986, about 163 coal mine fires were identified in India out of which 97 were present in Jharia (Saini et al., 2016) Fig. 7(a). The reclamation of surface mines is to bring back its aesthetic condition by refilling open mines by overburden materials Fig.7(c). Coal mine reclamation started in India around FY 08 (ending March 2008) (Shah 2013). The process of regular monitoring during and after the mining process is of prime concern to maintain control of land degradation and its reclamation. Fig.2 revealed a false-color composite remote sensing image of Landsat 8 OLI portraying the mining belt, Vegetation cover and Open-pit areas of Jharia coalfield.

DATASET

A. Satellite Data

Satellite image data provides a wide coverage area, extensive information, and is economical. It is a multi-temporal therefore bought on a large scale (Ozesmi & Bauer 2002; Anderson et al. 2004; Schroeter & Gl¨aber 2011). Here for the change detection analysis, Landsat 5 Thematic Mapper (TM) image from 2 December 2009 (Closer anniversary date imagery), a Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) image from 29 November 1999, and a Landsat 8 Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS) image from 2 February 2015(USGS- 2006b 1999; USGS-2006c 1999; USGS-2013 2013) get downloaded from the USGS Earth Explorer website. The downloaded datasets are the L1T standard data product, this data product are pre-processed by systematic radiometric correction and geometric correction with ground control points (GCPs) and a digital elevation model (DEM) (Wu et al., 2017) and projected at Universal Transverse Mercator (UTM) Zone 45 N Datum WGS 1984 with RMSE value of less than 0.4 pixels. In this study, all scenes achieved uniformity in surface reflectance through atmospheric correction which minimizes atmospheric effects of water vapour, aerosol, and gases. Table 1 shows the details of the downloaded images.

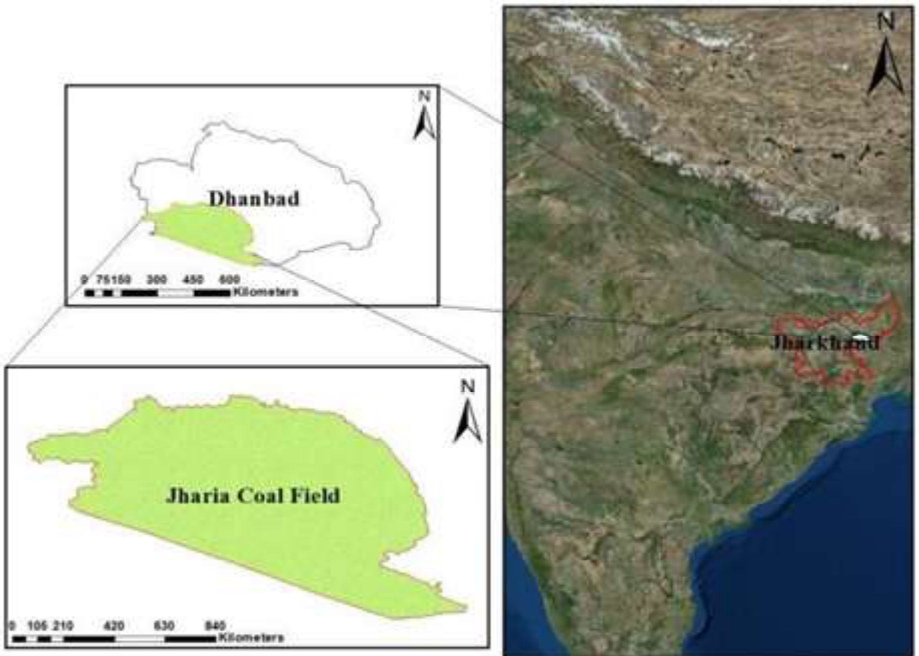


Fig. 1: Geographical location of Jharia coalfield for which Land use land cover change detection analysis was conducted

Table 1: Landsat data product along with their characteristics used in this study

	Landsat 5 TM	Landsat 7 ETM+	Landsat 8 OLI/TIRS
Acquisition Date	2 December 2009	29 November 1999	2 February 2015
Data Type	L1T	L1T	L1T
Spatial resolution (m)	30	30	30
Number of Bands	7	8	11

METHODOLOGY

Fig.3 details the pictorial depiction of the proposed method. In this study, the following steps were performed: 1) An unsupervised classification was performed by using ISODATA clustering on the individual Landsat scenes to build up a preparatory land cover classification of each date. 2) The Classification feature datasets (NDVI, 3 Principal Components Bands (PCs) and Tasselled Cap Brightness, Greenness, and Wetness) derived from the Landsat TM, ETM+, and OLI was used to relabelled clusters into five classes (Mining, Overburden (OBD), Vegetation, Barren, and Water) of every individual Landsat Scene. 3) Accuracy assessment of classified images was produced by ERDAS IMAGINE accuracy assessment tool. 4) Change detection analysis was performed by using the matrix union function tool of ERDAS software to estimate change type in a time series dataset.

Classification Method

The purpose was to map Mining (M), Overburden (OBD), Barren (B), Vegetation (V) (including agriculture and forest), and Water (W). An unsupervised classification method (ISODATA clustering) on multi- temporal and multi-spectral images were performed, to produce 80 clusters at a 98% convergence threshold.

For the assessment, feature dataset developed from each Landsat scene, PCs with the first three bands, were analysed for all the Landsat images, as they contained over 90% of the scene information., first three tasselled cap transformed bands provide the information regarding “greenness”, “brightness”, and “wetness” of the scene, while NDVI provides information of vegetation distribution. Initially, 80 clusters get reduced to five basic information classes and labelled as (M, OBD, B, V, W) by the information (spectral value) gained from the featured dataset. Some classes were misclassified as similar spectral reflectance was a limitation to the classification

Fig. 2: Landsat 8 OLI false colour composite image of Jharia Coalfield (R: NIR, G: Red, B: Green) date of acquisition (2 Feb 2015)

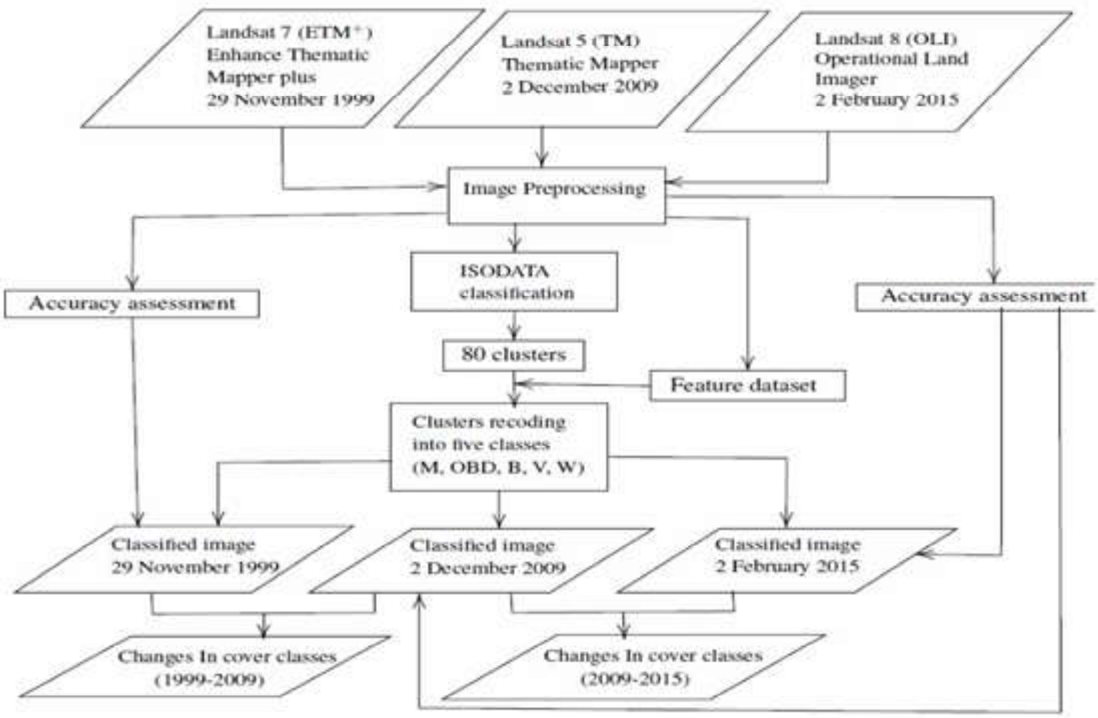


Fig. 3: Flowchart of the proposed method of change detection analysis

algorithm. In some places, OBD and Barren were wrongly classified because of their similar spectral brightness similarly, mines with water bodies; because of water in mines Fig. 7(b). Though it is complicated for the classification algorithm which works on pixels spectral value to differentiate two objects with the similar spectral value, while they are different geographically, to overcome this problem prior information about the study area is required to recode the mismatched classes to their original classes.

The preparatory map of land use classes was made by using ArcGIS for all the three images are shown in Fig 4.

ACCURACY ASSESSMENT

The classification accuracy of land use land cover maps was evaluated, through a stratified random sampling method. In this method, an accuracy assessment tool of ERDAS IMAGINE software was used to generate 300 stratified random reference points, with a set rule of minimum 50 reference points for each category class. Further for the validation of reference points, the high spatial resolution imagery, topographic maps, and Google Earth Pro historic imagery of the study area were used, as a base map. However, because of lack of availability of reference data in Google Earth Pro of the year 1999, Landsat 7 undergone pseudo accuracy assessment in which a single high-resolution color pan- sharped image, along with the same data set used in classification was also used, as a validation dataset for accuracy assessment of the year 1999 LULC map.

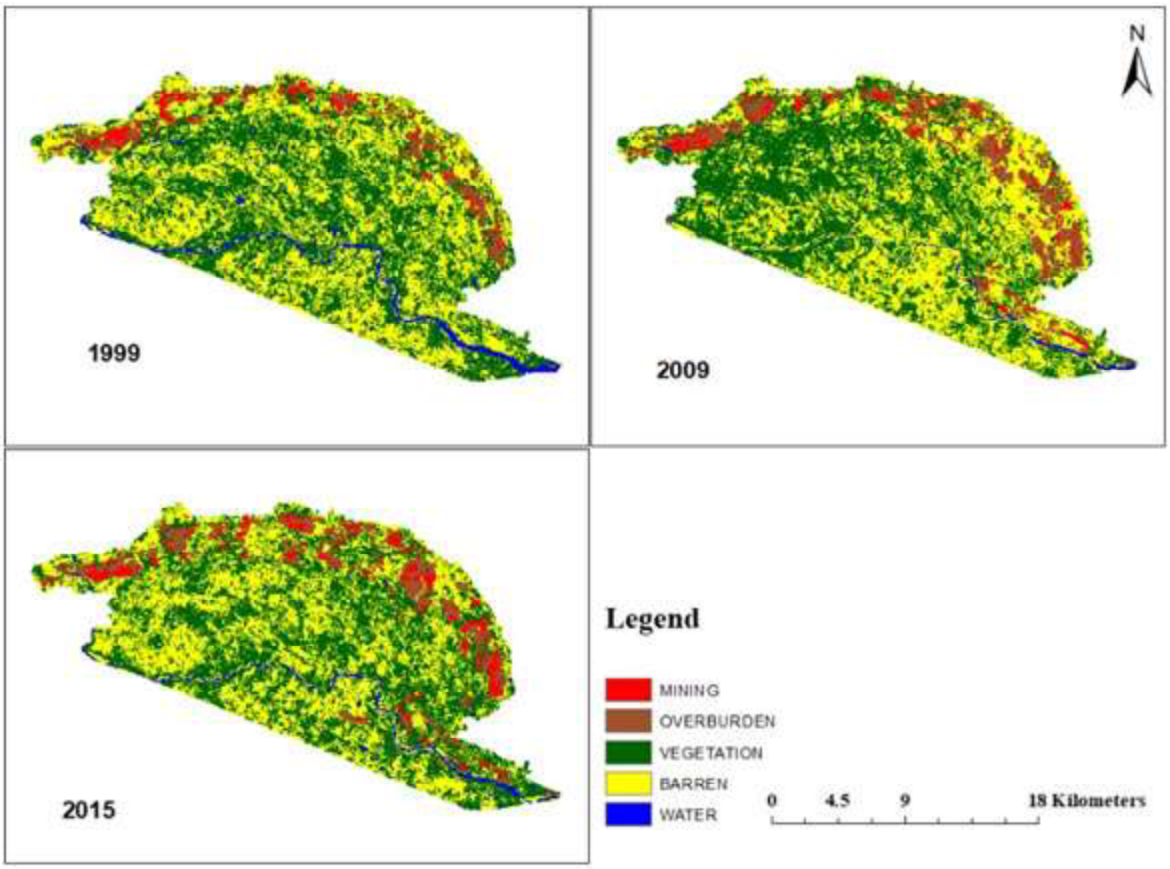


Fig. 4: Preliminary land cover Images of Jharia coalfield of the year 1999, 2009, and 2015 classified into five basic information classes (Mining, Overburden, Vegetation, Barren, and Water).

Based on the reference points, the confusion matrix computed the accuracy of every year by estimating: users accuracy, producers accuracy, Kappa (which is a discrete multivariate technique) (Congalton & Mead 1983; Jensen 1996), and overall classification accuracy. The outcome was cross-classified to determine "from-to" change, which enabled accuracy assessment.

CHANGE DETECTION

The post classification change detection was mostly used for multiple data analysis. In this technique, independently produced and spectrally classified images from each end of the time interval were used and followed pixel- by-pixel to detect change analysis on a cover type (Coppin et al., 2004). In this method, changes in the cover classes in each independent image were analysed, and not their spectral values. The changes among the classes in the time series analysis are mapped in Fig .5 and Fig.6.

RESULTS AND DISCUSSIONS

A. Results of change detection analysis

Table 2 and Table 3 define the matrices for change detection, these matrices determine the percentage changes in areas among the five classes (Mining, OBD, Vegetation, Barren, and Water) "from-to" (1999-2009) and (2009- 2015). Mining and reclamation got special emphasis, as both have significant characters in topography change. Table 2 results show that between the year (1999-2009), about 32.56% of the area remained unchanged and were undermining which includes some active mines (coal-producing mines) and passive mines (mines which have been consolidated, abandoned and non-producing). While changes occur in the remaining 67.44% areas, of which 66.15% areas converted to reclaimed mines and about 1.29% of the mining area inundated underwater, which may be because of an abandoned of mine quarries as the water gets collected in rainy seasons Fig 7(b).

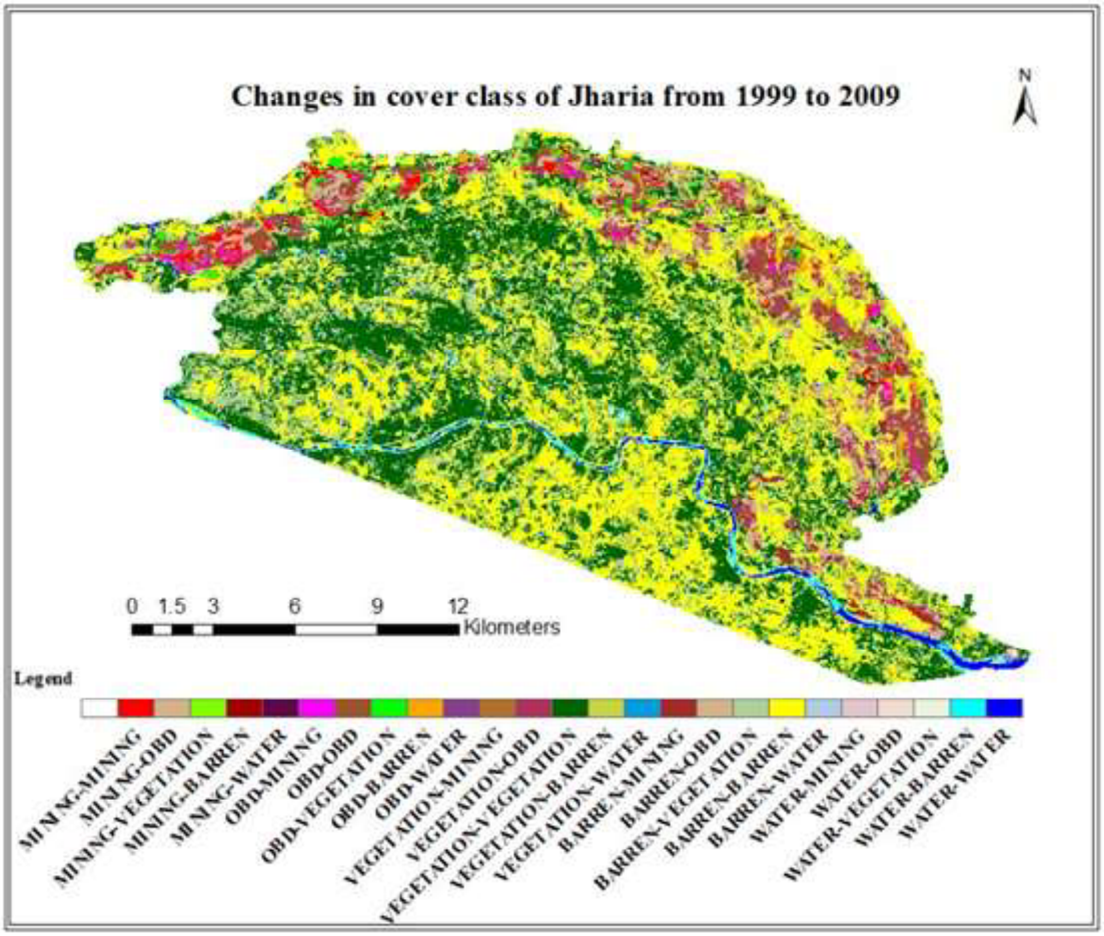


Fig. 5: Showing a change detection result obtained "from-to" of the year: 1999-2009 were different colour shows different change types

Table 2: Percent change of areas in land cover classes "from-to" year, 1999-2009

		Image 2009				
		Mining	OBD	Vegetation	Barren	Water
Image 1999	Mining	32.56	47.28	8.46	10.38	1.29
	OBD	2.64	63.76	14.50	18.92	0.01
	Vegetation	2.01	4.05	59.68	27.75	0.16
	Barren	5.70	18.02	8.00	68.02	0.24
	Water	0.1	2.68	6.48	21.72	68.27

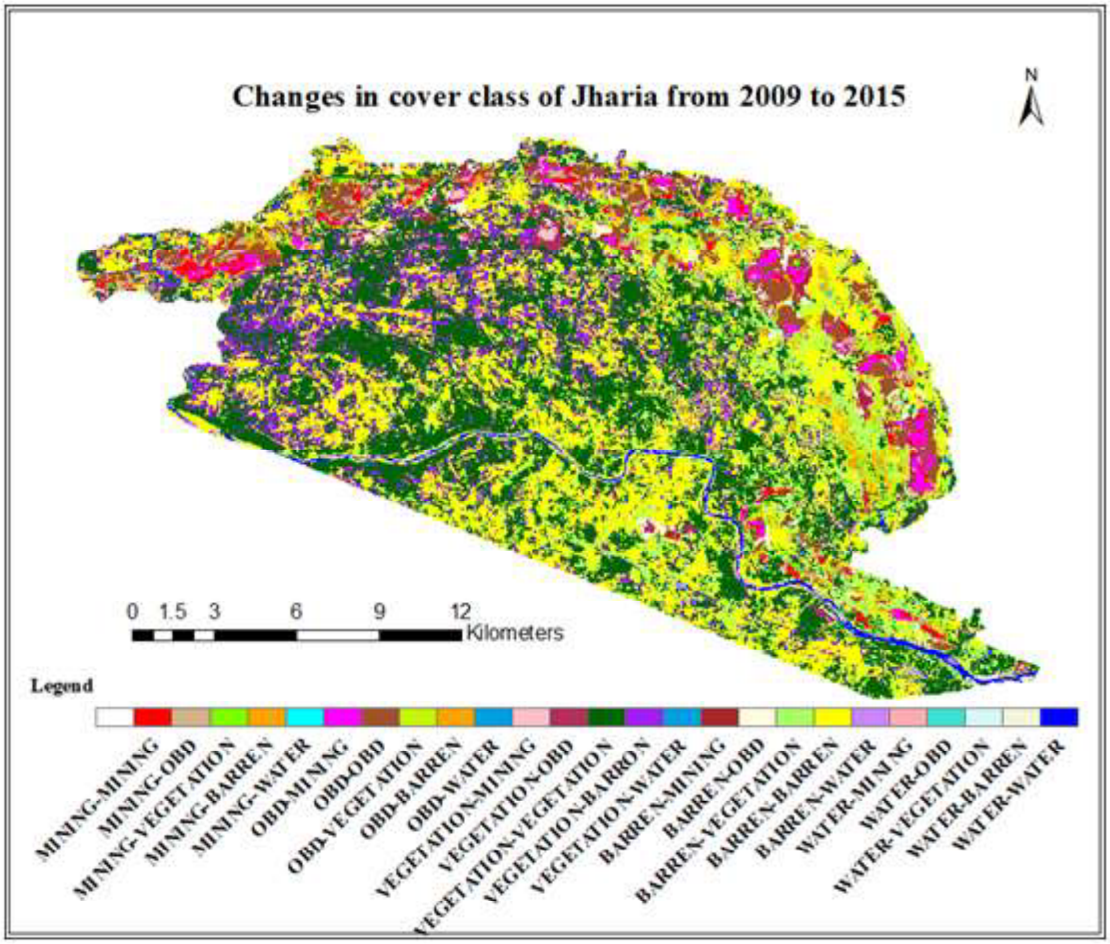


Fig. 6: Showing a change detection result obtained "from-to" of the year: 2009-2015 were different colour shows different change types

Table 3: Percent change of areas in land cover classes "from-to year", 2009-2015

		Image 2015				
		Mining	OBD	Vegetation	Barren	Water
Image 2009	Mining	47.35	37.77	8.92	4.39	1.55
	OBD	2.21	53.74	25.06	18.59	0.39
	Vegetation	1.86	2.71	67.70	26.86	0.82
	Barren	3.40	20.62	9.29	64.66	1.84
	Water	1.64	3.29	5.09	19.23	70.11

This 66.15% reclaimed area is the outcome of backfilling the abandoned mines with the OBD, after which about 8.46% of the reclaimed area shows vegetation cover which signifies that the area was vegetative reclaimed, while 10.38% of the reclaimed area left untreated which falls under Barren. The remaining 47.28% area covered with OBD, which may be because of the opening of new mines next to the old mines. Similarly, in the year (2009-2015) the results in Table 3 show that about 47.35% of the mining area is unchanged, whereas about 52.65% area show changes, the causes behind the changes are the same as mentioned above.

Overall, the results from both the matrices show that there is an expansion in mining, this may be because of the development of industrial sectors and their dependency on coal. Whereas, the gain in vegetation cover on the Mines and OBD in both the year matrices shows an acceleration in reclamation and indicating a positive change by the effort provided in reclamation.

Results of accuracy assessment

In this experiment of Landsat time-series data set, the overall accuracy of the ISODATA classification was higher. Table 4 illustrates a confusion matrix for accuracy assessment generated from a stratified random sampling method. The eventuality tables used for making Table 4 are in Appendix A. The producer's accuracy of mining increased from 66.67% to 83.33%, and the user's accuracy from 66.67% to 90%. Although, the overall accuracy of all the satellite imagery is above 90%, but the overall kappa of 2009 (Landsat 5 TM) is 0.88 which is less, as compared to that of the year 1999 (Landsat 7 ETM+) and 2015 (Landsat 8 OLI) which is around 0.91 and the reason is the finer spectral resolution of Landsat 7 and Landsat 8 as compared to Landsat 5 sensors.

CONCLUSIONS

This paper has mainly two objectives: first is to study the LULC of Jharia coalfield in the ten-year interval and in five-year intervals, and second is the accuracy assessment of LULC map produced from the ISODATA classification technique by using Landsat-5 TM, Landsat-7 ETM+, and Landsat-8 OLI/TIRS images of the year 2009, 1999, and 2015. Overall, there are about 34.92% changes in class between the year (1999-2009), and 36.67% in the year (2009-2015). This increase in changes in classes shows the drastic changes in and around the mining areas, while the increase in changes from (mining to vegetation) and (OBD to vegetation) from the interval (1999-2009) to (2009-2015) shows concurrent reclamation along with mining. The Barren land formed after reclamation, which may become the cause of soil erosion and land degradation, requires immediate attention. The results from the accuracy assessments show that the ISODATA classification techniques along with feature dataset can produce good LULC maps, necessary for making better environmental management plans.

Fig. 7A: Crack due to underground coal mines fire

Fig. 7B: Showing a change detection result obtained

Fig. 7c: Water accumulation in mine quarries

ACKNOWLEDGEMENT

The author likes to acknowledge the support provided by the Department of Environmental Science and Engineering, Indian Institute of Technology (IIT-ISM)-Dhanbad, while carrying out this work.

REFERENCES

- Alrababah, M., & Alhamad, M. 2006. Land use/cover classification of arid and semiarid mediterranean landscapes using landsat etm. International journal of remote sensing, 27:2703– 2718.
- Anderson, M. C., Norman, J., Mecikalski, J. R., Torn, R. D., Kustas, W. P., & Basara, J. B. 2004. A multiscale remote sensing model for disaggregating regional fluxes to micrometeorological scales. Journal of Hydrometeorology, 5:343–363.
- Bakr, N.,Weindorf, D., Bahnassy, M., Marei, S., & El-Badawi, M. 2010. Monitoring land cover changes in a newly reclaimed area of egypt using multi-temporal landsat data. Applied Geography, 30:592–605.

ADDITIONAL DATA

Accuracy assement of Landsat 7ETM+ (1999) by using a stratified random sampling

1999	Mining	OBD	Veget-ation	Barren	Water	Total
Mining	4	2	0	0	0	6
OBD	1	9	0	1	0	11
Veget-ation	0	2	117	0	0	119
Barren	1	5	0	104	0	110
Water	0	0	0	1	9	10
Total	6	18	117	106	9	256

Accuracy assement of Landsat 5TM (2000) by using a stratified random sampling

2009	Mining	OBD	Veget-ation	Barren	Water	Total
Mining	5	0	0	1	0	6
OBD	1	14	2	8	0	25
Veget-ation	0	0	113	3	0	116
Barren	0	1	1	103	0	105
Water	0	1	0	0	3	4
Total	6	16	116	115	3	256

Accuracy assement of Landsat 8 OLI (2015) by using a stratified random sampling

1999	Mining	OBD	Veget-ation	Barren	Water	Total
Mining	9	1	0	0	0	10
OBD	0	18	1	1	0	20
Veget-ation	2	3	109	3	0	117
Barren	0	0	1	103	0	104
Water	0	0	0	2	3	5
Total	11	22	111	109	3	256

- Barsi, J. A., Lee, K., Kvaran, G., Markham, B. L., & Pedelty, J. A. 2014. The spectral response of the landsat-8 operational land imager. Remote Sensing, 6:10232–10251.

- B´egu´e, A., Arvor, D., Bellon, B., Betbeder, J., de Abelleyra, D., PD Ferraz, R., Lebourgeois, V., Lelong, C., Sim˜oes, M., & R Ver´on, S. 2018.

- Remote sensing and cropping practices: A review. Remote Sensing, 10:99.

- Bindschadler, R. A., Scambos, T. A., Choi, H., & Haran, T. M. 2010. Ice sheet change detection by satellite image differencing. Remote Sensing of Environment, 114:1353–1362.

- Chatterjee, R. 2006. Coal fire mapping from satellite thermal ir data–a case example in jharia coalfield, jharkhand, india. ISPRS Journal of Photogrammetry and Remote Sensing, 60:113–128.

- Congalton, R. G., & Mead, R. A. 1983. A quantitative method to test for consistency and correctness in photointerpretation. Photogrammetric Engineering and Remote Sensing, 49:69–74.

- Coppin, P., Jonckheere, I., Nackaerts, K., Muys, B., & Lambin, E. 2004. Review articledigital change detection methods in ecosystem monitoring: a review. International journal of remote sensing, 25: 1565–1596.

- Demirel, N., Emil, M. K., & Duzgun, H. S. 2011. Surface coal mine area monitoring using multi- temporal high-resolution satellite imagery. International journal of Coal geology, 86:3–11.

- Hansen, M., Egorov, A., Potapov, P., Stehman, S., Tyukavina, A., Turubanova, S., Roy, D. P., Goetz, S., Loveland, T., Ju, J. et al. 2014. Monitoring conterminous united states (conus) land cover change with web-enabled landsat data (weld). Remote sensing of Environment, 140:466–484.

- Jensen, J. R. 1996. Thematic information extraction: Image classification. Introductory Digital Image Processing: A Remote Sensing Perspective, pp. 197–256.

- Koutsias, N., & Karteris, M. 2003. Classification analyses of vegetation for delineating forest fire fuel complexes in a mediterranean test site using satellite remote sensing and gis. International Journal of Remote Sensing, 24:3093–3104.

- Lawrence, R., Bunn, A., Powell, S., & Zambon, M. 2004. Classification of remotely sensed imagery using stochastic gradient boosting as a refinement of classification tree analysis. Remote sensing of environment, 90:331–336.

- Lillesand, T., Kiefer, R. W., & Chipman, J. 2014. Remote sensing and image interpretation. John Wiley & Sons.

- Lu, D., & Weng, Q. 2007. A survey of image classification methods and techniques for improving classification performance. International journal of Remote sensing, 28:823–870.

- Manandhar, R., Odeh, I. O., & Ancev, T. 2009. Improving the accuracy of land use and land cover classification of landsat data using post-classification enhancement. Remote Sensing, 1:330–344.

- Meyer, W. B., & BL Turner, I. 1994. Changes in land use and land cover: a global perspective volume 4. Cambridge University Press. Ozesmi, S. L., & Bauer, M. E. 2002. Satellite remote sensing of wetlands. Wetlands ecology and management, 10:381–402.

- Pal, M., & Mather, P. M. 2003. An assessment of the effectiveness of decision tree methods for land cover classification. Remote sensing of environment, 86:554–565.

- Prakash, A., & Gupta, R. 1998. Land-use mapping and change detection in a coal mining area-a case study in the jharia coalfield, india. International journal of remote sensing, 19:391–410.

- Richards, J. A., & Richards, J. 1999. Remote sensing digital image analysis volume 3.Springer. Rozenstein, O., & Karnieli, A. 2011. Comparison of methods for land-use classification incorporating remote sensing and gis inputs. Applied Geography, 31:533–544.

- Sabins, F. F. 2007. Remote sensing: principles and applications. Waveland Press. Saini, V., Gupta, R. P., & Arora, M. K. 2016. Environmental impact studies in coalfields in india: A case study from jharia coal-field. Renewable and Sustainable Energy Reviews, 53:1222–1239.

- Satellites, & sensors 2018. Satellites and sensors landsat eoedu. URL:http://eoedu.belspo.be/en/satellites/landsat.ht m. Schroeter, L., & Gl¨aber, C. 2011. Analyses and monitoring of lignite mining lakes in eastern germany with spectral signatures of landsat tm satellite data. International Journal of Coal Geology, 86: 27–39.

- Senf, C., Leit˜ao, P. J., Pflugmacher, D., van der Linden, S., & Hostert, P. 2015. Mapping land cover in complex mediterranean landscapes using landsat: Improved classification accuracies from integrating multi-seasonal and synthetic imagery. Remote Sensing of Environment, 156:527– 536.

- Shah, A. 2013. world coal ind. URL: http://cornerstonemag.net/reclaiming-indian- mines/. Simmons, J. A., Currie, W. S., Eshleman, K. N., Kuers, K., Monteleone, S., Negley, T. L., Pohlad, B. R., & Thomas, C. L. (2008). Forest to reclaimed mine land use change leads to altered ecosystem structure and function. Ecological Applications,18: 104–118.

- Sinha, P. (1986). Mine fires in indian coalfields. Energy, 11:1147–1154.

- Travis, W. D., Brambilla, E., Noguchi, M., Nicholson, A. G., Geisinger, K. R., Yatabe, Y., Beer, D. G., Powell, C. A., Riely, G. J., Van Schil, P. E. et al. 2011. International association for the study of lung cancer/ american thoracic society/european respiratory society international multidisciplinary classification of lung adenocarcinoma. Journal of thoracic oncology, 6:244–285.

- USGS-2006b 1999. Earth resources observation and science (eros)landsat enhanced thematic mapper plus (etm+). in: Earth resour. obs. sci. (eros) landsat enhanc Themat mapper plus. URL: http://eros.usgs.gov/#/Find_Data/Products_and_Da ta_Available/ETM.

- USGS-2006c 1999. Earth resources observation and science (eros) landsat thematic mapper(tm). in: Earth resour. obs. sci. (eros) landsat themat. mapper(tm). URL:
- http://eros.usgs.gov/#/Find_Data/Products_and_Da ta_Available/TM USGS-2013 2013. Earth resources observation and science (eros) operational land imager (oli) sensor and a thermal sensor. URL: https://eros.usgs.gov#/Find_ ata/ Products_and_Data_Available/OLI.

- Verbeke, L., Vancoillie, F., & De Wulf, R. 2004. Reusing back-propagation artificial neural networks for land cover classification in tropical savannahs. International Journal of Remote Sensing, 25:2747–2771.

- Verma, R., Bhuin, N., & Mukhopadhyay, M. 1979. Geology, structure and tectonics of the jharia coalfield, indiaa three-dimensional model. Geoexploration, 17:305–324.

- Wu, C., Du, B., Cui, X., & Zhang, L. 2017. A post-classification change detection method based on iterative slow feature analysis and bayesian soft fusion. Remote Sensing of Environment, 199:241– 255.

The Indian Mining & Engineering Journal, Vol. 60, No.03, March 2021, pp.31-40
Printed in India, @ IME Publications, ISSN 0019-5944

Highwall Mining- A Method to Extract Medium Grade, Thin Coal Seams Under Shallow Cover with Minimum Damage to Surface

R. Ahuja*

ABSTRACT

Coal deposits in India are available over a wide range of thickness and depth. Extraction potential of these deposits is mainly governed by the economics which in turn is governed by the geo- mining parameters and quality of coal. There are certain deposits which cannot be economically extracted by opencast or underground methods. For such deposits, Highwall Mining is a possible extraction method. Highwall Mining is being widely practiced in USA where-in nearly 4% of annual coal production is being reported from this method. This method finds application in extraction of medium grade (upto G6 GCV band), thin seams (minimum 0.75m thickness) under shallow cover and having gradient flatter than 1 in 7. This method is also amenable to multi-seam extraction, so long as the parting between the coal seams is more than 3.0m. Highwall Mining in India is a comparatively new concept in coal extraction techniques. A hybrid of opencast and underground mining technology, this method aims to maximise coal extraction percentage with minimum disturbance to surface. Highwall Mining till date has found application in extraction of coal blocked in batter/highwall of opencast mines or in barriers against water bodies and below built-up area. Its application in virgin property has been conceived in Batura UG Geogical Block. In this paper the applicability of highwall mining has been addressed in the context of coal mining in India and its possible application in the command area of SECL. Case study of Batura UG Block is being presented as a test case for application of Highwall Mining in virgin area. In order to make Highwall Mining a success for extraction of inferior grade coal seams, certain suggestions are being put-forth which may be considered at appropriate forum.

Keywords—highwall, contour, bench, trench, advancing launcher, push beam, cutter unit

HIGHWALL MINING TECHNOLOGY

Highwall mining is a remotely controlled mining method, which extracts coal from the base of an exposed high wall, typically via a series of parallel entries driven to a significant depth within the seam horizon and conveying the coal by some means back to the surface. The method allows recovery of coal from surface pits that have reached final high wall position, or in areas where coal has become sterilized, for example in service corridors oe below surface features. Highwall Mining is a hybrid system capable of accessing these reserves for substantially less capital cost and lead time than a full underground mine, while being capable of producing over one million tonnes per year per system. Highwall Mining also has a significant operating cost advantage over underground mining, because it is less labour intensive.

There is a limitation on length of drivages in coal seam due to various reasons. In case of flat virgin seams, entries to the seam can be made by cutting a trench to expose the coal seam and Highwall Mining can be done along the exposed coal seam available both at dip & rise side. This is commonly known as Trench Mining.

Highwall mining continues to grow its importance as a Mass Production Technology. Currently there may be up to 60 Highwall Mining Systems operating in USA. Recent estimates suggest that upwards of 45 MT of cleaned coal representing about 4% of the total coal production of USA comes from this technology.

METHOD OF MINING

The technology is quite flexible depending upon the availability of the coal block. Generally, three types of method are being practiced for creating highwall mining under different mining condition.

- Contour mining
- Trench mining
- Bench mining

A. Contour Mining Method

When any coal seam, particularly thin seam appears at

**Chief Manager (Mining), CMPDI, RI-IV, Nagpur*
**Corresponding Author: rajesh.ahuja@coalindia.in*

incrop/outcrop, conventional method of mining, i.e., opencast or underground mining may not be the best economic choice, Highwall Mining can be done economically and safely. Since, Highwall Mining follows the contour of the coal seam, method is known as Contour Mining by Highwall method.

Fig. 1: Contour Mining

A. Trench Mining Method

There is a limitation on length of drivages due to various reasons. For a dipping seam, with the length of drivages, the depth of overburden increases but if the seam is flat, further entries can be made by excavating a trench to expose the coal seam and Highwall mining can be done along the exposed coal seam available both at dip and rise side. This is commonly known as Trench Mining.

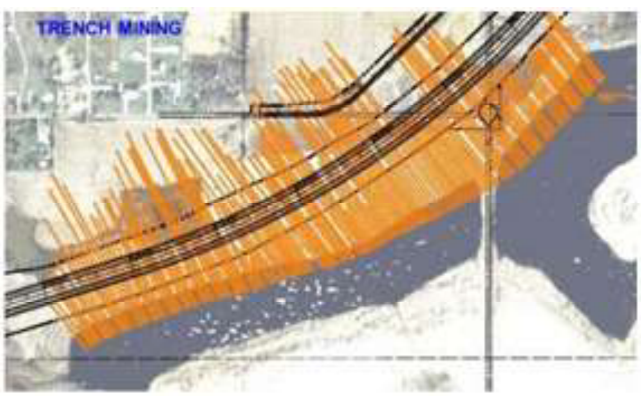


Fig. 2: Trench Mining

C. Bench Mining Method

For working multi-seam deposit, a bench is prepared in the top seam and mining operation is undertaken top downwards. Highwall Mining can also be done by preparation of benches from bottom upwards but there is possibility of damage to the coal of upper seams if there is any failure of web pillars at the bottom seams. Mining by preparation of benches in each seam for multi-seam working is called Bench Mining.

Fig. 3: Bench Mining

ADVANTAGES OF HIGHWALL TECHNOLOGY

a) Limited land degradation since only the area for trenches and OB dumps is disturbed. Size of OB dumps is minimized due to less OB excavation.
b) Flexibility in alignment of trenches so that any surface features/ infrastructure need not be shifted/ diverted.
c) Coal can be extracted from below surface features without having to leave barrier pillars of substantial dimensions.
d) Quality of coal can be sustained even while mining thin seams of the order of 0.75m thickness.
e) This method of mining is designed to cause zero subsidence on the surface. Yet it gives an extraction percentage of around 55% of mineable reserves, which is much higher in relation to Bord and Pillar mining being practiced in India.
f) Coal seams in thickness range 0.75m to 1.5m, which cannot be mined by available underground methods also become amenable to extraction.
g) Environment friendly method of mining.

LIMITATIONS OF HIGHWALL TECHNOLOGY

a) Seam gradient should be 1 in 7 and flatter.
b) Coal seam should be available at shallow depth so that volume of OB excavation in trenches is minimized.
c) Seam thickness should not exceed 3.05m.
d) Frequent undulations in floor of seam lead to cutting of roof / floor strata resulting in some amount of dilution.

e) The width of cuts, web pillar and barrier pillar in highwall mining have to be designed to ensure zero subsidence, Slope and strain on the surface.

f) The back-filling operation in opencast mines where highwall miner is to be deployed in future needs to be programmed in such a way that access to flanks is available without resorting to re-handling of OB.

g) Since highwall mining is an operation of discontinuous nature in case of opencast mines, a single set of equipment needs to be deployed in a no. of mines in sequential manner in order to fully utilize the equipment.

APPLICATION OF TECHNOLOGY

The technology is quite flexible and can be used for extraction of coal from:

- Thin seams of thickness over 0.75 m.
- Beyond economic strip limit of opencast mines.
- Coal blocked in Highwall boundaries.
- Below sterilized overburden dump.
- Below permanent structures like road, rail and power line.
- Below villages.

STRENGTH OF HIGHWALL MINING TECHNOLOGY

A. Safety

Since no man is going inside the drivages, it is the safest method of mining.

B. Production Potential

Production potential of the Highwall Miner depends upon the thickness of the coal seam and the condition of the exposed sides. Highwall machines can produce approx. 7200 tpd for thick seams, 4000 tpd for medium seams and 2500 tpd from thin seams having thickness 0.75 to 1.3m. Production over 100000 tonnes per month is being achieved in a sustained manner in other countries.

C. Higher Productivity

The machine is being operated with 3-4 crew members per shift with very high productivity. Depending on the thickness of seam, output per man shift can be as high as 300-400 t. This cannot be achieved by any other technology.

D. No Ash Dilution

The cutter head only cuts coal. The cut coal is transported inside the closed push beam upto the discharge conveyor behind the machine. So scope for dilution is ruled out. The length of pushbeam is 6m and scope for articulation between the pushbeams is 2°. In case the floor undulation exceeds this limit, some amount of dilution could occur.

E. Conservation Of Coal

This technology recovers that coal which in normal case cannot be taken out by any other technology. Percentage of recovery of coal by this technology is quite high as compared to conventional underground mining technology. Depending upon the thickness of coal seam, strength of coal and depth of cover of the seam, recovery of coal to the extent of 50% to 60% is possible.

F. Mobility

Machine is mounted on four hydraulically powered crawlers with 900 movement. This allows the machine to move both in straight and transverse directions. This helps the machine to position itself in the next hole accurately with least time. Moreover, the machine is modular in construction and can be broken into modules in one day and can be assembled in 3 - 4 days.

HIGHWALL DESIGN AND GROUND CONTROL ISSUES

A. Highwall design

Design of a highwall mining is based on the following site and working parameters.

- Mining height
- Hardness of coal and in-situ strength of coal
- Depth of cover at beginning and end of cut
- Width of drivages
- Strength of overlying strata

The pillar strength, applied stress on the pillar and desired pillar stability factor are required to be ascertained.

Based on the above parameters, width of web pillar, number of web pillars between two barrier pillars and width of barrier pillar are determined.

Nomograms published in the paper “Ground Control Design For Highwall Mining” By r. Karl Zipf, Jr., Niosh, Pittsburgh, PA have been used to determine the width of web pillar and barrier pillar for different depth range considering factor safety 1.6 and 1.0 respectively, width of cut 3.66m and mining height 1.22m, strength of coal 6.20 MPa and width of panel 61.0m. The nomograms are reproduced below:

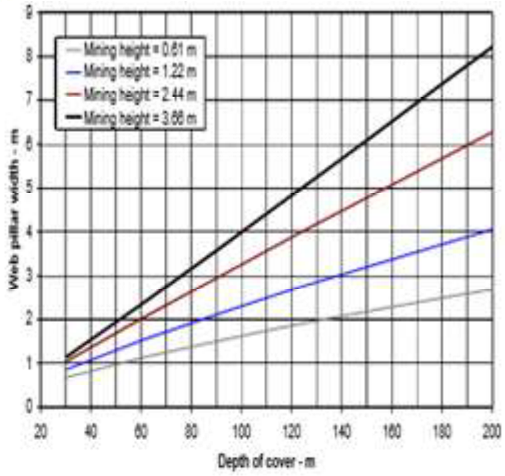


Fig. 4: Suggested web pillar width with stability factor of 1.6, coal strength of 6.2 MPa and 3.66 m wide hole

SALIENT FEATURES OF HIGHWALL MINER

- Base unit/advancing launcher
- Reels and chains
- Controls
- Push beam
- Cutter Unit

A. Base unit/advancing launcher

Main Base unit is placed at surface/trench where most of the drives and all controls are positioned. On the top of the Base unit, there is a closed operator's main control cabin from where all the main operations are controlled. It also houses hydraulic power-pack to feed power to push rams and cutter heads. Two push rams, which push the push beams inside the drivage holes, can exert push-in & pull out force of 170 tonne and 350 tonne respectively. The length, width and height of the base unit is approximately 22m, 8.3m and 6.5m respectively.

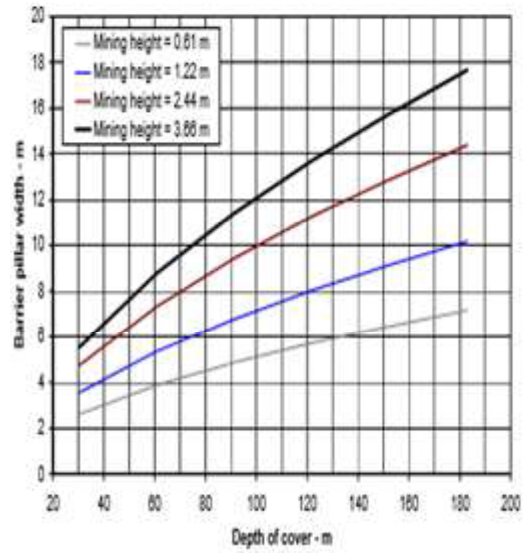


Fig. 5: Suggested barrier pillar width for 61.0 m wide panel assuming coal strength of 6.2 MPa and stability factor of 1.0.

Table 1: Web Pillar Width (m)

Web Pillar Width (m)

Depth/ Mining Height	30m	40m	50m	60m	70m	80m
1.22m	0.95	1.05	1.25	1.50	1.75	1.95
2.44m	1.00	1.30	1.60	2.05	2.25	2.70

The total installed power ranges from 1057 kW to 1525 kW depending on type of cutter unit.

Rigidity of the structures does not provide any horizontal movement. Moreover, auger being placed inside the push beam, possibility of contamination of coal due to roof fall is eliminated and dilution of grade of coal is completely avoided.

Table 2: Barrier Pillar Width (m)

Barrier Pillar Width (m)

Depth/ Mining Height	30m	40m	50m	60m	70m	80m
1.22m	3.75	4.10	4.75	5.50	5.90	6.10
2.44m	4.75	5.75	6.30	7.25	8.00	8.30

B. Reel and Chains

Reel automatically unwinds and winds considering the movement of the push beam and contains the following Cables & Hoses:

- Power cable for cutter head
- Control cable for cutter head
- Methane sensor cable
- Hydraulic pressure hose for cutter
- Cooling water hose for cutter motor

Fig. 6: Highwall Miner

C. Control

Total operation can be either by automatic programmable logic controller or manually by touch screen technology. It contains self- diagnostic health monitoring system to know the status and health of the machine as well as environment where the cutter works.

D. Push Beam

Push beam plays an important role for parallel drivage of entries as well. It is rigid in construction and contains two contra-rotating augers for transportation of coal from the coal face. Articulation in-joint between two push beams provides vertical movement, which allows the cutter head to negotiate the undulating contour of the coal seam.

Fig. 7: Reel chain and control system

E. Cutter Unit

The cutter unit that goes inside the coal seam is basically the cutter head of continuous miner and the operation is fully remote controlled from the operator's cabin, positioned at main base unit. Depending upon the height of coal seam, there are two types of cutter modules i.e. thin seam and medium thick seam. It can cut coal seams having the thickness ranging from 75 cm to 3.05 m.

Fig. 8: Highwall miner

Diameter of cutter motor varies from 61 cm to 112 cm while power of cutter motor varies from 246 kW to 350 kW. The entire cutter modules are interchangeable with the machine.

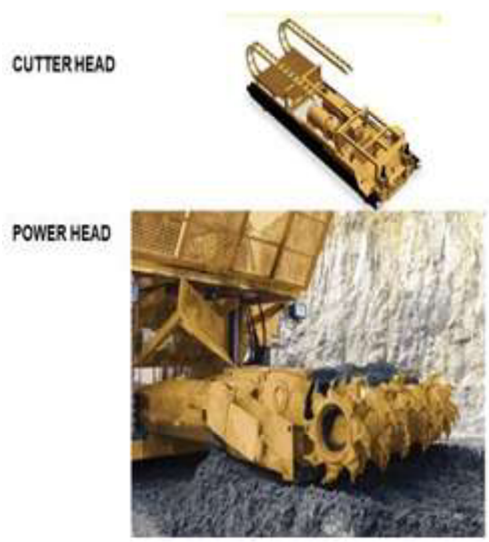


Fig. 9: Cutter and power Head

F. Coal Conveyance System

Highwall Mining is a continuous process of mining and there is no provision of any pumping in the drivage. Whatever make up of water comes from strata is mixed with coal and possibility of high wet/slurry coal cannot be ignored. Under such situation, conveyance system by auger plays a very important role over other system of conveyance of coal from face.

It is a pair of large diameter augers rotating in opposite direction and carries the coal mixed with water from coal face to the main base unit, where it delivers it to chain conveyor placed in the center of base before it discharges to rear belt conveyor.

CASE STUDY- HIGHWALL MINING IN BATURA UG GEOLOGICAL BLOCK

Batura UG Block is flanked by Batura O/C and Batura Extn O/C Blocks to the east and Batura West Extension Block to the south- west. In both the flanking blocks, opencast projects have been planned. Batura UG Block is overlain by a no. of surface features and the coal seams have limited aerial extent and low thickness in relation to the adjacent blocks.

This block cannot be annexed to the adjacent Batura West Extension Block due to presence of fault F1-F1 of 35m throw and dyke D3.

Due to availability of limited geological reserves (5.6417 Mt), high stripping ratio (+25 m3/t) and presence of surface features (tarred road, Jamunia Nalla, pond, 4 nos. villages, 132 kV OHT lines and Forest) an independent opencast mine could not be proposed in Batura UG Block.

Although the block was identified for underground mining, the geological reserves in +1.5m thickness range are only 1.25 Mt. For these meagre reserves opening an independent underground mine was not feasible. Therefore, underground mining is ruled out in Batura UG Block.

Highwall Mining is possible in seam thickness +0.75m to 3.05m and is suitable for low thickness shallow deposits having nearly flat gradient. The geo-mining conditions in Batura UG Block are conducive for deployment of Highwall Mining, therefore this technology has been shortlisted for Batura UG Block. Highwall Mining by trenching method is being practiced with reasonable success in nearby Sharda Project since 2011 on total hiring basis.
Highwall mining consists of mainly two operations, viz.

- Construction of trenches
- Drivage of cuts below superjacent strata.

A. Construction of Trenches

Trenches are constructed by opencast method by drilling, blasting. Loading, transport and dumping of overlying OB. Trenches shall be driven from surface upto the floor of Seam – II. The trenches shall be so aligned as not to disturb the existing infrastructure / surface features.

The width of trench at floor of Seam – II has been envisaged as 35m and the width at surface shall vary with depth of seam. The final slope of trench sides has been considered as 45° since the depth of seam is less than 100m.

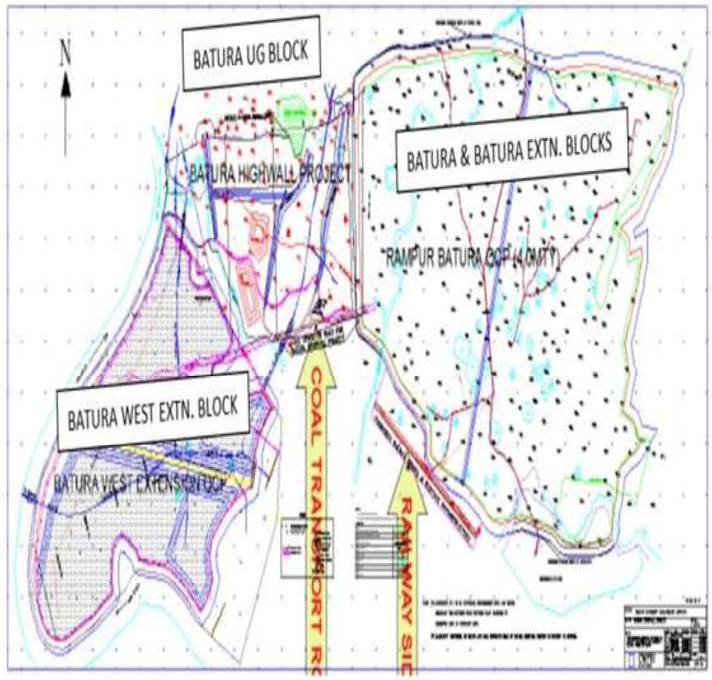


Fig. 10: Batura blocks

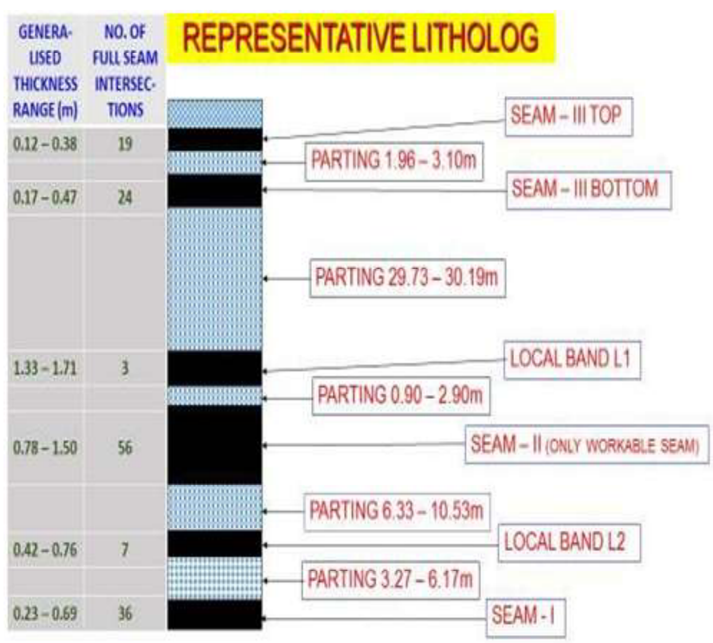


Fig. 11: Representative litholog

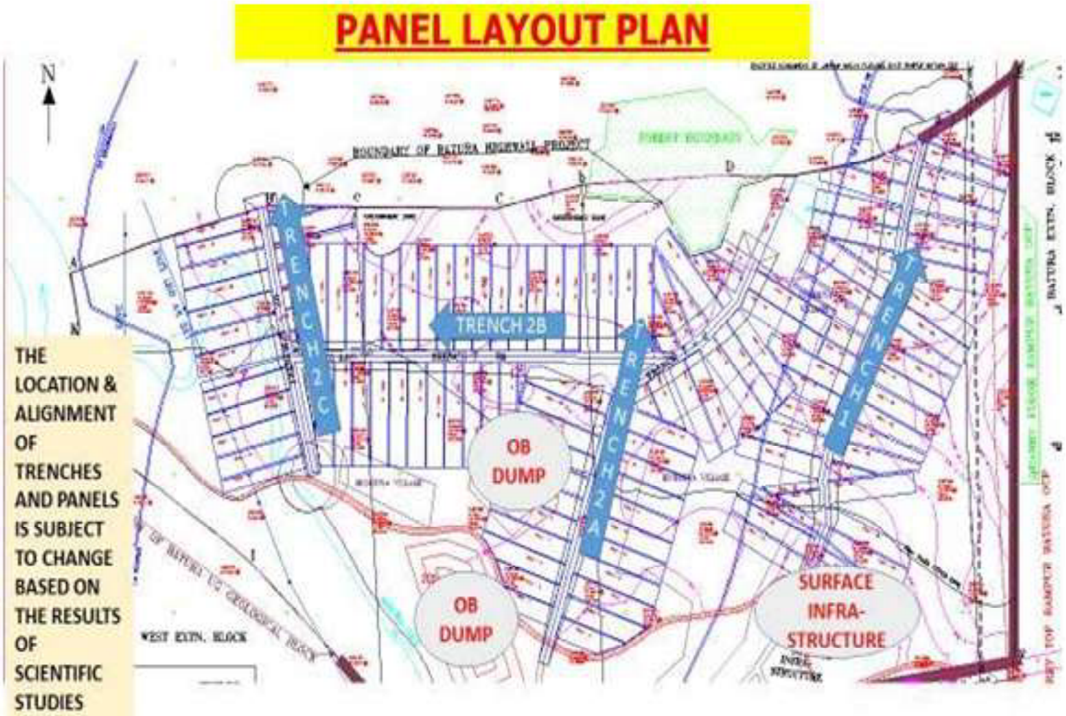


Fig. 12: Panel layout plan

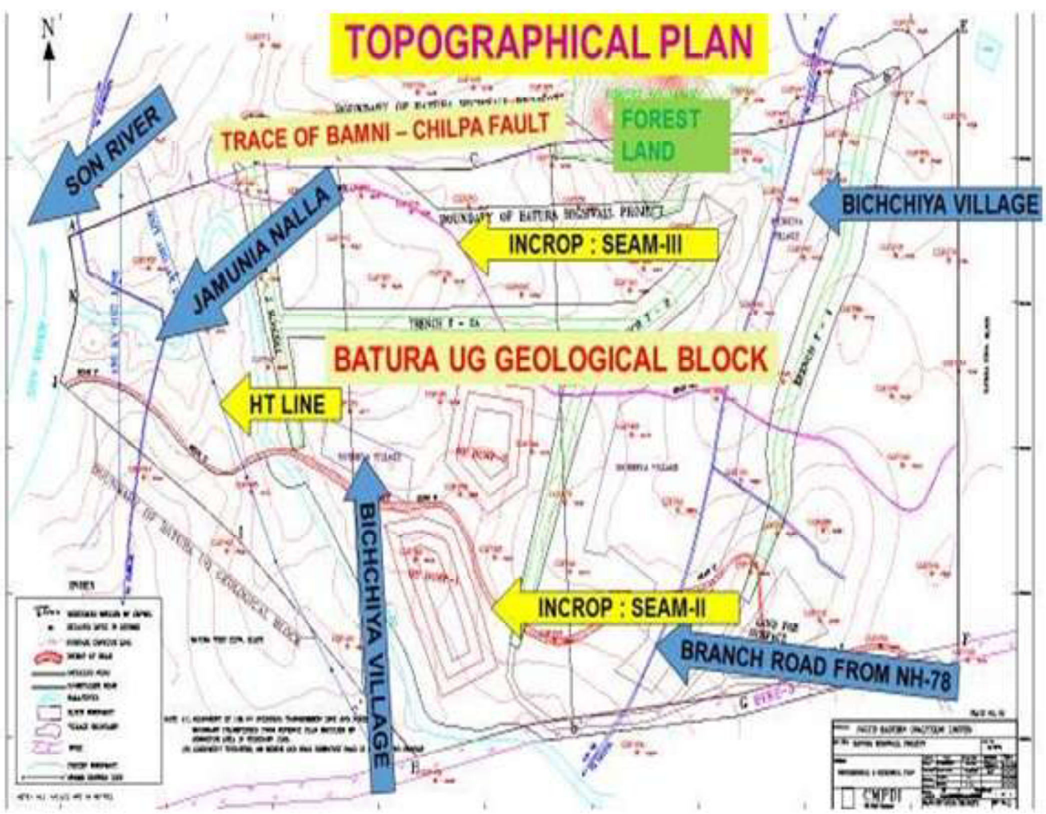


Fig. 13: Topographical plan

B. Drivage of Cuts below Superjacent Strata

The highwall cuts are driven at 90° to the trenches upto a maximum length of 305m on either side. The area beyond 305m is either left virgin or extracted by the next trench. Between the cuts rectangular pillars of solid coal referred to as web pillars have to be left intact in order to support the overlying strata. Highwall Mining is a zero subsidence method of mining. To ensure that subsidence and tensile strain remain within permissible limits, web pillars have to be designed keeping in view the thickness of extraction, width of cut, depth of seam and strength of overlying strata.

A highwall panel consists of a no. of cuts and web pillars. Between two highwall panels a barrier pillar of solid coal is to be left intact to absorb the effect of subsidence and tensile strain. The design of barrier pillar depends upon the width of panel, thickness of extraction, depth of seam strength of overlying strata. For purposes of reserve estimation, the width of web pillar in the panels falling below Jamunia nalla and where thickness of hard cover is less than 15m has been doubled.

Batura Highwall Project is affected by the following features:

1. 4 nos. villages
2. Tarred road branching from NH-78
3. Jamunia nalla
4. Two nos. 132 kV OHT lines
5. Two nos. ponds
6. In nearly 25% of project area the thickness of hard cover is less than 15m.

For Batura Highwall Project, the trenches have been aligned keeping sufficient distance from tarred road, Bichchiya village and Jamunia nalla. The length of cuts has been maximized to 305m. The no. of trenches has been minimized to cause minimum damage to surface. Due to this reason, some patches in Seam – II remain virgin although the seam thickness is +0.75m.

EXPERIENCE AT SHARDA HIGHWALL PROJECT

At Sharda Highwall Project, DGMS has insisted upon the following:

(1) Acquisition of land even above the highwall cuts.
(2) Leaving a solid barrier of 60m between the ends of highwall cuts driven from adjacent trenches.
(3) Factor of Safety of atleast 2.0 for the web pillar.

As reported, regular subsidence survey is being carried out at Sharda Highwall Project and till date no subsidence has been recorded.

Table 3: Coal characteristics

Particulars	Characteristics of Seam - II
Mine Area km^2	4.20
Workable Area km^2	3.60
Seam Thickness range (m)	0.38 – 2.50
Workable Thickness Range (m)	0.75 – 2.50
Average Mining Thickness (m)	1.50
Seam Gradient	1 in 20 to 1 in 60
Depth of Cover range (m)	6.50 – 65.00
Range of Parting with upper seam (m)	5.15 – 65.00
Average GCV Band	G4
Immediate roof	Sandy shale / Fine to medium grained sandstone
Immediate floor	Fine to medium grained sandstone
Geological Reserves (Mt)	
Proved	5.5647
Indicated	Nil
Mineable Reserves (Mt)	5.25
Extractable Reserves (Mt)	2.75
Status of Mining	Virgin Seam

Test Results on Physico-Mechanical Properties of Drill Core Samples of Borehole No. CSBT-355 of Batura West Extn. Block, Sohagpur Coalfield.

Table 4: Physico-Mechanical Properties

Sample No.	Rock type	Depth (m)	Den-sity (gm/cc)	Compresive strength (MPa)	Tensile strength (MPa)	Shear strength (MPa)	Young's Modulus (GPa)
				Mean, std. deviation & no. of specimen tested			
1	CGD/VCGDS ST	7.94-22.24	2.39	16.07 4.67 5	3.30 0.37 5	5.63 0.25 5	2.26 0.46 4
2	COAL/SH COAL (L1 Band)	22.24-23.86	1.42		3.83 1.42 3		
3	MGD/CGD SST	23.86-32.00	2.35	22.41 6.70 5	2.81 0.11 5	4.54 1.14 5	2.62 0.78 4
4	SANDY SH/FGD SST	34.00-35.12	2.24	25.52 - 1	5.73 0.11 5		1.22 - 1
5	FGD/MGD/ CGD SST	36.22-44.00	2.46	19.23 5.73 6	3.90 1.11 5	4.42 1.23 5	2.32 0.70 6

Table 5: Tri-axial test

Sample No	Rock Type	Depth (m)	Compressive Strength (Mpa) Mean, Std Deviation & No. of specimens tested			Angle of internal friction "f" (degree)	Cohesion "C" (MPa)
			At 0 MPa Confining	At 5 MPa Confining	At 10 MPa Confining		
1	CGD/VCGD SST	7.94-22.24	16.07 4.67 5	51.93 13.95 2	75.37 6.70 2	36	3
3	MGD/CGD SST	23.86-32.00	22.41 6.70 5	51.27 1.61 2	73.08 8.32 2	36	4.1
5	FGD/MGD/ CGD SST	36.22-44.00	19.23 5.73 6	57.98 5.01 3	81.94 11.33 3	35	3.5

The compressive strength of coal and its HGI indicate that the coal may be moderately difficult to cut.

Table 6: Land Requirement

S. No.	Head For Land Requirement	Quantity (ha)
1.	Area of trenches	51.00
2.	Area for surface infrastructure	5.10
3.	Area for coal transport road	9.48
4.	Area for OB dumps	20.82
5.	Total surface area required for highwall mining operations	86.40
6.	Area of highwall panels	201.39
7.	Total area required for highwall mining operations	287.79
8.	Area for R&R site	10.603
9.	Area considered for acquisition in report	420.975

Fig. 14: Working plan

SUGGESTIONS FOR MAKING HIGHWALL MINING COST-EFFECTIVE

(1) Land acquisition should be minimized and restricted to trenches and infrastructure area only. Controlled blasting techniques need to be adopted during trenching to minimize land acquisition for safety zone. This will have a major impact on the overall economics of the project.

(2) Leaving a solid barrier of 60m between the ends of highwall cuts driven from adjacent trenches will result in sterilization of large quantities of coal in all seams. This may be reviewed in view of conservation of coal.

(3) Departmental operation and maintenance of Highwall Miner with a view to indigenize the machine.

FUTURE PROSPECTS OF HIGHWALL MINING IN SECL & WCL

Bishrampur and Lakhanpur Coalfields under the command area of SECL have mainly thin seams under shallow cover. Gradient is never an issue in SECL fields. Prospects of deployment of highwall mining technology in SECL are very bright subject to cost effectiveness of the project. In WCL command area, most opencast mines have yet to reach their economic limit. Therefore, prospects of highwall mining in WCL are not very bright in the near future.

ACKNOWLEDGEMENT

Author expresses his sincere gratitude to Shri Rajesh Kumar Amar, Regional Director and Shri Manoj Kumar, Chief Manager (Mining)/ HOD (Mining) for giving the opportunity and guidance to present this paper.

Author would also like to thank the management of SECL, Sharda Highwall Project for providing field data and sharing their experience of Highwall Mining operations.

The views expressed in this paper are solely of the author and not of the organisation which he represents.

REFERENCES

"Ground Control Design for Highwall Mining" By R. Karl Zipf, Jr., Niosh, Pittsburgh, PA.

Equipment catalogue and brochure of Caterpillar Highwall Miner.

Geological Report on Batura UG Block, CMPDI, RI:V, Bilaspur, December 2009.

Project Report for Batura Highwall Project, CMPDI, RI:V, Bilaspur, March 2015.

Data obtained from Sharda Highwall Project, Sohagpur Area, SECL.