MGMI NEWS JOURNAL

Vol. 47, No. 4 • January-March • 2022

:: Theme ::

Strata Control in Underground Coal Mining

THE MINING GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA 1906

THE MINING, GEOLOGICAL AND METALLURIGCAL INSTITUTE OF INDIA

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:: THEME ::

STRATA CONTROL IN UNDERGROUND COAL MINING

THE MINING GEOLOGICAL & METALLURGICAL INSTITUTE OF INDIA
1906

THE MINING, GEOLOGICAL AND METALLURIGCAL INSTITUTE OF INDIA

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President's Message

IMPORTANCE OF STRATA CONTROL STUDY DURING UNDERGROUND COAL MINING

Coal is an important energy commodity for India as its share has been above 55% of total commercial energy consumption for the last four decades. At present, more than 95% of the coal production comes from opencast mines. Considering the exhaustion of shallow coal deposits, energy demand, subsurface features and environmental concerns, underground mining method is considered as the future of mining industry for producing coal. Earlier around 200-300 tonnes of coal used to be produced in a day using conventional drilling and blasting from underground mines but there has been a paradigm shift in coal production by the introduction of mechanised technology like long wall and continuous miner packages. Continuous miner-based mass coal production technology has proven its potential by producing average 2,000 tonnes of coal and found to be more suitable for Indian coalfields compared to long wall technology considering the range of variation of Indian geo-mining conditions. It is the main reason that only three long wall faces running in India compared to more than 20 continuous miners in operation in different Indian coalfields. In spite of introduction of mechanisation in underground mines, the mining industry is yet to compete with daily coal production from opencast mining. The large increase in coal production envisaged now can be achieved only by focussing on the technology and productivity in both underground and open cast mines. This would call for increasing the level of mechanization, introducing the state-of-art machines and ensuring their optimal utilization as per international standards.

Considering the future of underground mining, a number of challenges will arrive with the introduction of mechanisation at deeper cover (300-600 m) like in-situ stress measurement, rock mass characterisation, rock mass properties, rock mechanics, caveability, calibration of numerical model, ventilation etc. There is a requirement of being ready with all these aforementioned issues based on comprehensive scientific studies before shifting to deeper cover. This is the time, where mining industry can offer maximum R&D projects to academic and scientific institutions targeting these challenges. It will enable the industry to achieve maximum share of underground coal production like China and Australia. Indian mining industry cannot imitate a foreign technology and blindly introduce it in Indian coalfields as there is a need of comprehensive knowledge of the rock mass behaviour of a site before its implementation.

Strata control is the main current and future challenge during underground winning of coal. It is defined as stability of roof and pillar around the number of openings in underground coal mines. It is important for the safety and efficiency of the underground coal mining operation. Its importance increases more during the depillaring operation compared to development. During development, design of gallery is the only strata control problem, while there are a number of structures involved during depillaring for better strata control. Most of the fatality cases in underground coal mines are related to inefficient strata control measures during pillar extraction due to poor understanding of rock mass. Regulation No. 123 of Coal Mines Regulation (2017) mentions about preparation, formulation and implementation of strata control and monitoring plan based on scientific study. It includes the span of hanging roof in the goaf during underground working, induced stress, roof sagging, induced blasting, roof span for first and subsequent falls, extent of unsupported roof span and pillar spalling during the depillaring operation. It becomes important to determine a threshold limit value of induced stress, roof sagging and roof span during pillar extraction for efficient management of strata.

It is my privilege to have the honour of working for MGMI in the capacity of the President of this century old Institute. I am glad to note that the current issue of our News Journal has special focus on Strata Control in Underground Coal Mining, which offers a great potential to achieve good global performances in terms of productivity and viability.

P M Prasad
President, MGMI

From the Desk of Editors

Introduction to the Special Issue :

STRATA CONTROL IN UNDERGROUND COAL MINING

In continuation of our efforts to provide a deeper focus on contemporary issues, *MGMI News Journal* continues to bring out special issues edited by guest editors. This special issue focuses on the critical challenge of strata control during underground coal mining. Strata control may simply be defined as application of scientific knowledge and technique to manage the surrounding rock mass, in and around an opening, for safe and efficient underground mining. In fact, different locations in a mine require different requirements of stability of the surrounding rock-mass, which call for a wide spectrum of scientific and technical approaches (even sometimes contradictory to each other) to achieve the goal of strata control. Strata control introduces a very stable roof strata in main roadways but the stability of roof strata inside the goaf is, generally, destroyed for destressing of the working area around the line of extraction. Further, the approach of strata control varies considerably even for the goaf under different types of roof strata. An excessive caving roof strata (weak and laminated) in a depillaring operation requires special design of the manner of extraction so that some natural supports are left out inside the goaf[1] to arrest the tendency of roof instability in slices due to disproportionate caving. On the other hand: a clean sweep extraction (involving complete dilution of even ribs) is adopted in depillaring below competent roof strata, at least for some initial pillars[2], to alleviate the chances of delayed caving of such strata, which may bring unwarranted issues like dynamic loading and goaf encroachment.

Regulatory body for mine safety in the country has paid considerable attention on strata control issues during underground coal mining. Stipulation of Systematic Support Rules (SSR) in Coal Mines Regulations (CMR) 1957 is an example, where a depillaring operation needs to be systematically supported in advance up to a range of 30m or two pillars, whichever is more. Here, main purpose of SSR is to counter the adverse effect of mining induced stress on exposed roof strata over the gallery. On the basis of different experiences, it is realized that every mine has unique site conditions and, accordingly, the SSR of CMR 1957 has evolved to Strata Control and Monitoring Plan (SCAMP) in CMR 2017. In SCAMP, the owner, agent and manager of every

1. Oldroyd, C., Bigby, D., Leeming, J., Meyer, L. (2006). Successful Application of Rock Bolt Support and Mechanised Depillaring in Difficult Roof Conditions at Tandsi Mine, Western Coalfields, India.Proceedings of the 25th International Conference on Ground Control in Mining, Morgantown, WV, USA, pp. 396-400.
2. CSIR-CIMFR Report, 2010. Mechanised depillaring of King Seam at VK-7 Incline mine, Kothagudem Area, SCCL; 44pages.

mine shall prepare, formulate and implement a SCAMP based on scientific study considering the geotechnical data, information and the method of development and extraction of coal or the excavation required therefrom, which also includes a support plan to secure the roof and sides of below ground workplaces, and shall be subject to revision with change in condition, for all workings below ground.

Strata control represents a major area of concern for mining engineers and needs careful analyses of geo-mining conditions for adoption and execution of safe and productive systems for underground extraction of coal. When an opening is made to extract coal, the existing natural state of stress equilibrium is disturbed, and as a result the altered state of stresses starts threatening stability of the opening. Stability of the opening is vital for efficiency and safety of the mining operation. The stability issue remains, generally, "local" during primary working, i.e., development of the seam and the final extraction, i.e., depillaring/longwalling often encounters "global" instability. Local instability involves movement/fall of, mainly, immediate roof strata[3] in roadways/junctions or side spalling of pillars, which are managed by applied supports if the surrounding rock-mass fails to remain stable for the designed dimensions of the openings. Global instability brings considerably large amount of strata movement, generally inside the goaf, which attracts the issue of dynamic loading, instability of natural supports[4], air-blast etc. Pre-assessment of likely global instability requires a thorough study of the nature of overlying strata and design of a matching manner of extraction (final) and natural supports.

Strata control in underground coal mining adopts both active and passive approaches. For the latter approach, a detailed study of the site conditions including properties of the involved rock mass and anticipated stress field is done for the design of different underground structures for mining. However, sometimes the given design fails to work during actual practice and then an intervention like improvement/dilution in efficacy of the designed natural supports, induced overlying strata caving[5] etc. are done. Such interventions, in addition to the planned mining operations, fall into active approaches of strata control. In fact, an accurate assessment of the rock mass properties and stress field are difficult and, therefore, the performance of the designed underground mining structures are monitored by suitable instrumentation for both safety and further improvement of the design.

Considering inhomogeneity and anisotropy of the involved rock mass, it is always desirable to deploy the instruments as closely as possible in the available underground space and monitor them continuously in time. The initial assessment of required instrumentation is often practically very difficult and, therefore, available knowledge base of the rock mass is used to install them for subsequent optimization keeping in view the cost of instrumentation and monitoring vis-à-vis the level of safety being achieved. A good match of types and location of the instruments with the working plan and expected rock mass behavior adds significant value to this approach. For monitoring, it is convenient to have simple and direct access to the installed instruments, but data-loggerbased system gives near continuous

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3. Mark, C., Karabin, G., Zelanko, J.C., Hoch, M.T., Chase, F., 2002. Evaluation of pillar recovery in southern West Virginia. In: 21st Int. Conf. Ground Control in Mining, Morgantown, WV, USA
4. Mark, C., 2009. Deep Cover Pillar Recovery in the US. In: Proc. 28th Int. Conf. on Ground Control in Mining, Morgantown, WV, USA.
5. Kumar R, Mishra AK, Kumar A, Singh AK, Ram S, Singh Amit K and Singh R. 2022. Importance of Fracturing Hard and Massive Overlying Strata for Complete Extraction of Thick Coal Seam – Case Studies. Jour. Geol. Soc. India (2022) 98:203-210.

readings in time, which is found to be useful, especially, in the context of dynamic strata loading. In brief, underground instrumentation and monitoring represent a technical activity and requires skilled manpower and specialized instruments for its effectiveness.

When we consider the current Indian coal mining scenario, opencast method is contributing around 95% of total coal production. Indian underground coal mining is yet to be competitive as it severely lacks mechanization. Probably, strata control is the single most important factor for the collapses so far encountered and goaf overriding problems faced by some of the prestigious mechanized underground coal mining operations (mainly long wall packages) in India. These failures have adversely affected underground mechanization strategy of the coal mining industry resulting in the dwindling contribution of underground coal production. Some of the prevailing geo-mining conditions of different mines initially supported development of a coal seam on Bord and Pillar (B&P) method, but, subsequently, depillaring of these developed coal seams became difficult. This difficulty in depillaring was, mainly, due to strata control issues. Discontinuous nature of conventional depillaring at slow rate of extraction under competent overlying formations added to strata control problems and, therefore, large number of coal seams have remained standing on pillars. A fast rate of depillaring operation like Continuous Miner (CM) based depillaring has lately been giving good results[6], where strata control is achieved more scientifically. A faster rate of extraction coupled with scientific approaches like selection of a manner of extraction as per the site conditions, application of high capacity, pre-tensioned, resin grouted and stiff roof bolts in galleries and at the goaf edge as breaker-line support along with availability of pit-top maintenance for the machine problems has facilitated the CM faces for their reported successes in the country.

To improve the status of underground coal mining, Indian coal mining industry had gone for different international collaborations. These collaborations brought advanced coal extraction and roof support equipment, but during actual field trial some of these collaborations experienced strata control difficulties, mainly due to adverse behavior of the surrounding rock-mass and stress conditions. Probably, a lack of understanding in Indian site conditions by foreign experts made proper deployment of imported technologies and machines troublesome. Considerable investigations have been made by different research institutions to address the distinct characteristics of Indian coal measures. Development of different indigenous empirical approaches[7, 8, 9, 10] in the recent past has provided considerable improvement in design and performances of the associated underground mining structures for successful mechanized depillaring. Indigenous empirical design norms have been proven to be important inputs for success in strata control practices during mechanized underground mining operations.

6. Ram S, Singh R, Kumar A, Singh AK, Kumar R, Rao AR, Rao VS. 2022. Stability assessment of heightened rib/snook during extraction of a thick coal seam by continuous miner in single lift. Geomech. Geophys. Geo-energ. Geo-resour. (2022) 8:74.
7. Ram, S., Kumar, D., Singh A. K., Kumar, A. and Singh, R. 2017. Field and laboratory studies for an efficient placement of roof bolts as breaker line support. Int. J. Rock Mech. Min. Sci.,93(2017):152–162.
8. Sheorey, P. R., 1994. A theory for in situ stress in isotropic and transversely isotropic rock. Int. J. of Rock Mech. Min. Sci, 31(1):23-34.
9. Singh, A.K., Singh, R., Maiti, J., Mandal, P.K., and Kumar, R. (2011a) Assessment of mining induced stress development over coal pillars during depillaring. Int. J. of Rock Mech. Min. Sci, 48(5), pp.805-818.
10. Singh, R., Kumar, A., Singh, A.K., Coggan, J. and Ram, S. (2016) Rib/snook design in mechanised depillaring of rectangular/square pillars. Int. Jour. Rock Mech. Min. Sci., v.84, pp.19-29.

Additionally, *in situ* performance monitoring of the associated rock and coal structures has provided an opportunity for further improvement in their design. Current status of strata control techniques is well poised to accomplish the demanding task of improvement in efficiency and safety of underground coal mining in India.

We are honoured to feature the interview of Mr. R.V. Shahi, Former Secretary, Ministry of Power, Government of India to headline this special issue. Mr. Shahi has talked about the multifaceted challenges that would be seen in the evolving power sector, including its interactions with coal. A perspective piece has also been provided by long-time MGMI Council member, Mr. V.K. Arora, on the historical context under which Indian coal mining operates. This article continues the story of coal mining in India, which had started with exploitation of coal in the Ranigunj coalfield in the year 1774. Three technical notes on different issues concerning strata control during underground coal mining are included in this volume, which cover both active and passive methods of strata management during underground coal mining. CM based depillaring has introduced application of roof bolts at the goaf edge (first time in the country) and the design of roof bolt based breaker line support for caving and stowing cases of goaf treatments is discussed and presented in the technical note of NIT Rourkela by Dr. Sahendra Ram and colleagues. Performance monitoring of the designed underground structures during final extraction,i.e., depillaring, is a challenging task. This requires specialized equipment and skilled manpower, which are given in the paper of Dr. Arun K. Singh et al from CSIR-CIMFR, Dhanbad. Many times, the planned approach of strata control by the designed manner of extraction (passive approach)fails to work, mainly, due to the involved geological uncertainties in rock mass and stress regime. Here, an intervention is required to manage the strata (active approach). This particular issue of strata control is discussed in the technical note of IIT-ISM Dhanbad led by Prof. Arvind K. Mishra. In addition, a novel note is also presented by Drs. Binoy Saikia and Ajay Sah of CSIR-NEIST, Jorhat on the utilization of low-value coal. Here, they talk about beneficial valorization of coal to produce carbon quantum dots. This issue has been edited jointly by the Guest Editor, Dr. Rajendra Singh, a life member of MGMI and myself.

In terms of next steps, ***MGMI News Journal*** and ***MGMI Transactions*** are increasingly interested in inviting contributions from early-career scholars. Moreover, a key thrust is a collaborative engagement between industry, academia, and policy-making communities. The work featured in this particular issue is representative of that. It is noteworthy that, as we speak, there is global discourse on this. During the time of writing of this editorial, the approval session of the Intergovernmental Panel on Climate Change is ongoing for its Working Group III Contribution. Moreover, a bipartisan bill was introduced in the United States Senate to grow the mining workforce. This bill aims to establish a grant program for mining schools and proposes the Mining Professional Development Act to evaluate applicants and recommend awardees. Clearly, these themes have a worldwide focus, and we invite contributions from readers linking academic research to translational policy action.

DR. RAJENDRA SINGH
Guest Editor
Former Chief Scientist, CSIR-CIMFR

DR. AJAY K. SINGH
Honorary Editor
MGMI

HEADQUARTERS ACTIVITIES

MINUTES of 891st Council Meeting

(Held through Hybrid Meeting Physical and Virtual Platform through Zoom https://us02web.zoom.us/j/72555875837?pwd=eUMvY00wTE51SzduZllhNTdlZVl2UT09)

Date & Time : Saturday, 11th December 2021 at 3:30 P.M.

The report of the 891st Council Meeting (2nd Meeting 116th Session) at MGMI Bldg, GN-38/4, Sector-V, Salt Lake, Kolkata 700091 on 11th December 2021 at 3:30 P.M. (Duly approved in the 892nd Council Meeting held on 27th February 2022).

PRESENT : Shri P M Prasad, President in the Chair. The meeting was attended by Prof Banerjee Sakti Pada, Prof. Dhar B B, Dr. Nanda N K , S/Shri Jha N C , Ritolia R P, Saha R K, Jha Anil Kumar, Goenka J P , Lochan Rajiw, Singh Chandra Shekhar, Chakraborti Bhaskar, Dr. Singh Ajay Kumar, Roy Prasanta, Bhola Singh,Bose L K, Gautam N N, Barnwal J P , Biswas Anup , Chakrabarti Smarajit, Prof Dey N C , Prof Karmakar G P , Prof Sarkar Bhabesh Chandra, Dr A K Samantaray, Dr Sen Kalyan, Dr Sinha Amalendu , Khuntia G S, MishraP.S, Wadhwa I P, Tafcon and Talapatra Ranajit

Item No. 0Opening of the Meeting

1.1 The meeting which was held in a hybrid mode due to the still existent virus scare, was called to order by the President. The President welcomed the Past Presidents, Past Secretaries, Present Secretary, Chapter Chair Person and existing Council Members, along with invitees who were present physically as well as virtually in the meeting.

1.2 President requested the Hony. Secretary to take up the Agenda for deliberations.

1.3 Leave of absence was granted to those who could not attend the meeting.

1.4 Hony Secretary, thanked and welcomed everyone including the President, Past Presidents, Vice Presidents and Council Members alongwith Invitees.

891.1.0 To Confirm the Minutes of the 890th meeting of the Council held in Hybrid platform at MGMI Bldg. Kolkata-700091 on 17th October, 2021 at 11:00 A.M.

The draft minutes had been circulated to all the Council Members. Two comments were received from Shri R.K. Saha and Shri Rajiw Lochan. The minutes have accordingly been modified and circulated to all the Council Members. The Council resolved that:

Resolution: The Minutes of the 890th (1st meeting of 116th session) meeting of the Council held on Saturday, the 17th October, 2021 at 11:00 A.M. is confirmed.

891.1.1 To consider matters arising out of the Minutes

The Council considered the Action Taken Report in respect of the Minutes of 890th Council Meeting held on Saturday, the 17th October, 2021 at 11:00 A.M. (on hybrid mode).

891.2.0 To discuss the progress of the 9th Asian Mining Congress and Exhibition

The Honorary Secretary requested Shri I.P. Wadhwa, Managing Partner, M/s. Tafcon to apprise the Council about the progress made so far for organising the 9th IME. Shri Wadhwa informed the Council that preparations are being made very fast. The up to date information has been shared through Social Media as well. He also informed that Poland and Germany may join. He also further informed that he has already received the consent of group participation from Germany with about 18-19 companies. The German Consulate General in Kolkata will lead the delegation, provided he is invited for the inauguration. Similarly, he has got confirmation from 10-12 Australian companies and their Consular Head in kolkata may lead the contingents. The Polish Ambassador may come for the inauguration if a proper letter is sent confirming the Chief Guest's name. Czech Republic and Russia will also be participating. He mentioned that if direct daughter companies working in India are considered, then more than 20 countries will be participating. The members discussed about the ongoing buzz about the increasing Omicron infections and extension of the govt bar on opening all international flights. It was unanimous that the next 2-3 weeks would be critical in seeing how things pan out. He informed that this time an Innovation pavilion is being set up with the help of IIT-ISM Dhanbad and they will also rope in IIT-Kanpur, IIEST, Shibpur and IT-BHU.

Shri Wadhwa placed the draft copy of MOU for discussion and approval of the Council wherein he mentioned that the minimum guarantee payment by TAFCON to MGMI is proposed as INR 35 lakhs instead of INR 40 lakhs, which was agreed in the previous Council meeting. As Mr. Wadhwa explained the situation considering present circumstances, Chairman, Co-Chairman and Convener of the Exhibition Committee felt likewise and the Council agreed this one time to further revise the amount to 35 lakhs. However, if the minimum target participation i.e. booking inside the Hall and for outside display area of 4500 sqm and 3000 sqm, respectively, are achieved, M/s. Tafcon will agree to pay MGMI a minimum guarantee amount of INR 40 Lakhs. MGMI will allow one delegate per 12 sqm stall in the conference of the Asian Mining Congress at concessional rates as applicable to the academic institutions, but the maximum no. of such delegates will be limited to 50 (fifty).

Whatever may be the guarantee amount, Tafcon will pay to MGMI INR 6 lacs (Rupees Six Lac only) per month w.e.f. March 31st, 2022, till the total amount is completed. Other clauses are almost the same as MOU of 8th AMC.

Council agreed to it and approved and MOU was signed by Hony Secretary and Tafcon signatory.

Shri Bhola Singh, the Chairman of 9th IME, mentioned that it seemed that progress is on the right track and re-iterated that the Buyer Seller Meet be planned properly. Mr V K Arora, Convener, Buyer Seller Meet mentioned that to keep the event from being too long but at the same time a big one, only 5-6 big companies like CIL, SCCL, NALCO, NMDC etc shouldbe requested to give presentations towards the business opportunities of the several exhibitors who would comprise the seller spectrum. He suggested that extending invitations to these companies3-4 weeks before the eventshould be enough.

On the request by Hony. Secretary, the Convenor of the 9th AMC, Shri Rajiw Lochan updated the Council. He also shared that so far 45 organisations have been approached for sponsorship of different categories under the signature of the President of MGMI.

Shri P.S. Mishra, Chairman, Organizing Committee said, though time is very short and considering the pandemic, all-out efforts are needed to organise the Congress for two days in befitting manner. He was very much optimistic that many Asian countries will participate in the Conference too.

President mentioned that Ministry of Coal, Government of India has requested MGMI to organize **'The Capacity Assessment'** seminar during the 9th IME, 2022 with the Coal companies, CMPDI, Private Sectors for Stakeholder consultation, during the exhibition and read out the letter sent by Ministry to Chairman, CIL in this matter. It was decided that a whole session will be organised in the Conference on the topic on the 2nd day in compliance of the request of MoC.

CEOs of large companies dealing in coal, mining or otherwise, as desired, will be invited to speak. The members present, discussed about the objective and possible way ahead for organising this Seminar and deliberations veered to the view that it should focus on the different capacity assessment of utilisation, manufacturing of Equipment, capacity of production, etc. Chairman, Conference suggested encompassing a broader meaning and asked Convener, Conference and Chairman, Technical Committee to focus on the issues and sectors that could possibly be incorporated in this session. He also assured that he would try to find out what the Ministry of Coal wanted and the thoughts of Secretary (Coal) on this matter. It was unanimously agreed that the Capacity Assessment seminar had to be done and it would be best if it was incorporated in the Conference itself.

Convener, Conference, Sri Rajiw Lochan said that this was one of the rarest opportunities for MGMI where Secretary (Coal) was directly involving himself in the event. For this he thanked the President and the 2 Chairpersons of the Conference and the Exhibition. He reminded that though IME was the word in the letter, what must have been meant was the Congress Seminar itself. However, he insisted that whenever it was held, on 15th or 16th of February, it would be held in the post lunch session.

Regarding roadmap, he said that Chairman, Conference, Sri Mishra had already given a guideline and a proposal would be placed very soon as Ministry has demanded a plan of action to be sent to them. He mentioned that already 2 Organising Committee meetings have been held and very soon another would be held with more crystallised plans and schedules.

He listed about 9 keynote speakers as confirmed and said that CIL subsidiary CMDs would also be requested for the same. About 31 abstracts of papers have been received, and hence there would be 2 parallel technical sessions in the conference. For this he said, there were rooms at the venue as 3 halls have been booked.

He informed the members that the new US Consulate General had expressed her interest. However, he said that Poland will be associating only with the Exhibition and hence there will be no Country partner. However, he said that to live up to the reputation of AMC as an International event, there needs to be international participation in the conference too, and that is possible only through digital methods in this pandemic. Hence to get a professional and efficient hybrid logistic system, a good up-linker has been contacted, and his fees are high. He mentioned that he has kept this provision in the budget.

Hony. Secretary read out the budget placed by Sri Rajiw Lochan, Convener, Conference who projected an approximate income from 9th AMC and IME as INR 1,42,00,000 and estimated expenditure as INR 59,50,000. The budget was accepted after Sri Rajiw explained the costs, including justification for the apparently high budget for digital part.

Agreeing that the budget is on the higher side, Sri Rajiw insisted that during this pandemic, to live up to the image of AMC as a grand international event, with large foreign participation, a hybrid mode is a must for roping in international resources. Dr. Amalendu Sinha, Chairman, Technical Committee seconded this outlook and the budget was accepted after further discussions.

The Hony. Secretary requested Chairman, Technical Committee, Dr Amalendu Sinha to brief the Council about the present position of papers and keynote speeches. Dr. Sinha briefed the Council that so far 04 (Four) consents have been received for Keynote Address and 30 (Thirty) abstracts received for paper presentation. He expected some more abstracts will come.

He was of the opinion that, as Sri Mishra has advised, a draft paper with the road map may be placed to the Ministry with a visualisation of Capacity Assessment and wait for comments, rather than leaving everything tothe interpretation of the Ministry.

He assured that he will try to give very good shape to the seminar papers and keynote addresses. However, he said that 90% of the papers are on coal and felt that there should be more effort to get non-coal papers too. It was informed that letters have been written to the CEOs of HCL, HZL, MOIL and others by the President and hopefully things will materialise favourably. It was informed that President has been taking the initiative of talking to Heads of companies to rope them in.

891.3.0 To consider applications for membership and membership position of the Institute

The Hony. Secretary informed that Six (06) Life Membership applications have been received. The applications were approved by the Council for Life Membership of MGMI.

Membership Position (As on 11.12.2021)

	17.10. 2021	Add	Trans	Loss	11.12. 2021
Member	41	-	-	-	41
Life Member	1912	06	-	-	1918
Associate	18	-	-	-	18
Student Associate	04	-	-	-	04
Life Subscriber	27	-	-	-	27
Subscriber	01	-	-	-	01
Life Donor	01	-	-	-	01
Donor	01	-	-	-	01
Patron	05	-	-	-	05
Corporate	08	-	-	-	08
Life Corporate	02	-	-	-	02
	2020	06	-	-	2026

891.4.0 Any other Matter with the permission of the Chair

Foundation Day Lecture

Hony. Secretary informed that MGMI generally organises **Foundation Day lecture** on 16th January of every year. He proposed that the next Foundation Day Lecture may be organised, somewhere in Kolkata, on Sunday, 16th January, 2022, with Prof. S.P. Banerjee as the speaker. Fortunately, as Prof. Banerjee was attending the meeting online, his consent was obtained instantly and he was given full freedom to decide the subject matter.

The President was requested by the Hony. Secretary to formally close the meeting with a few words. The President thanked all present once again for sparing their valuable time and taking part in the deliberations.

The meeting ended at 4:30 P.M. with a vote of thanks to the Chair and others present both physically and virtually, by Hony. Secretary, Shri Ranajit Talapatra.

NEW MEMBERS

(As approved in Council Meeting on 27. 02. 2022)

10874 –LM, Dr B Satish, M.Sc (Appl.Geol), Ph.D (Appl.Geol), Manager (Geol), CMPDI, C-23, CMPDI Colony, Seepat Road, Bilaspur, Chattisgarh – 495006; (M) 7509008507; Mail: b.satish@coalindia.in

10875 –LM, Shri Bidya Nath Jha, B.Tech (M), MBA(HR), GM(UG)/HOD, South Eastern Coalfields Limited, Seepat Road(HQ), Bilaspur, Chattisgarh – 495006;(M) : 9669716912 /8770574982; Mail:baidyanath.jha89@gmail.com, Bnjha2008@rediffmail.com

10876 –LM, Shri Birendra Kumar Thakur, M.Tech (Rock Mech), BE (Min), MBA(HR), Chief Manager (Min)UG, D-9, CMPDI Colony Complex, Seepat Road, Bilaspur, Chattishgarh -- 495006, (M) : 9479001607/9926630098; Mail:thakur1.bk@gmail.com, bk.thakur@coalindia.in

10877 –LM, Shri Boothukuri Veera Reddy, M.Tech(Min), B.E.(Min), Director (Tech), Coal India Limited, Premises No.04, Plot No. AF-III, Action Area 1A, New Town, Rajarhat, Kolkata – 700156;(M) : 9002356666 Mail: dt.cil@coalindia.in

10878 –LM, Shri Piyush Srivastava, B.Tech (Min), MBA(Fin), Chief NRD, TATA Steel, 5, Park Road, Northern Town, Jamshedpur– 831001; (M) 9234567661(O) –0657-6645781 (R) / 0657-6643116; Mail: Piyush.srivastava@tatasteel.com

NEWS ABOUT MEMBERS

As on 31/03/2022

Shri Sukanta Acharjee (9153-LM) MMGI is now at Bashisthapur Bye lane – 4, PO Beltola, Dist Guwahati (Metro), Pin - 781028, Assam

Shri Shyam Sunder Dang (6526-LM) MMGI is now at H-192, DLF Ultima, Sector -81, Gurgaon – 122004; email: ssd1945@gmail.com

Shri NVR Prahlad (10107- LM) MMGI is now Dy General Manager, MB – 59, 2nd Lane, Writer Basti, Kothagudem, Bhadradri Kothagudem Dt, Telangana – 507101; email: nvr.prahlad@gmail.com

Shri Jagat Paikara (7622-LM) MMGI is now at C2-102, Neelkanth Greens, Manpada, Thane, Maharashtra - 400610, (M) 8169319791/9323629440; email: jpmay17@gmail.com

Shri Laxmi Narain Maheshwari (6677-LM) is now at 81/103 Eden Court, Loyola School Road, Bilaspur -- 495006 (CG); email: lnm631@gmail.com

Shri Ram Prakash Singh (10386-LM) MMGI is now at L/08/01, Celebrity Garden, Sector B, Sushant Golf City, Lucknow – 226030; email: bharat2ram@yahoo.co.in

Shri Shrikant Sharma (7891-LM) MMGI is now Former GM Excv C/28, Vidyanagar, Bilaspur CG 495001; email: sksharma5157@gmail.com

Shri Shibdas Bhattacharjee (9159-LM) MMGI is now at Office of the General Manager, Baikunthpur Area, South Eastern Coalfields Ltd., P.O.–Baikunthpur, Pin – 497335, Dist.–Korea, Chhattisgarh

Shri Sisir Kumar De (8997-LM) MMGI is now at Room # 1, Aumorto, P.O, Brinda Khali, Ramnagar, Baruipur, West Bengal -- 743387

Invitation

We request our senior members
to write articles for a proposed MGMI Publication
on Indian Mining History.
Any members having old photographs, booklets etc.
related to Indian Mining experiences of the past may
kindly send to the MGMI office for digital archival.

OBITUARY

Amar Kumar Mazumdar (LM – 2901, 1978-79), former Honorary Joint Editor of MGMI, passed away on 19th January 2022 at Kolkata. Late Mazumdar was born on 22nd December 1937. He postgraduated in Geology from the University of Calcutta. He was Director in Geological Survey of India. He was an active Member of the Institute with involvement in most of the activities of the Institute including the biennial Asian Mining Congress and Exhibition.

Late Mazumdar had a very amiable personality. He was very much approachable by one and all. He is remembered for his smiling personality. He will be deeply missed by his family, friends and all members of MGMI.With heartfelt grief the MGMI members wishes his soul to rest in peace in his heavenly abode. May almighty give strength to his surviving family members and to bear the lost.

Hiranmoy Niogy (LM – 416, 1953-54) expired on 15.12.2021

POLICY PERSPECTIVES ON INDIA'S POWER SECTOR

For the interview in this edition, we had a very special guest, Mr. R.V. Shahi, Former Secretary, Ministry of Power, Government of India. His tenure as the Power Secretary was extremely important in terms of the restructuring of the Indian electricity sector with the institution of the Electricity Act, 2003 and subsequent National Electricity Policy, 2005 and National Tariff Policy, 2006. Prior to this role, he served as the Chairman and Managing Director of BSES Ltd, and in key positions in the National Thermal Power Corporation Ltd. In addition, he was Chairman of World Energy Council- Indian Member Committee and Member of the Policy Group of Carbon Sequestration Leadership Forum. Currently, he is the Chairman of Energy Infratech Pvt Ltd. Mr. Shahi has been recognized for his distinguished leadership in the power sector, particularly as a Fellow of the Indian National Academy of Engineering. He is also widely published, as the author of the book "Towards Powering India" (Excel Press) and co-author of "Carbon Capture Storage and Utilization" (TERI Press). MGMI is grateful to Mr. Shahi's time and insights. The interview was conducted by a team led by Dr. Ajay Kumar Singh, Honorary Editor, MGMI and Prof. Amit Garg, Professor, IIM Ahmedabad.

Could coal coexist as a part of net zero greenhouse gas emissions in India?

It's a question of the time duration. There will be a gradual transition. As of today, we cannot wish away coal in India. In the last 5-6 years, the proportion of coal (installed capacity) has come down. Its capacity addition speed is coming down. The plant load factor of coal-based power generation has also come down due to other options. So, we will see a phenomenon now, in which 2-3 things may happen. India may have to phase out some of the very inefficient coal-based power plants, not necessarily of long age, but based on efficiency of coal utilisation. The plants whose heat rate is very high need to be phased out. We have some 30,000 to 40,000 MW capacity coal plants which are inefficient and need to be phased out in the next few years and to that extent new capacities can come, which are technologically more superior in terms of utilisation of coal. That would be a part of the transition phenomenon. The pace of coal power plant capacity addition would not be the same as we witnessed post the "Electricity Act, 2003". There was a huge response post the "Electricity Act, 2003" and coal power plant capacity addition was around 75,000 MW as compared to around 25,000 MW in a plan period. In eleventh plan period, based on the preparation that was done during the tenth five-year plan, the pace saw such huge change.

Coal and other energy sources will co-exist till 2050 or 2060 with the share of coal plant capacity as also coal based power reducing gradually. During this period or after that (2050-60), the sector will undergo major reform. There will be substantial change in the mindset of people who manage the sector, (technical as well as policymakers). The extent to which they respond to this emerging situation, will determine what will happen to the fate of the sector.

Also, it is not that we are talking about carbon emissions now only. I have been in the sector for 45 years and ever since I have been in the sector, climate change has been discussed and carbon emissions have been discussed in detail. Many things such as CDM (Clean Development Mechanism) came and they have already been discussed. Today, we are talking of COP26, but previously there have been 25 COP (Conference of Parties) meetings which have already taken place. There was the "Kyoto Protocol" also in the past. Solar has also been existing for many years. For example, California's solar power generation system was developed in the 1960's. These technologies have to become relevant in terms of commercial viability and in terms of affordability. Technology has to become affordable otherwise it will not be acceptable. The coal sector will also have to think about how to do things differently. Recently, the Government of India has announced a big program on coal gasification, coal to methanol etc. Also, they have announced the policy on commercial coal mining. They will allow some discount on the royalty that they are trying to incentivise coal to gasification to hydrogen could be a promising route. Power sector people at NTPC and others should work on developing carbon capture and utilisation technologies. It is costly, but it is a challenge for technology people that they should try to bring technology in a manner that the problem of carbon dioxide is reduced and nearly eliminated in a cost-effective manner.

Are low carbon sources of energy competitive with coal-based electricity in India?

Yes, solar energy is more than competitive, though people do make a point (and there is some weight in what they are saying) that there are some hidden costs in the solar power that we are supporting. For example: land is being made available etc. So, even if we count for that, solar and wind are more than competing. With respect to hydro, we have an issue of back loading of tariff and back loading of loan repayment. If the government sets these things right in the policy that they devise on hydro or maybe with further revision, hydro (pumped storage) could be a good option. With solar, the drawback is that it is not available in the evening and night. Hence, storage in the form of a battery would be required. But the battery technology has not come up in a big way. People are saying that it will develop in the next 5-6 years. Hence, we have compulsion for coal.

Do you think because of net zero and climate change discussions, it will be a positive wind in favour of nuclear power now?

Nuclear power is definitely acceptable. It is a carbon free power generation. As of today its share in the total capacity is about 2%. By the year 2050, if nuclear power capacity becomes even 10%, we would be very happy. It's a very tall order target. However, I don't see nuclear becoming 10% by 2050 or 5% by 2040. But if nuclear power share becomes 5% by 2040 in terms of capacity, it will be great.We may not see a sudden increase in the capacity addition for nuclear power, it will be gradual. Few days back, we had a webinar on what role nuclear power will play in the coming years, and whether it will continue to remain on the margin. In India, nuclear based power is marginalised and it has hovered around 2% of the total power generation and of late, it has gone down because other options have taken over. So, we have been concerned about this. Nuclear based power is a zero-carbon emission option, so it is one of the good options for power generation. But the cost is high and it takes a lot of time to build nuclear based power plants. However, India has had a very successful experience of operating nuclear power plants (a large number of them) and we have close to 7000 MW installed capacity.

I recall that in the year 2004-05, when I was Secretary (Power), and Dr. Anil Kakodkar was Secretary (Department of Atomic Energy), nuclear fuel availability was a major issue. At that time, nuclear power installed capacity was in the range of our 4500 MW and even for that 4500 MW, we were not having enough uranium (fuel). As a result, those days (in the first decade of this century), the generation in the existing plants was also not to its full capacity (the plant utilisation factors were low). We have our agreements in place now, and we understand that we will have adequate fuel. Also, we are working on the Fast Breeder Reactors (FBR's), where, with a little bit of contribution from uranium, the generation process generates more and more fuel. Obviously, there are a lot of issues in accelerating the capacity addition programme. There has to be a little more push and it also requires some institutional change.

For reduction of carbon dioxide, what is the potential for retrofitting supercritical and ultra supercritical power plants with carbon dioxide capture and storage?

The supercritical power plants are not being utilised to the full extent (plant load factors are less) and thus we do not get the type of benefit that we expect. As a result, supercritical plant provides only a marginal improvement in the heat rate. The thermal efficiency of subcritical plants is around 38% and for supercritical plants, it is around 41%. But retrofitting the supercritical and ultra supercritical plants with carbon capture and utilisation and/or storage (CCUS) technologies is possible but these technologies are costly as of today. The coal cess was introduced by the Government of India and if the coal cess fund is provided to the development of the CCUS technologies, then the high cost of CCUS technologies can be partially mitigated. If we load all these costs on the power tariff, I don't think people will find is acceptable. India needs power through which our industries can be competitive. We cannot make power available at high costs by loading these things. Already, we have started to install pollution control equipment such as FGD (Flue Gas Desulphurisation) into coal power plants. So, if we have to install FGD, if we have to install CCUS and yet if we don't want it from something like coal cess, (that was done earlier and which has now been merged with GST), then these things will remain just as talks. But these are issues which need to be pursued. We cannot totally say that we will not care for CCUS.

Today what we are seeing in solar is not the technology contribution of India. We are not responsible for bringing about a solar technology revolution. All that has happened in the field of solar in India is mostly (70-80%) imported technology. So, it's a challenge for all of us and I am not being critical of others, we are being critical of ourselves. The biggest energy source in India is coal with reserves around 370 billion tonnes, and hence it is our responsibility to develop the required technologies- Pre combustion and post combustion both and for CCUS. It is a challenge and opportunity for our scientists and engineers. Institutions like the Central Institute of Mining and Fuel Research Institute (CIMFR) and other CSIR labs need to come up with some technologies by which we can utilise our most abundant fuel (coal) in an environment friendly manner

What are the key challenges to solar and wind energy from the perspective of generation and transmission issues?

Solar energy is available between eight o'clock in the morning to around four or five o'clock in the evening. We have an issue that in the evening and night, it is not available. Today we are able to manage with some challenges, but if solar based capacity becomes 450,000 MW in the next 10-15 years, we do have a problem because if that much power is not available in the evening, the grid management will be a problem. So far grid management has not been a problem because we only have about 40,000 MW of solar based installed capacity today out of approximately 400,000 MW of total installed capacity. To some extent, wind acts as a backup to solar, as wind is available in the evening and night. The challenges for solar and wind is that how do we manage the grid when they are not available. To solve this issue, battery storage is being talked about at the international level and at the national level also. But as of today, battery storage is costly and hence it is not economically feasible.

We have also started talking about pumped storage in hydropower stations where we raise the height of water to create a reservoir and implement the pumped storage power projects. Many states have started studies on this. We are also talking about staggering of loads. For example, where rural areas (which have smaller and medium sized solar plants) do their irrigation during daytime rather than in the evening. Hence, load management also needs to be done. The challenges are grid management, challenges are backing up of solar and wind at the times when they are not available. The new policies should support more pumped storage based hydro projects, and it could be an answer to the storage issue.

I am associated with South Asia Group on Energy (SAGE) of RIS as its Chairman. I am also associated with the World Bank as Senior Energy Advisor. We have been discussing that we can have the advantage of hydropower from Nepal, hydropower from Bhutan and they in turn can have the advantage from us in the form of conventional power and solar power during daytime. India will moderate the pace of renewables in a manner that is possible for it to do. There could be challenges here and there but the increase in solar based capacity will definitely take place, which is good because it has proved its cost effectiveness. India has land where we can develop large solar plants either in desert areas such as Kutch or in wastelands. So solar will definitely develop and the transition away from coal will take place gradually till 2050-60. People working in the coal sector will definitely come out with new technologies.

India is also talking in terms of Hydrogen energy. Power consumption will see a very major change. Some of the sectors which have not been using power will also start to use power. For example: the transport sector will use power (electricity) in a bigger way, our kitchens will use power (electricity) in a bigger way. Hence, power consumption and demand will increase. Another challenge is in what form the generation or the supply side management will be done. In the supply side management, hydrogen energy is emerging and hydrogen to power and power to hydrogen are the options available. Also, hydrogen itself can be used as a transport and as a backup fuel. All the MNC's such as Reliance, NTPC, Adani and Tata have come out openly with committed programmes on hydrogen. Coal India is also thinking in terms of coming out with certain programmes. The Ministry of Coal has come up with the programme of coal gasification (not in the way they talked for 40 years but now in a more serious manner). Many of the things which were just being talked about are now bound to be picked up and implemented because of pressure and because of the challenge that this sector faces. We cannot write off coal, but we hope that the coal sector will be able to withstand these challenges and will occupy a different shape of its working not only as coal, but as coal to methanol and as coal to gasto Hydrogen etc.

A lot of talk is there in terms of the critical minerals and materials that will be required for the energy transition away from coal. Do you think that is a major challenge? Will we have to rely a lot on imports or is that just a minor issue?

It is a valid point which has to be looked into. Even in the 40,000 MW of solar based capacity in India, 70-80% is imported. Tata Power has been in the solar business for some time. BHEL has been in the manufacturing business since the 1950's. However, we have not spent money on technology development for the manufacture of solar modules. Only recently, we are seeing some major organisations that have come up on the solar manufacturing side, but that manufacturing is also dependent to the extent of 65 to 70% on imports. I think they all have programs to reduce imports but the imports cannot be totally ruled out and we will still have around 25-30% dependence on imports and that's not bad. It is not that import per se is bad. The question is, for solar we are dependent to the extent of 70-80% on import and it has come to the notice of the government and the government has also taken action. The Government has introduced a production linked incentive (PLI) scheme where the companies that manufacture and develop will get incentives. The government response has been quite dynamic to solve the major problems of the imports. Petroleum import in India today stands at 85%. So, if we change our transport to fuels other than petroleum largely and progressively, then we can save a lot of money there. Different programmes and schemes are in place and people are also conscious. Rapid increase of the share of solar based capacity is a good thing, but it should also be backed with development of manufacturing capacity within India. Imports cannot be eliminated, but imports will substantially be reduced. If some minerals are not available with us, we will import. If something is available within India, it can be explored.

There are multiple ways by which we can bring in environmental regulations, like carbon markets, like REC (Renewable Energy Certificates), there is also a ESCerts market which is running at 250 rupees per TOE with very low numbers, there could be SOx market there could be NOx market. In foreign countries, all markets are available as conjoined or disjoined markets. Why can't such markets coexist in India? Why should we only have one energy market and nothing beyond that?

I did not think that it is not possible or that it is not required. But I do think that the response in the past to these types of markets from outside buyers has been poor. The carbon market was made available under the CDM scheme, but it did not succeed. I think it (carbon market) should be done. There is no harm in trying it out. If it picks up, then it will definitely be good for us. I am only saying that many of the people in the west said that these things will grow, but they did not. I was the chairman of the CII (Confederation of Indian Industry) committee on CDM (Clean Development Mechanism). On one of our business trips to the USA, we did some road shows and other such things to create awareness. A lot of projects were identified, but the mechanism of CDM was made so complicated that people who started trying to put their projects, their success rate was very low. But there is absolutely no harm in trying out these things. I was also involved right from the beginning in the genesis of the Power Exchange in India and initially people were sceptical about this. It has emerged as a great success. Hence, I am not being cynical or sceptical about these kinds of markets (environmental regulations). I am only saying that in the past, such exercises have not worked well, and hence we need to be careful and design it in a manner or propagate it in a manner so that it becomes effective. Any scheme or policy that contributes to the development of a carbon free or pollution free economy, we should go ahead with it and to that extent, support in the form of different markets aiding that sort of objective will be good.

Recently, the Government of India opened up commercial coal mining to the private sector. Do you see a major impact on coal productivity or sustainability either positive or negative?

Commercial coal mining was long overdue. When I was part of the leadership group responsible for bringing in the "Electricity Act, 2003", before it came about, we had a lot of resistance. I used to talk with the Chief Ministers of various states, the legislators, the politicians, technocrats, media people and before passing of the bill in the Parliament, we had a lot of resistance. When it was enacted in Parliament, then again I went on sort of a road show throughout the country to convey the advantage of various provisions of this Act and at that time my expectation was that the "Coal Act" would also come. At that time, the Coal Bill was also pending in the Parliament and the Coal bill was for the opening up of the coal sector. Definitely I support this (commercial coal mining), but it has come 15-20 years later. India's power sector is so much dependent on coal just as the coal sector is so much dependent on power. The Electricity Act will be fully effective only when the Coal Act also comes into existence and implementation. I have been a strong supporter of reforms in the coal sector and also a critic of the delay that has happened in the introduction and implementation of these reforms.

If we look at any sector in India, whether it be civil aviation sector, telecom sector, automobile sector, the benefit to consumers has happened only when we opened up the sector. If we keep it as a closed door shop with few people having licences then it does not benefit the consumers. It's not the question of criticising the people in the coal sector or power sector. Power sector itself has remained a victim of this prior to 2003. Today, after the successful implementation of the "Electricity Act, 2003" and after 18 years, we are not talking of deficit, we are talking about how to manage the surplus. I think it (commercial coal mining) will have lots of benefits and productivity will be improved. Sometimes when we talk to individuals in the sector, they start feeling that they are being criticised, but that's not the issue. Even though I was working in the power sector, I was a critic of it (power sector) as well, and I was one of the key players responsible for opening it up.

What is the possibility of reemployment of skilled and unskilled workers currently in the thermal power plants to renewable plants?

There is a good possibility, they are all competent people. The renewable power plants require less manpower. It is not the question of the thermal sector alone. About 7-8 years back, a very good research paper came out that stated that in the next 10-15 years, 70% of the people working in industry will become redundant, unless they upgrade their skills. And I remember quoting the conclusion of the paper, in a national seminar on human resource development and one of the points I was pursuing was that this is a study which I believe is on the right track. It may not happen in 10 years, it might happen in 15 years, but it will happen. Unless we change our own skills, we all will become redundant. What will happen when the automobile sector undergoes changes from today's liquid fuel to electricity. We do not have even 10% of the existing components now in the electric vehicle. Hence, the entire automobile industry with so many skilled people will have to learn new skills in order to stay relevant or employable. This question can be generalised for most of the sectors.

What are some of the policy reforms you would wish to see in terms of Indian regional power markets?

For the last 10 years I have been Senior Energy Advisor to the World Bank (part time) and I am exactly doing that -working on policy reforms, regulatory issues, creating cross border transmission connectivity etc., with the involvement of power secretaries of different countries in South Asia. We are having many meetings and trying to create consensus in Nepal, in Bangladesh, in Bhutan, in Sri Lanka, in other countries, even in Pakistan. It is a tough task for us to create regional interconnections of transmission. The resources are located in different parts of South Asia. For example, there is around 200,000 MW of hydropower potential in Nepal, about 30,000 MW of hydropower potential in Bhutan etc. They all have to be connected through transmission interconnections and power system developments should be looked upon in a holistic manner for South Asia. That will benefit everybody because maybe when we (India) have huge solar, we can export and when we have huge wind power in Sri Lanka, we can import also. This is a subject which I have been pursuing and also achieved some degree of success. In the past seven years, the power trade amongst South Asia in the BBIN (Bangladesh, Bhutan, India and Nepal) region has increased threefold from 7 billion units to about 20 billion units. Things are moving in the right direction; all governments are conscious of this and we would see a more vibrant and more enlarged power market in South Asia in the years to come.

At the moment, they are talking of East Asia and Southeast Asia. But you may have heard our honourable Prime Minister Shri Narendra Modi Ji saying "One Sun, One World, One Grid". This particular slogan also will become a reality. It will take years, but it will become a reality. He is the one who has introduced the concept of "International Solar Alliance" and that is going ahead very well. We are talking of South Asia getting connected with Southeast Asia. In the case of Sri Lanka, all of us had been trying. Even when I was Secretary, Ministry of Power, I tried about this. But the Transmission through the sea in between has been a challenge. Power Grid has found a solution that we can even do overhead transmission from India to Sri Lanka. The sun never sets anywhere in the world at the same point, So, even if the sun sets at a particular location, we can have the grid to transfer the power.

Symptoms of the coronavirus disease?

The virus can cause a range of symptoms, ranging from mild illness to pneumonia.
Symptoms of the disease are fever, cough, sore throat and headaches.
In severe cases difficulty in breathing and deaths can occur.

Attention Branches

Branches are requested to send the list of the members of the
Executive Committee with their Addresses, Telephone Numbers, and e-mail IDs
for maintaining record at MGMI Headquarters.
They may also activate their Branches and send
Reports for inclusion in the News Journal.

Perspective piece

HISTORY OF COAL MINING IN INDIA

Virendra K. Arora*

Introduction

Production and availability of coal has now become a parameter of the country's progress. We now have well defined coalfields in West Bengal, Bihar, Jharkhand, Odisha, Chattisgarh, Madhya Pradesh and North East, which contribute to a total production of 550 MMT per annum. Who could have imagined that coal mining in India had such a humble beginning with a number of Indian and British entrepreneurs investing precious capitals to produce and transport coal over long distances to make it available to the industry? It is sometimes a good move to acknowledge the initiative and entrepreneurship of the people who took serious risks to develop the coal mines and the areas. Credit also goes to an excellent crop of indigenous mining engineers who made it possible and then the massive contribution of the railways to lay out the Railway lines in the coalfields and to make it possible to bring coal for use to the industry situated in Bengal, and later to upcountry as far away as Uttar Pradesh, Delhi and Punjab. Everyone associated with the coal industry of that time needs to be acknowledged and appreciated for the efforts of millions of persons who made it possible. This article will trace the history of those efforts and compile some of the great work done by the pioneers in this field.

The process of chemical formation of coal in the womb of mother earth, as found out by researches, appears to be somewhat interesting. It is stated that vast areas of trees and jungles were uprooted and swept down, perhaps several million years ago, as a result of abnormally large storms, floods, earthquakes, avalanches or near deluge. The vegetable debris pressed for ages under huge accumulation of silt and sand converted them through natural and chemical action into lignite, coal, bituminous and anthracites. It is not, however, known who first discovered coal so formed under the mother earth.

Coal industry: the oldest

The coal industry is admittedly the oldest amongst all industrial ventures in India. It had its birth 81 years before the first mile of railway track was brought into commission by the East Indian Railway in 1855. The first pound of Indian tea was brought into Calcutta in 1838, the first Cotton Textile plant was set up in Bombay in the mid-sixties and first Jute Mill (Clive Jute) was established near Calcutta in 1873, the first Iron Foundry (Bengal Iron Company) was started in 1874 and the first Paper Mill (Bengal Paper Mill) went into production in 1891.

History of the Indian coal industry

No authentic record of the existence of coal could be available in India before 1774. A view has, however, been expressed in some quarters that the name Angarpathra is derived from the Sanskrit AngarPathar (stone of charcoal) and other names like Barakar (a big mine), Kalipahari (a black hillock) and Kankanee indicate that coal and its uses were known in India several centuries ago.

*Chief Mentor, Karam Chand Thapar & Bros. (Coal Sales) Ltd., Kolkata, India. E-mail: vkarora@kctgroup.com

Looking back to the early history of the Coal industry in India, Bengal assumes a pride of place in making the first venture to exploit coal in the Ranigunj coalfield in the year 1774. Between 1839 and 1846, however, the output of Indian coal rose from 36,000 tons to 91,000 tons and the rise was in large part due to the formation in 1843 of the Bengal Coal Company on the foundations of an earlier venture to which were added other small mining leases in the neighbourhood. The progress was facilitated by the systematic geological survey of the field which was undertaken in 1845-46 and again in 1858-60 and also by the installation of the first mile of railway track by the East Indian Railway in 1855 and by 1860 nearly 50 collieries produced about 282,000 tons of coal per annum in the Ranigunj area.

During the 19th century, the Ranigunj field was the most important producer of coal in India; out of an overall production of 6.12 million tons in 1900, the field raised 2.55 million tones. The importance of Jharia field which opened in 1893, however, was becoming increasingly apparent by the end of the century and with the development of the additional Railway facilities, the output of the field grew rapidly and by 1906 exceeded that of the Ranigunj field.

The beginning of coal mining in the Central Province dates from the year 1862 and in the Rewa State from 1884. The Singareni field in the Hyderabad State was discovered in 1872 and went into production some 15 years later. Appreciable developments also took place in Upper Assam from 1881 and in Baluchistan and in the Punjab in the last decade of the 19th century.

At the beginning of the last century, coal production in India had reached a total of about 6 million tons, of which nearly 5 million tons were obtained from the Raniganj, Jharia and Giridih fields. Further progress was made during the years preceding the First World War and a number of new fields (Bokaro, Pench Valley and Chanda Valley) were opened so that by 1914 the total Indian output had risen to nearly 16.5 million tons per annum. The Jharia and Raniganj fields, with output of 9 million tonnes and nearly 6 million tonnes respectively, however, continued to dominate the scene. In this period of rapid growth, by far the greater portion of the output was used for steam raising by the railways and industry. But the development of the Jharia field, with its rich coking coal, may have provided some encouragement to the iron industry. The establishment of the Tata Iron & Steel Company at Jamshedpur in 1911 was a very important step towards proper utilization of the coking coal of Jharia.

The increased demand for coal during the 1914-18 war gave a further impetus to the coal industry. There was a considerable increase in industrial activity throughout the country and the requirements of the railways and, in the early years, coal exports also increased appreciably. By the end of the war, the output had increased to nearly 21 million tonnes per annum, of which the share of the Jharia and Ranigunj fields was about 11 million tonnes and 6½ million tonnes respectively.

Subsequently, there was a short-lived period of increasing production from 1927 to 1930. Many of the lost coal markets had been recaptured and there was also an appreciable revival of industrial activity. Equally, the continuing fall in prices made coal a more attractive proposition as a source of industrial power. But soon the economic depression of 1930 and of the subsequent years, aided and abetted by the fundamental weakness of the Indian coal industry, exposed the industry to the most serious economic blizzard in its history.

⏩ Railways' demand

The railway track mileage increased from 1581 miles in 1861 to 28,084 miles in 1905. Surprisingly, however, even in 1907 the Railways' consumption of Indian coal was no more than 3.5 million tonnes. One explanation of this relatively low off take was the use of wood fuel by the Railways. Its consumption being as high as 4.9 lac tonnes in 1903 which dropped, however, to 1.6 lac tonnes in 1908. Still another reason why the railway demand for Indian coal did not grow in the nineteenth century was its partial dependence on imported British coal.

⏩ Exports

India's coal industry established an export record of 5.4 lac tonnes in 1900-01 when the total production hardly exceeded 6.1 million tones. In 1906, however, the export rose to over a million tonnes and for almost a decade ending in 1915 the export stood at an average level of 0.77 million tonnes a year. In 1920, however, all previous records were broken and export rose to 1.22 million tonnes falling, however, next year to 0.27 million tonnes. Then for a year or two Indian coal practically lost its overseas market. By 1926 the export was revived at 6 lac tonnes which after a rise to 7 lac tonnes in 1929 went on diminishing to below 2 lac tonnes in 1936. From the very next year an opposite trend set in and by 1940 the export stood at 2.1 million tonnes but again dwindled to 1 lac tonnes in 1944. The most dramatic episode in the history of coal export from India was recorded in 1951 and 1952 when the tonnages reached 2.8 and 3.3 million tonnes respectively. The exports were mainly through the shipping routes to Hongkong, Ceylon, Burma and was tightly controlled by British companies, and Thapars (KCT) were the first to break the monopoly by offering competitive rates. Some quantities, interestingly were also railed to Pakistan by all rail route.

⏩ Imports

Even as early as 1857-58, that is to say, coinciding with the introduction of Railways in this country when the annual output of Indian coal was no more than 2,93,000 tonnes there was a record import of coal in that year to the extent of 92,000 tonnes, with still higher import of 8 lac tonnes of British coal in 1881. In 1901 the import was still recorded at 1,42,000 tonnes.

⏩ Early methods of mining

The earliest mining of coal in India was confined to quarrying the outcrops of thick seams, the quarries being extended to the dip until the amount of over-burden made further exploitation uneconomical. Owing to the shallowness of a large number of seams and their closeness to each other, quarrying was the most favorable form of coal mining. All they had to do was to dig for a few feet, remove the earth and rocks to get the coal seam. As they proceeded, the seam went deeper and the stage was reached when it was no longer possible to dig and remove a comparatively large mass of earth, stone and rock to remove every ton of coal. At this stage, coal had to be worked by inclines. An element of mechanisation became necessary. The gin came into existence and coal was drawn by a rope wound round a gin turned by woman labourers. Later, steam haulages came into existence. When the distance of haulage became longer and the seams had to be worked deeper down, working by shafts and pits came into being and greater mechanization of haulages etc. became necessary. To work a quarry did not require much capital or skill and technical knowledge. But to sink a deep shaft, capital was required and mining became not a matter of merely cutting coal but a specialized technical process of engineering and several British experts came over to the country. Mr S Heslop, in his Presidential Address – MGMI Transactions Volume V, Part I, 1910, observed that "Quarrying generally is a most ruinous system for a colliery causing as it does constant and heavy inlets of water entailing permanent extra cost for pumping as long as the colliery or property lasts. Evidence of this can be seen in long lines of quarries along the outcrop of valuable seams. Extensive areas have been lost by thrust or by fire in the absence of adequate provision of isolation."

The next stage began when the more enterprising owners realised the limitations of quarry working, and began to sink inclines and shallow pits, and introduce winding and hauling arrangements. The head-gears consisted of two tall brick pillars supporting a wooden cross-bar and pulley, while the winding machine, known as a gin, was a vertical drum turned by animals or women, the coal being raised at the end of a hempen rope in a large basket or bucket and water in a leather container. The area worked from each shaft was limited by the distance coal and water could be carried economically by women from the working places, a new shaft being sunk when this limit had been reached.

⏩ Early history of perennial transport bottleneck

The earliest exploitation of coal for commercial purposes dates back to 1774 when Messrs. Summer and Heatly were granted permission by Government to raise and dispatch coal from a large area at Sitarampur in the Raniganj field. But it was a tragic irony, as revealed in the Report of the Coal Mining Committee, 1937, that the work was abandoned after the first consignment of 2,500 maunds of coal was transported to Calcutta by river in 1775 and found inferior to English coal. No further prospecting was done until 1814 when Mr Rupert Jones was deputed by Government to examine the area. With Government assistance, he opened mines at Egara village near Raniganj which were taken over and worked until 1835 by Messrs. Alexander & Co., and later by Messrs. Carr, Tagore & Co., both of Calcutta. In 1824, Messrs. Jessop & Co., opened mines at Damulia and Narainpur and worked them until 1839 when they were transferred to Messrs. Gilmore, Homfray& Co. In 1843, Messrs. Gilmore, Homfray& Co. and Messrs. Carr, Tagore & Co. amalgamated to form the Bengal Coal Co. which was later the most important coal-producing company in India. Messrs. Apcar & Co. were also among the pioneers in the Raniganj fields and were the first to put down shafts near Sitarampur to work the Dishergarh seam.

In those days, coal from the mine-head used to be brought down to Calcutta by the boats plying along the Damodar. There are old records which show that the Calcutta authorities of the Company sent in 1818 as many as 900 boats to carry coal from Panchet. But, unfortunately, only 200 out of this convoy could get near the mines. River-borne coal then used to sell at Calcutta at Rs. 15/- per ton against British coal costing a rupee less landed at Bombay.

Development was slow owing to the lack of transport facilities, rivers the only means of conveying coal to the Calcutta market being shallow and unsafe for boats to ply during monsoons on the Damodar. The opening of the East Indian Railway upto Raniganj in 1855 was followed by more rapid development and the increasing demand for coal for railway and industrial purposes resulted in a steady increase of output. The extension of the East Indian Railway to Barakar in 1865 soon brought in a further impetus. In 1871, the East Indian Railway acquired extensive coal bearing areas at Giridih and opened mines there to meet their increasing coal requirements.

Mr. Treharnee Rhees who made a study of the Jharia and Raniganj coalfields reported interalia in 1919 that the regular supply of sufficient wagons was of considerable importance to the coal industry. The number of wagons supplied to the collieries in the Jharia and Raniganj coalfields were totally inadequate and there was loss of coal on this score. He added 'coal being so largely the foundation of the future industrial welfare of this country, it is imperative that proper supplies of railway wagons for coal traffic should be provided without delay, for until this is done much of the waste that is now taking place on the surface of the collieries cannot be prevented'.

⏩ Early history of coal prices

Prior to statutory control over coal prices which was introduced for the first time in 1944, the prices of coal, like those of any other commodity, were governed by the normal forces of supply and demand and contemporary financial and economic circumstances. As a result, prices fluctuated widely over a period of about twenty-five years. Thus, in 1922, the prices of coal which stood on an average, at Rs. 8/- per ton, declined to a low level at Rs. 2.80 per ton. Price then gradually rose to Rs. 4.70 in 1942, after which again it registered a steep increase to Rs. 11.70 in 1943. Production rose and fell sharply as a result of these price variations. Many collieries unable to stand competition closed down, whilst others survived with slaughter exploitation.

The Second World War years of 1942-45 brought about a coal famine of unparalleled proportion. There was a sudden steep drop in production amounting to over four million tons in 1943 over the raisings of the previous year. Prices naturally rocketed sky high. Coal was therefore brought under control in 1944 to arrest the decline and boost production. The rates quoted by the Calcutta Selected Coal Association, with due allowance for current wage costs, were made the basis of the controlled prices, and the prices fixed secured an adequate margin of profit to the collieries. These were enforced as 'fixed prices', and not 'ceiling prices' to prevent unhealthy competition, and consequent wasteful forms of mining. Initially, they were fixed under three sizes and six grades, but subsequently revised to two sizes with an increased differential between the sizes. The reduction of sizes from three to two was to check the increasing tendency to dispatch all coal as 'run-of-mine' which gave the collieries the largest profits. In 1946 following labour discontent, wages were increased on the basis of a report of a Conciliation Board, and as promised to the industry, a Committee was appointed to examine the costs of production of a few representative mines and to suggest revised prices for coal. Prices were revised accordingly in July, 1947.

⏩ Second World War

The most notable event in the year 1939 was the outbreak of war in Europe which had considerable repercussion on the coal industry. A legislation was introduced on stowing in the coal mines and the Coal Mines Stowing Board commenced functioning at the end of the year 1939.

⏩ Memorable visit of Lord Linlithgow, Viceroy of India to the Jharia coalfield

It will be revelation to many that Lord Linlithgow, the then Viceroy and Governor-General of India, paid a visit on 14.12.1940 to the Jharia coalfields where he inspected the various safety measures that were in operation on the fire areas. He visited the local fire area where sand-blanketing operation was being carried on by the Stowing Board. The Viceroy and his party went round the area on foot and proceeded to see the Kusunda fire. The following relevant extract of the Viceroy's speech delivered at the luncheon meeting with the members of the coal trade at the Railway Institute, Dhanbad on 14.12.40 may be of interest to the readers.

'The coal mining industry of India dates back to the time of Warren Hastings. Permission to work coal mines in Bengal was first granted in 1774 and the important total of about 100 tons of coal were delivered to Government in 1775. For various reasons this adventure did not succeed. No further attempt was made for nearly 40 years until 1814 when mining was commenced in Raniganj. The first systematic geological survey of the field was made during 1845-46 and a more detailed examination was made during 1858 and 1860, by which time some 50 collieries were already in existence. The development since 1868 had been rapid. In 1868, the output of the coal mines in India was only about 500,000 tons. The present output exceeds 28,000,000 tons annually.

"During these years, with the growth of public consciousness in such matters there has also been a gradual but marked development in the measures taken for the safety of those who work underground.

"This morning I have seen some of the work which is being financed by the Coal Mines Stowing Board set up under this Act. In the course of the last few years, the fires in the two areas which I have visited have resulted in several million tons of coal being burnt underground, and they have also threatened the safety of a large number of coal mines in the district."

What is the moral of this memorable visit of the then highest administrative authority of India which moved him from the Viceroy's lodge to the remote Jharia coalfield? Coal was then truly realised as the most important basic industry without the progressive development of which the wheels of all other industries in the country would be stalemated.

⏩ Leading mineowners and mining engineers who brought the change

Till 1947, most of the mines belonged to the British companies who had imported British mining engineers who were manning all the important positions. Employment of Indians were confined to the lower orders like surveyors, mining sardars, over men etc. Indian School of Mines, fashioned along the lines of Royal School of Mines became an important Institution whose students worked very hard to excel themselves in the science and art of mining. Subsequently, these mining engineers set very high standards for themselves and occupied all the senior positions in the British and Indian companies. While persons like Grewal and Jabbi went on to become the Chief Inspector in the Inspectorate of Mines, there were heroes like J R Sharma in KCT, Dhadwal in Equitable Coal, Vashisth in Bird & Co., B H Engineer and R N Sharma in Tatas and lot of other personalities who had created an image larger than life. Of course, the list is not complete as I may have missed a large number of persons but we would like to pay a tribute to all of them who had the vision and the capacity to turn these mining companies into Institutions well respected by all. These mines were able to produce about 70 MMT when the nationsalisation of coal mines took place. Thereafter, overnight there was an increase in production by working the lower grade seams which were not considered viable earlier. The story has not ended as the country is now poised to increase its production from 700 MMT to 1000 MMT with another 500 MMT proposed from captive and commercial blocks. The ambitious levels of production would help to run the wheels of the industry, fire the boilers which are going to produce power and also provide much needed coal and coke for steel industry. And most important of all, Indian mines and not the Indonesian and South African mines will meet the needs of the country.

DRILLING AND BLASTING BASED HARD ROOF MANAGEMENT DURING UNDERGROUND COAL MINING

Arvind K. Mishra[1*], Awadh K. Mishra[2], Manmohan Rout[2] and Romil Mishra[1]

Abstract

Continuous mining is a most popular mining method in USA and Europe. Nearly 60% of coal mining in the West is through continuous mining process in underground mines. Continuous miner technology, which has of latebeen introduced in India, is able to extract 65–74% of the coal in a panel depending upon the seam parameters as against 50–60% by semi-mechanized Bord and Pillar system of mining with SDL/LHDs, which is popular in India. The rate of extraction by the continuous miner being high is able to create larger panels, and thus, reduces the coal loss in barrier pillars. Presently, efforts are being made to introduce this technology on a larger scale in underground coal mines of Coal India Limited in India. When the first depillaring panel started its operation in November 2009 at Jhanjra, the panel was stopped after extraction of nine pillars by the Indian regulatory body (Directorate General of Mines Safety, DGMS, GOI) as the geological conditions of the overlying strata gave trouble of non-caving. The anticipated roof fall did not take place. The exposed roof area reached 10,400m^2, which was equivalent to 46,800m^3 of the void volume posing a threat of air blast. Since all the attempts to induce caving by underground blasting failed, an attempt was made from surface to induce the caving by distress blasting. This paper deals with the design of blasting parameters and execution of destress blasting keeping in view the safety and sentiments of nearby villages.

Keywords : Induced caving; Rock fracturing; Blasting parameters; Surface caving; Cavability; Destress blasting.

Introduction

Jhanjra colliery of Eastern Coalfields Limited (ECL) is situated in the North-Eastern side of Raniganj Coalfield. The Grand Trunk Road of National Highway-2 is about 15 km south of the Jhanjra Block and Durgapur Township is about 15 km by road to south-east of the area (Fig.1).

Jhanjra block covering an area of about 11.50 sq.km is surrounded by a number of faults with throws varying from 15 to 110m. Jhanjra block has eight extract able seams with a total reserve of about 200 million tonnes (Mt). The block has been divided into six sectors namely Sector A, B, C, D, E and F. In sectors 'C' and 'D', located towards the northern half of the Jhanjra fault-bounded block in R-VI seam, Jhanjra Colliery, the development of coal seam has been carried out by continuous miner and associated accessories. After completion of development of the first continuous miner panel (CM1), its depillaring started adopting splitting and slicing method.

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⏩ Prevailing Condition at the Mine

It had been proposed to depillar the already developed panel (CM1) as well as the developing panel (CM2) using continuous miner. The quantitative and qualitative nature of the abutment loading is highly dependent upon the properties of the overlying rock strata [1–6]. Here, the characteristic of overlying strata is represented by *Cavability Index [7]. However, delay in natural roof caving in the depillaring panel CM1 has been anticipated due to the presence of hard-rock strata within the immediate roof of R-VI seam, which has Cavability Index of more than 5,000. It was presumed that the coal ribs (Rib- the side of a pillar or the wall of an entry.) as designed earlier would eventually collapse (as the designed factor of safety was 0.5) and provide no resistance to the caving. However, the natural caving had been delayed, as the sizes of ribs or stooks left might have caused this. The working had been made unsafe due to overhanging roof and was stopped by the management of mine and Inspector of Mines, Directorate General of Mines Safety, Government of India.

Fig. 1 : Location map of mine

Cavability Index** --The Cavability Index,'I***' is directly proportional to the intact rock compressive strength, bed thickness and average core length. This index can be represented thus:

$$I = \sigma_c \frac{t^{0.5}}{5} L^n$$

where ***I***, is Cavability Index, σ_c is intact rock compressive strength (kg/cm^2), ***t*** is bed thickness (m), ***L*** is average core length (cm) and ***n*** is 1.0 for RQD **<**80 and 1.2 for RQD **>**80.

The roof categorization can be done on the basis of the Cavability Index:

Category of roof	Cavability Index
Category-I: Easily Cavable	Up to 2,000
Category-II: Moderate Cavable roof	Above 2,000–5,000
Category-III: Roof Cavable with difficulty	Above 5,000–10,000
Category-IV: Cavable with substantial difficulty	Above 10,000–14,000
Category-V: Cavable with extreme difficulty	Above 14,000

⏩ Management of Competent Roof Rock

The caving of a competent overlying roof can be managed by a controlled pre-fracturing or fracturing during workings [8]. The fracturing can be achieved by high-pressure water jets or explosives. Both of these approaches are applied to pre-fracture the competent roof strata during longwall mining [9–12]. Long hole drilling and blasting can be used to manage the caving of a competent overlying roof of a deep coal seam. Here, all these operations are to be carried out from the working horizon of the seam only. A good approach for this purpose is described by Konicek [4,5,10,13]. Here, upward (inclined) drilling of around 100 m long holes in the roof, across the massive strata, is done from the gate roads of a longwall face. Charging of these holes is done pneumatically, and nearly 3,000–5,000 kg of rock-blasting explosives is blasted at a time. However, this is difficult to be practised in an Indian coal mine as that amount of explosive handling is not permitted underground.

⏩ Geo-Mining Parameters of the Depillaring Panel

Within the depillaring area using continuous miner, depth of cover from surface to the R-VI seam varied between 110 and 140 m. The development works had been carried out up to the full seam thickness using a continuous miner. The average pillar size was 26 m x 26 m, corner to corner. The height of the gallery varied between 4.0 m and 4.5 m, whereas the average width of the gallery was 6.0 m. The gradient of the seam was 1 in 16. The average width of the panel was 100 m (3 pillars width), whereas the length of the depillaring panel would be sectionalized as per the incubation period, rate of practical retreat, ventilation parameters etc. The average uniaxial compressive strength of coal (R-VI seam) was25.82 MPa. The overlying roof rock of R-VI consisted of medium to fine-grained sandstone. As per the report submitted by Roy et al. [14], three beds were identified with the likelihood of difficulty in caving during depillaring, where the Cavability Index was more than 5,000 in the immediate roof, which was considered up to 20 m from the coal seam. It was assumed that the overlying roof rock will be destressed if the immediate roof rock fails (Table 1).

Table 1 Classification of R-VI coal seam roof based on cavability index

From the roof level of R-VI seam upward	Average core length (*L*) in cm	Bed thickness (*t*) in m	Cavability Index (*I*)	RQD	Remarks
Bed-I	43.0	1.40	5,222.66	92.14	Roof cavable with difficulty
Bed-II	78.0	0.88	24,466.54	88.64	Cavable with extreme difficulty
Bed-III	37.8	1.94	9,371.16	97.42	Roof cavable with difficulty

Bed-I is laying immediately above the R-VI seam and the average thickness of this bed is 1.40 m. The Cavability Index of Bed-I is 5,222.66, which comes under the category of 'roof cavable with difficulty'. Bed-II is located at 4.68 m height from the coal seam roof and the average thickness of this bed is 0.88 m. The Cavability Index of bed-II is 24,466.54, which is under the category of 'roof cavable with extreme difficulty'. Bed-III is located at a height of 7.30 m from the roof of R-VI seam (Fig. 2).

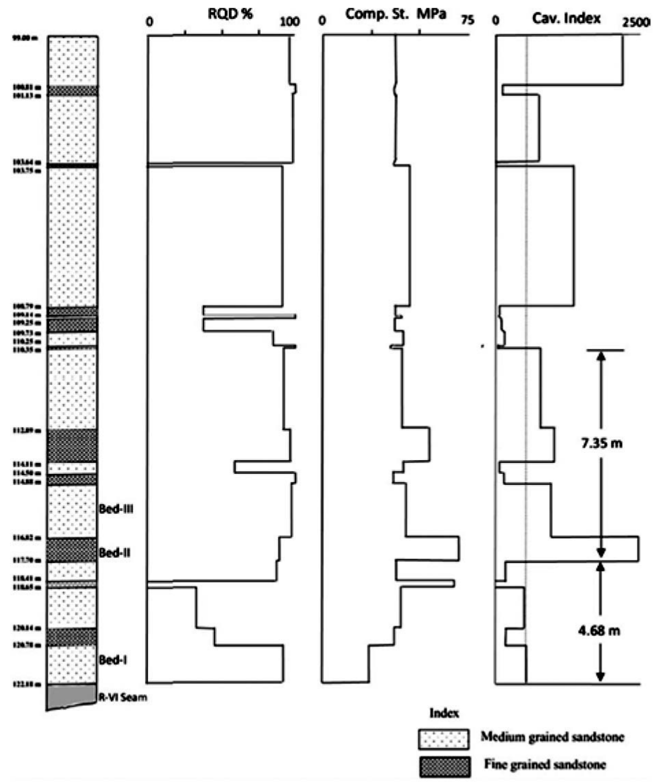

Fig. 2 Strata lithology with RQD, Compressive strength and cavability index

The presence of these three beds might have caused a delay in the natural roof fall in the depillaring panel. As per the technical report submitted by Roy et al. [14], the first main fall in the CM1 panel was expected after the area of roof exposure reached about 6,748 m^2. Therefore, induced caving by blasting would be necessary to reduce the stress abutment in the working areas as well as to mitigate the impact of air blast if regular natural roof fall does not take place during the initial phase of depillaring (Fig. 3). For effective induced blasting, it was essential to fracture the main roof rock that delayed the natural caving of an overhanging roof. In the depillaring panel at Jhanjra Project with a continuous miner (CM1), the three beds which had been found with higher values of Cavability Index were located within the height of 7.30 m from the immediate roof of the coal seam. Therefore, these three beds have to be fractured/broken by destress blasting to facilitate effective roof fall if the overhanging roof does not fall by its own weight after the depillaring. Initially, the induced blasting was tried out from the underground depillaring workings (Fig. 4).

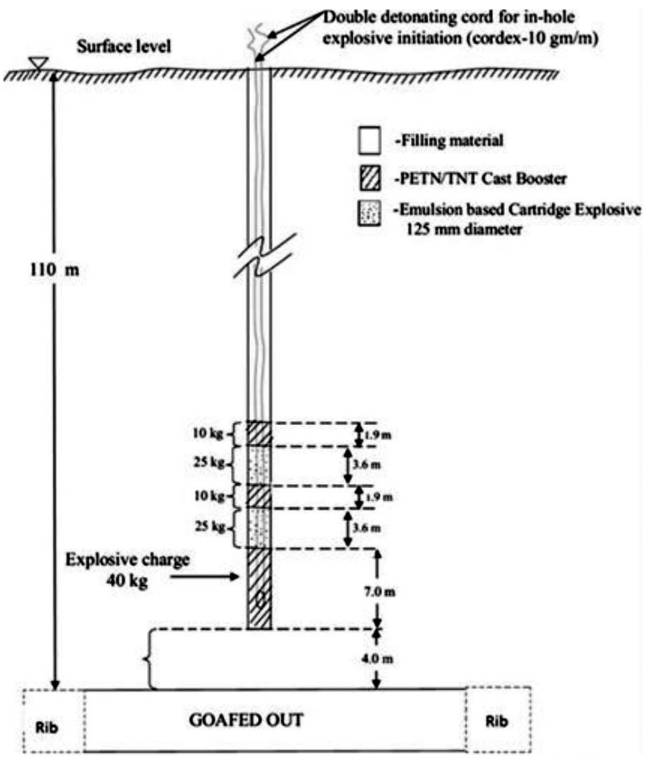

Fig. 3 Section of the blasthole showing charging pattern

The blast holes were drilled by jumbo drill machine of 42 mm diameter. The holes were drilled in fan pattern from the breaker line of next working pillar, inclined towards the goaf with 30° up from horizontal (Fig. 5). The length of hole was 15 m. The collar spacing and toe-spacing had been kept as 0.5 and 3.5 m, respectively. The blast design parameters are presented in Table 2. Each ring consisted of five holes. The packaged explosives of permitted category P-3 of 32 mm diameter were used. Low grammage (3.6 g of PETN per meter) detonating cord was used for initiating the explosive column.

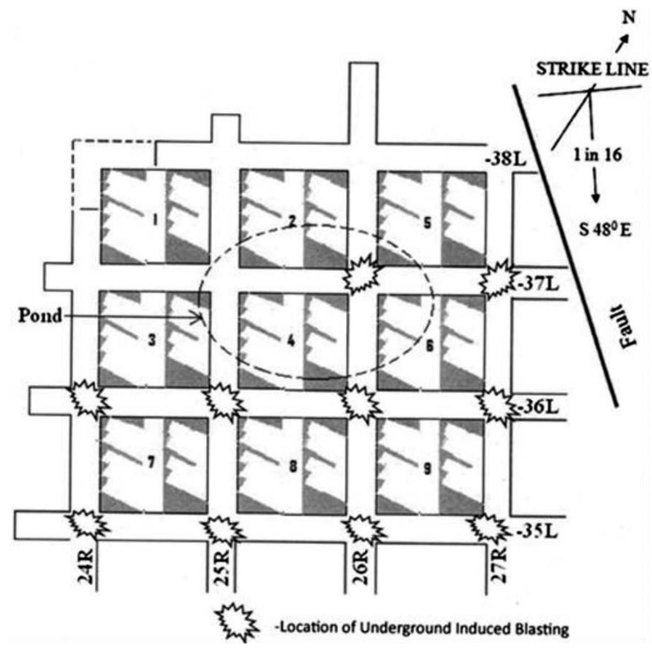

Fig. 4 Plan of panel (CM-1) with location of underground induced blasting after extraction of pillars

Inside fire-resistant polyvinyl chloride (PVC) pipe used for ring hole blasting in blasting gallery method of mining. The charging pattern of holes is shown in Fig. 6. Copper coated, the instantaneous electric detonator was used for each hole to initiate the detonating cord and explosive column. Unfortunately, destress blasting from underground could not induce the caving. Once again, an attempt of induced caving from underground could not be taken up as the working had been rendered unsafe due to the previous attempt of blasting to induce caving. Therefore, it was decided to cave the roof rock from the surface above the depillared panel CM1. Based on the discussions made with the DGMS officials, Sitarampur Area, Mine Management of Jhanjra Colliery, ECL, it was decided that induced blasting would beconducted from the surface as the roof could not cave even after extraction of nine pillars in the panel as shown in Fig. 7. The pillars were initially split along dip rise and then were sliced, leaving rib pillars as presented in Fig. 7.

Table 2 Blast design parameters for induced blasting from underground workings

Blast design parameters	
Blast hole diameter	42 mm
Number of holes per ring	5
Depth of hole	15 m
Swing angle (measured from the vertical plane along the axis of the gallery)	38°, 48°, 58°, 68° and 78°
Burden	
Front-burden	1.35–1.75 m
Toe-burden	7.00 m
Spacing of holes	
Collar spacing	0.50 m
Toe-burden	3.00 m
Explosive charge length	8.00 and 10.00 m
Explosive charge per hole	7.40 and 9.25 kg
Total explosive charge per ring	40.70 kg

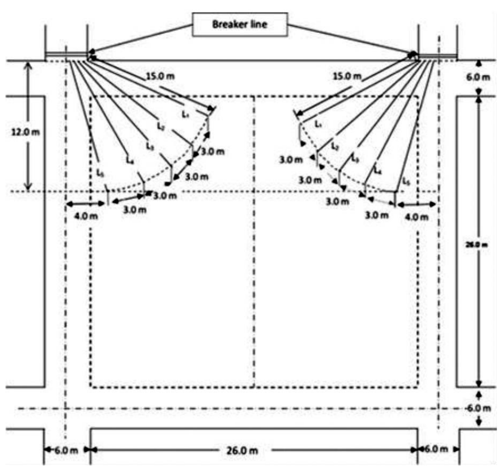

Figure 5 Drilling pattern for induced blasting from underground

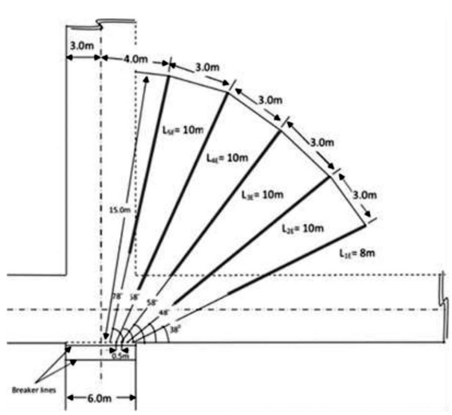

Figure 6 Charging pattern for induced blasting from underground

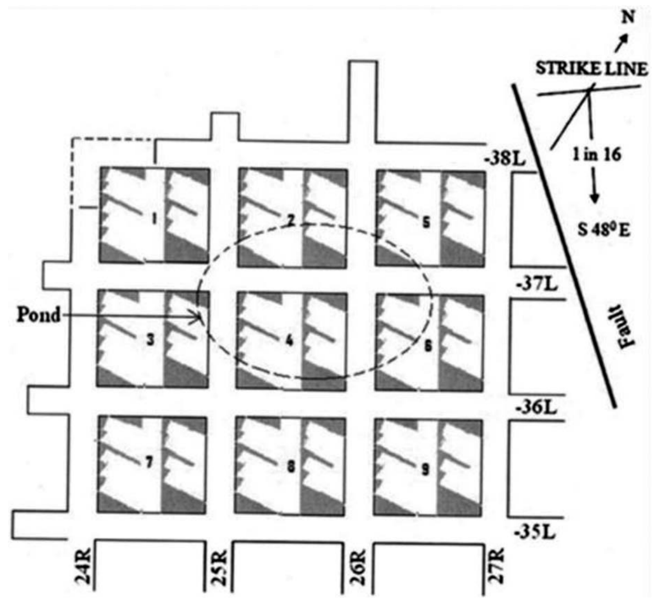

Fig. 7 Plan of the panel (CM-1) after extraction of pillars

The sequence of extraction is shown with pillar numbers in the figure. The extraction started away from the fault and proceeded towards the fault. The drilling and charging pattern of holes for induced blasting from the surface at the depillaring panel in the Jhanjra Project using continuous miner (CM1) are given in Table 3 and Fig. 8. Holes were drilled inline pattern, as shown in Fig. 8 above the panel. The pattern followed a semi-circle as straight-line drilling could not be performed due to the presence of a pond on the surface.

Table 3 Summary of blast design

Sl. no.	Design parameters	Values
1	Hole diameter	150 mm (6 in.)
2	Total hole depth (from the surface)	110–111 m
3	Parting between hole bottom and roof of the gallery	4.0 m
4	Spacing of holes	6.5 m
5	Bottom explosive charge length	7.0 m
6	Total explosive charge length	18.0m
7	Quantity of explosive for bottom charge	40 kg
8	Total explosive charge per hole	110 kg
9	Total no. of holes	16
10	Total explosive charge	1,760 kg
11	Maximum charge per delay	220 kg

⏩ Problems encountered during execution ofthe project

The following problems were encountered during the execution of thedestress blasting at the above-mentioned site.

- There was a pond on the surface of the CM1 panel, which created a lot of problems in drilling blast holes on the surface.
- There was a problem of desensitization of emulsion explosives at a depth of 106 m.
- Explosive manufacturers refused to provide a guarantee for the detonation of emulsion explosives on account of hydro-static pressure at a depth of 106 m.
- The villagers expressed concern about surface blasting, which they thought would damage their houses.
- There had been an associated risk of blown through shots in underground workings while conducting the destress blasting.
- There was no guideline to handle the misfire if it occurred at a depth of 106 m.

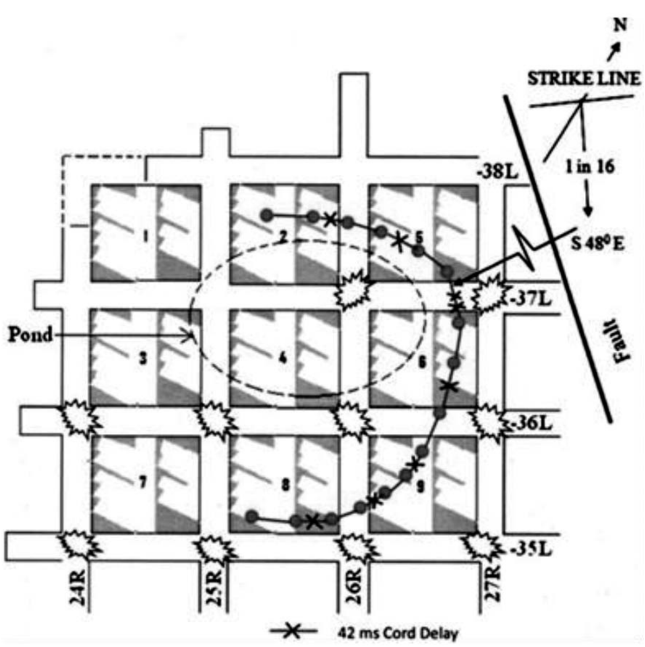

Fig. 8 Plan showing the drilling pattern and firing sequence above panel CM-1 OFDMA uplink system

⏩ Methodology Adopted to Overcome Issues

Single-hole firing of cartridge emulsion explosive was tried, and continuous in-hole velocity of detonation (VOD) was measured using the VOD Mate instrument of Instantel Inc., Canada. The sensing cable was low resistance coaxial cable with a data acquisition system of a 2 MHz sampling rate. (Velocity of detonation is the rate at which the steady-state detonation wave travels through an explosive column). It was found that explosives could not attain steady-state VOD, which may be due to the desensitization of explosives at such a depth and hydro-static pressure. Looking at the above fact, it was decided to use PETN/TNT-based explosive to induce the caving. Cast boosters (Pentolite of PETN/TNT based) of 100 and 250 g were tied, and a train of the cartridge was formed to cause the fracturing of overlaying strata at CM1 (Fig. 9).

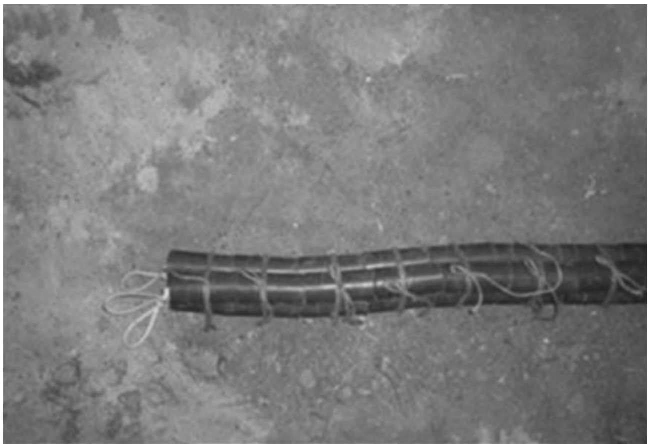

Fig. 9 Preparation of explosive before charging

Down the hole and surface trunk line initiation was planned with detonating cord of 10 g per meter. Down the hole delay could not be provided due to detonating cord being used as down the line, only surface delays were provided. There are three villages at a distance of 300, 315 and 335 m, respectively, from the blast site towards West, South-West and South. The houses of the villages are made of mud and brick. Therefore, it was decided to keep the vibration level within 5 mm/s.

The seismometers of Instantel Inc., Minimate and Minimate Plus, were used with standard tri-axial transducers and microphones. Three seismometers were installed at the nearest edge of each village at 280, 290 and 305 m, respectively, from the blast site towards the West, South-West and South (Fig. 10). The theory of pre-splitting was used, but due to restriction of holes on account of blast-induced ground vibrations, only two holes at a time were initiated so that a clear fracture plane could be created for caving of the strata. A person was deployed near the exit of mine to monitor the coal dust cloud and other gasses. All mine people had been withdrawn on the surface. Villagers and their representatives were briefed about the operation and consequences along with civil administration to avoid rumors. Mine Inspector, officials of Joy Mining Company and Golder RMT (Rock Mechanics Technology Ltd.), London, was also briefed about the project as they were also the stakeholders in the operation of the mine. The overlaying strata caved after 15 min of firing that shot for induced caving as the coal dust cloud could be observed at the exit of the mine. It was confirmed with a visit to under-ground workings after 6 h of the blast.

Fig. 10 Location of seismometer near village

Conclusion

Three rock beds had been identified in the immediate roof of the proposed depillaring panel (CM1) with a Cavability Index of more than 5,000. The delay in natural roof fall might have been due to the presence of these hard rock strata within the immediate roof of the R-VI Seam. Problem on natural roof fall has also been anticipated due to increased size and number of rib pillars left during each pillar extraction. The technical know-how and blast design for destress blasting to induce caving over the first-ever panel (CM1) at a depth of 110 m from the surface have been successful from the surface after unsuccessful attempts from underground. The situation was more critical due to the increased awareness of the nearby villagers and their irrelevant worries. Recorded blast-induced ground vibration was less than 2 mm/s at the nearest village boundary. The size of rib pillars may be reduced by looking at the cavability problem of the mine. Although surface blasting to induce caving has been difficult and troublesome, but a successful implementation could restart the mine and the revenue flow, thereby giving relief to the management.

Acknowledgements

The authors are thankful to late Sri N. Kumar, Director Technical, Eastern Coalfields Limited, for his valuable suggestions, support and help during the execution of the project. They are also grateful to the management of the Jhanjra project and members of the drilling and blasting crew of the Jhanjra Area who were involved in the work.

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Technical Note

INSTRUMENTATION AND MONITORING FOR STRATA CONTROL IN DEPILLARING

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Abstract

Strata control problems needs special attention during coal extraction by different underground mining methods. It becomes a key issue when we plan for high production, productivity and safety of miners and machineries. Fall of roof and sides continued to remain the sole reason of fatal accidents in underground mines. There is a need to check the design validity of different underground structures, which are done using empirical, analytical and simulation approaches. This validity check is, generally, done by field instrumentation and monitoring. Performance evaluation of stability of pillar and roof strata can be carried out by installation of different geotechnical instruments and continuous monitoring of their readings for efficient observations of ground movements and the stress build up around the excavations. It is better to monitor the strata control parameter remotely, particularly near and inside the goaf, when the areas under interest are surrounded by hostile rock-mass geo-mining conditions. This paper presents a brief description of different instruments which are being used for ground control and also attempts to summarize the results of the roof movement and induced stress at some conventional and mechanised depillaring panels of Indian coalfields.

Keywords: Depillaring; Goaf; Roof fall; Empirical design, Strata Control; Instrumentation; Monitoring.

Introduction

Underground mining is one of the most hazardous activities where different operations are carried out against the law of nature. In this method, the coal seam is extracted in two stages i.e., development is the first one and depillaring is the latter one. In development stage, openings are made of smaller size varying between 4.0-6.6 m, which is surrounded by bigger size of natural solid pillars. There is no scope of major strata control problems at this stage. The problems of ground control increases when the width of opening increases during pillar extraction (depillaring) in the developed coal seam. Under such conditions, the stability of underground structures, which have been designed generally using empirical, analytical and simulation approaches, must be evaluated through instrumentation and monitoring of different strata control parameters. Based on previous experiences of strata control monitoring

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in different mines of the country (Sheorey, ***et al.***, 1995; Singh and Singh, 1999; RMT Report, 2003), it has been found that underground mine environment, excavation size, depth and nature of rock mass are the major responsible factors which are to be considered before planning for depillaring during an underground investigation programme based on instruments. The observations of induced stress, roof sagging and load over the supports give indication of impending roof fall in the goaf which may encroach towards the working during depillaring operation in underground mines. Reliable instrumentation and continuous monitoring of roof strata around the depillaring face provides early warning of potential hazards. This paper presents a brief description of different instruments which are being used for ground control and also, summarizes the results of small-scale monitoring of roof movement and induced stress at some conventional and mechanised depillaring panels of Indian coalfields.

⏩ Parameters to be studied

For stability assessment of underground structures during extraction of coal seam, various strata control parameters like ground movement, stress buildup over the pillars, load on the supports and support deformation etc. are required to be monitored. These monitored parameters need to be continuously recorded as it conveys possible warning signal about the occurrences of any hazards. Variation of these parameters are dynamic in nature which can be visualized only through regular monitoring of strata during a depillaring operation.

The basic and critical parameters which are to be monitored during depillaring in advance of the face, over the line of working and within goaf are (Mandal et al., 1999): Roof fall parameters like (i) convergence or roof and floor closure, (ii) bed separation, sagging and deflection, iii) load on supports; side fall parameters like (i) dilation or side closure, (ii) pillar strain and (iii) stress concentration and side crushing; and Goaf behaviour parameters like (i) convergence or roof and floor closure, (ii) rib crushing and side spalling, (iii) caving trend or sequence of fall, and (iv) goaf filing or cushioning.

⏩ Instrumentation and monitoring

The main aim of the instrumentation is to impart safety to men and machineries with enhanced production and productivity. Further, it helps in prediction of rock mass behavior with progress of pillar extraction. Generally, field investigation on the site requires network of instruments (in time and space) for measurements (Hoek and Brown, 1980) of different strata control parameters. Existence of strong and massive roof strata and discrete operations in an instrumented depillaring panel make the field observations difficult due to dynamic conditions. Existence of geological discontinuities affects the performance of instruments in recording behavior of rock mass in addition to the existing high recovery in and around an instrumented site of a depillaring face (Singh, ***et al.***, 1996). These constraints can be taken care by a strata movement study with matching nature of instrument and skilled manpower for the monitoring. Judicious selection and locations of the instruments is required to be studied to achieve meaningful outcome from the instrumentation programme. In order to attend the desired results of any field instrumentation and monitoring study in convenient and reliable fashion, the instrumentation system should fulfill the basic conditions satisfactorily. In general, every component of a monitoring system should be simple with durable and robust and easy to install instruments in a depillaring panel.

Essential features of instrumentation (Venkateswaralu et al., 1999) are like (a) proper layout including type and number of instruments and their appropriate location must be determined before the commencement of the instrumentation in the studied panel, (b) reliability and accuracy of instruments- only reliable instruments with the required accuracy should be used. The accuracy or repeatability is the range within which the instrument can reproduce the readings taken in succession at a particular time, and is expressed in terms of +/- percent of the full-scale reading (it should not be more than +/- 0.5%) and (c) recording of parameters should be frequent and duration should be followed as per the planning before start of pillar extraction in the panel. Different instruments which can be used for monitoring the strata control parameters may be of mechanical, hydraulic, electrical (strain gauge based), Linear Variable Differential Transformer (LVDT), vibrating wire or photo-elastic type. Different instruments' type which are generally used for the purpose is summarized in the Table 1.

Table 1: List of some strata control instruments and parameters recorded by them.

Name of instruments	Parameters measured by the instrument
Closure meters/ Convergence indicator/ Single Height, Dual Height, Rotary, Auto-warning Telltale	Roof to floor closure/ Roof sagging/ deformation at different roof horizons
Bore hole extensometers (Single/ Multiple point)	Bed separation from different roof horizons
Stress meters	Stress on the pillars/ ribs/snooks
Load cells/ instrumented roof bolt	Load on supports/Load along the roof bolts

Ground Movement

When an opening is driven in the rock mass below the ground, the strata around the opening moves in different direction to acquire its equilibrium state. The stability of the underground structures is greatly influenced by the ground movement. The magnitude of these displacements depends upon the geometry of the opening, the magnitude of the stress and the properties of the surrounding rocks. The ground movement study will provide the information to evaluate the stability of underground structures, which is measured through different type of convergence indicator, telltales and borehole extensometer.

Convergence Indicator

The closure or the relative movement between two fixed points is regularly measured for strata control investigation. In fact, the stability of the underground structures depends on the amount and direction of the rock movement. Telescopic convergence indicator and remote convergence indicator are commonly used for measuring the closure/convergence between the roof and floor. Telescopic convergence indicator (Fig. 1) is a very simple and manual type of instrument which consists of a scale marked on the rod (with a least count of 0.5 to 1 mm), enclosed in a cylinder for monitoring of movement between 2 to 4 m depending upon height of the excavation. The measurement locations are prepared by grouting two pegs vertically in the roof and floor at the monitored location. Observations of convergence are recorded by setting the rod between the grouted pegs. Tape extensometer are used to measure closure of galleries between two points located in opposite direction.

To monitor the closure between roof and floor at the inaccessible places like goaf in the mine, remote convergence indicator (Fig. 1) (potentiometer or vibrating wire type) can be used. This instrument is permanently fixed at the desired location during commencement of extraction of the panel and the reading is taken till completion of the panel or before the damage of the instruments. It has been observed at several sites that a sharp increase in the rate of convergence has resulted in subsequent ground failure. The absolute values depend on the characteristics of surrounding strata and the pattern of excavation. The ground condition may be stable, short-term stable or unstable depending upon the value and trend of change of rate of convergence. In case of stable ground condition, the rate of convergence ceases or decreases. If the rate of convergence remains constant, the ground may be termed as short-term stable. Under the condition of unstable ground condition, the rate of convergence increases sharply till failure of the ground. Thus, convergence monitoring improves the safety of work place and in turn worker's security, which has a direct bearing on the productivity of the mine.

⏩ Single height / Dual height / Rotary / Auto warning Telltale

Single/dual height telltale provides values of movement of roof strata in the opening of a coal seam. Limiting values of roof sagging are also marked on the instruments which indicates warning of possible roof failure. Remedial actions should be taken when the observed value of roof sagging exceeds the cut-off value which is decided based on experience of working in a panel and geo-mining conditions of the site. Dual height telltale instrument records the roof separation above and below the rock bolted horizon depending upon the location of grouting horizon which is can be distinguished easily. It gives instant, constant and regular information about roof condition to the underground workers and operational management can take appropriate remedial measures based on roof sagging history.

When it is required to record even small movement of roof strata, then rotary telltale instrument is used in such cases which measures the vertical movement (<10mm) by magnifying it into a rotational movement i.e., 5mm = 60° of rotation. It is generally used during development of pillars and galleries and splitting of galleiries where the amount of roof sagging is less. Therefore, it monitors strata movement during depillaring in a panel. Further, it is a non-electronic device which needs no external connections or energy source.

Auto warning telltales (AWTT) records the roof separation with reference to an anchored horizon, where the reference anchor of this instrument is fixed (Kumar et al., 2019). This instrument records the roof movement when there is any movement of roof strata occurring below the reference anchored point of this instrument. This instrument starts flashing automatically after attaining the fixed/set value of strata movement in the instrument. The trigger level on the indicator is to be fixed for varying geo-mining conditions which can be adjusted by the user if design monitoring indicates that a more appropriate level should be adopted. Therefore, this instrument keeps constant vigil (continuous in time) for the set safety level of the strata movement. This instrument has become popular and gained faith of the miners especially under dynamic conditions of depillaring operations when there is high risk of occurrence of any hazard in the mine close to a developing goaf. Different type of telltales used for measuring the roof sagging is shown in Fig. 2.

⏩ Bore hole extensometers

Bore hole extensometers are basically used to monitor the movement of different roof layers during development of opening in the rock. It is single, double or multi-point anchor type depending on the number of roof horizons, where bed separations are to be monitored. This instrument has different working principles like potentiometer and magnetic type. The magnetic type extensometers are used where a large number of points are to be monitored. The anchors are fixed inside each layer through borehole at desired depths using expansion shells or by grouting. Grouted type anchors are mostly preferred to avert any slippage or damage of anchors due to blast vibrations. It may be installed from the surface as well as in the roof of the opening from underground. To monitor the bed separation in accessible places in the underground mine like goaves, this instrument is installed from the surface to reduce the possibility of damage of the instrument during caving/roof fall. Different types of borehole extensometer used for bed separation in the roof strata during drivage of openings is shown in Fig. 3.

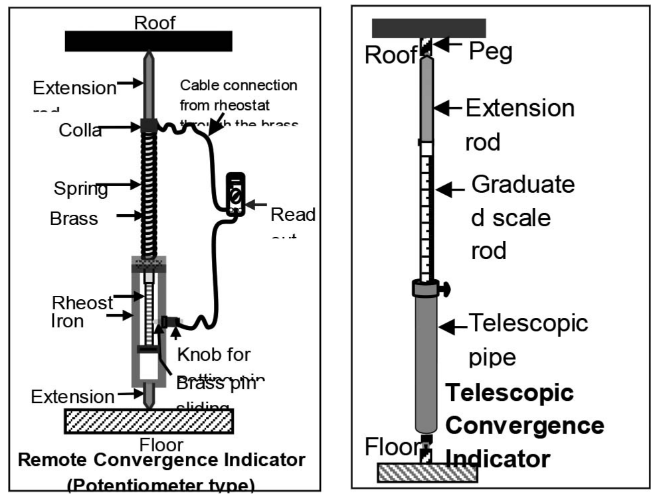
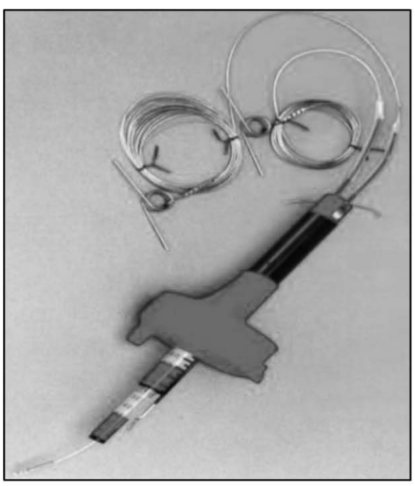
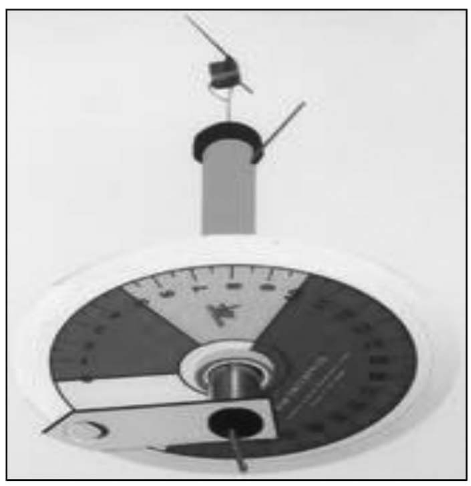


Fig. 1: Remote and telescopic convergence indicators.



Dual height telltale



Rotary telltale

Auto warning telltale

Fig. 2: Different type of telltales used for measuring the roof sagging.

Fig. 3: Different type of borehole extensometer.

Stress redistribution

Stability of the underground structures which are formed during underground mining is being, generally, threatened by two types of stresses: ***in-situ*** stress and mining induced stress. However, ***in-situ*** stress is more or less static in nature for a particular site but the mining induced stress is highly correlated with strata equilibrium dynamics around the goaf edge (Singh et al., 2002). Direction and value of induced stresses due to mining affects the design of underground structures and manner of pillar extraction (Singh et al., 2011a). Thus, it becomes important to estimate the value and direction of mining induced developing over the natural pillars/supports around the goaf edges which is also a concern to the mining engineers. Geotechnical instruments have been developed to monitor the mining induced vertical stress due to mining activity. There are induced stress measuring instruments which include photo elastic plugs and discs, contains hydraulic pressure cell, which uses electric resistance strain gauge sensors to measure the strains induced in the plug. These instruments are installed in a horizontal borehole and monitors the stress change in vertical direction only which is also a disadvantage. Stress meters based on vibrating-wire are more popular and reliable and preferred for prolong monitoring as it uses frequency as output signal instead of voltage (conventional electrical resistance or piezoelectric transducers). The output signal (frequency) of this instrument can be communicated using long cables without deterioration or alteration in original readings of the instrument caused due to change in cable resistance, contact resistance, ground leakage, induced voltage or noise. The vibrating-wire transducer uses the basic principle of the change in natural frequency of a elongated wire is proportional to the change in tension of the wire. Gauge wire is stretched diametrically across the walls of a hollow steel cylinder in the vibrating wire stress meter (Fig. 4). Stress changes in the surrounding rock cause small change in the diameter of the cylinder, which are measured as changes in the natural frequency of vibration of the tensioned wire. Frequency of vibration is related to the magnitude of stress change. For monitoring mining induced stress on the natural pillars, the stress meter is installed into the horizontally drilled borehole by setting tool and tightened with wedge and platen assembly. The reading of change in frequency or time period is taken by readout unit, which is converted into induced stress.

Load on Supports

Load over the installed support is monitored to study the efficacy of adopted design of support system used at the working places in underground mine. Load cells are installed beneath or on the top of the wooden/steel props for the purpose of monitoring the efficacy of support system. The load cells work on mechanical, hydraulic, electrical (strain gauge based), LVDT, vibrating wire or photo elastic principles. Mechanical and hydraulic load cells are widely used in underground mine due to their raggedness and robust in nature. Strain gauge and vibrating wire-based load cells are also used. In a strain-gauge load cell, electrical resistance strain gauges are attached to the periphery of a spool of high strength steel or aluminum cell treated with heat. Strain gauges are mounted in a full bridge configuration which takes care of the uneven distribution of loads. These can be used to monitor the support remotely.

For monitoring load distribution along the full column grouted roof bolt/cable bolts, “instrumented bolts” or “Irad bolt” are used, in which strain gauges are fixed along the length of roof/cable bolts at different intervals. Rock bolt having load cells of mechanical, electrical or vibrating wire type are also used to measure the load in roof/cable bolt. In recent years, a bolt-meter has been developed for evaluating the bonding between the grout and the rock bolt. This instrument uses the principle of diffusion of compression and flexural waves in uniform medium and wherever flaws are encountered, the waves are reflected back. But there are some practical problems in using this system for regular monitoring of the rock bolts. Load cell and instrumented roof bolt, used for measuring the load on conventional supports and roof bolts respectively, are shown in Fig. 5.

⏩ Monitoring of rock mass behaviour- case studies

In fact, the strata control monitoring uses a network of instruments measurement in space and time. But, generally, the number of the observational points/stations in a panel is optimized to meet the economical consideration of the study. This optimization is achieved through experience of working under similar geo-mining conditions. During the monitoring, locations of the instruments is fixed and the line of extraction overtakes all these locations with increase in width of excavation. It has been observed that the trend of variation in different strata control parameters is different from mine to mine due to variation in their geo-mining conditions. Further, the mining induced stress (Singh et al., 1996) observed over pillars and roof-to-floor convergence during depillaring, generally, increases with decrease in distance from the goaf edge. Similarly, the values of other parameters like bed separation, load on support etc. are also influenced by the face advance in a depillaring panel. Further, the peak of the strata movement problem is encountered during major roof fall. As an underground investigation needs instruments to be installed before commencement of depillaring, the peak of strata movement generally does not match (Singh, 2010, Singh et al., 2011) with the zero position of the instrument. Therefore, the actual shift of major roof fall from the zero-face position of the instrumented site is adjusted (Singh, 2010, Singh et al., 2011) for analysis and development of a relationship.

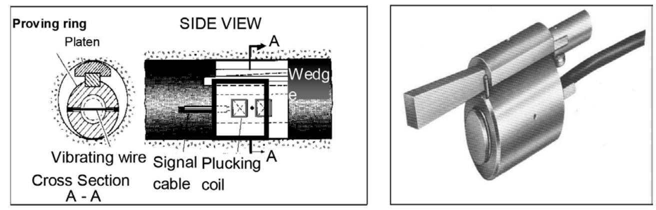


Fig. 4: Vibrating wire type stress meter used for stress measurement over pillars/stooks/ ribs/ snooks

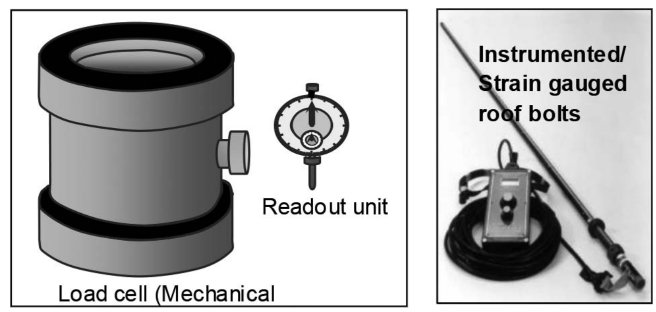


Fig. 5: Load cell and instrumented/ strain gauged roof bolt

⏩ Mining induced stress

It is difficult to control massive and strong overlying (stiff) strata through an applied roof support during depillaring. Laboratory and field investigations have demonstrated (Sheorey et al., 1994) that the proper design of stiffness of natural supports can effectively tackles the problem of depillaring under uncaveable coal measures. However, here study of mining induced stress developed over the pillars for varying dimension of excavation becomes an important issue to understand the interaction between the natural support and overlying strong and massive strata during different stages of the depillaring (Singh et al., 2011a).

Generally, a number of stress meters (Fig. 6) are fixed to pick up the variation of mining induced stress with face advance in a depillaring panel. The readings of a single instrument provide some idea of variation of mining induced stress but found to be broken in nature and inconclusive to estimate the nature of strata movement. Variations of readings of different individual stress meters (shown in Fig. 6) with face advance are shown in Fig. 7. However, a better nature of the stress variation is obtained when all these data are combined together in one figure (Fig. 8). To have a better shape of the variation, the shift of zero position of the face from the peak value of mining induced stress is adjusted (Singh, 2010, Singh et al., 2011). Further, the data is subjected to statistical analysis to eliminate the observational crowd (Singh, 2010, Singh et al., 2011) and interpolation is done to represent the value of stress at regular interval (Fig. 9). The analysis adopted biasedness of preserving peak value of the stress because the frequency of observation remains low in this range of study, mainly due to strata equilibrium dynamics during the major ground movement. Application of a microprocessor based data-logger for continuous monitoring of the variation during major ground movement may prove to be of strategic importance for the analysis.

Field measurements suggest that the mining induced stress depends on geo-mining parameters of the site. Fig. 10 represents field measurements of mining induced stresses of two sites A and B. The overlying strata conditions of these two mines A and B are shown in Fig. 11 (a

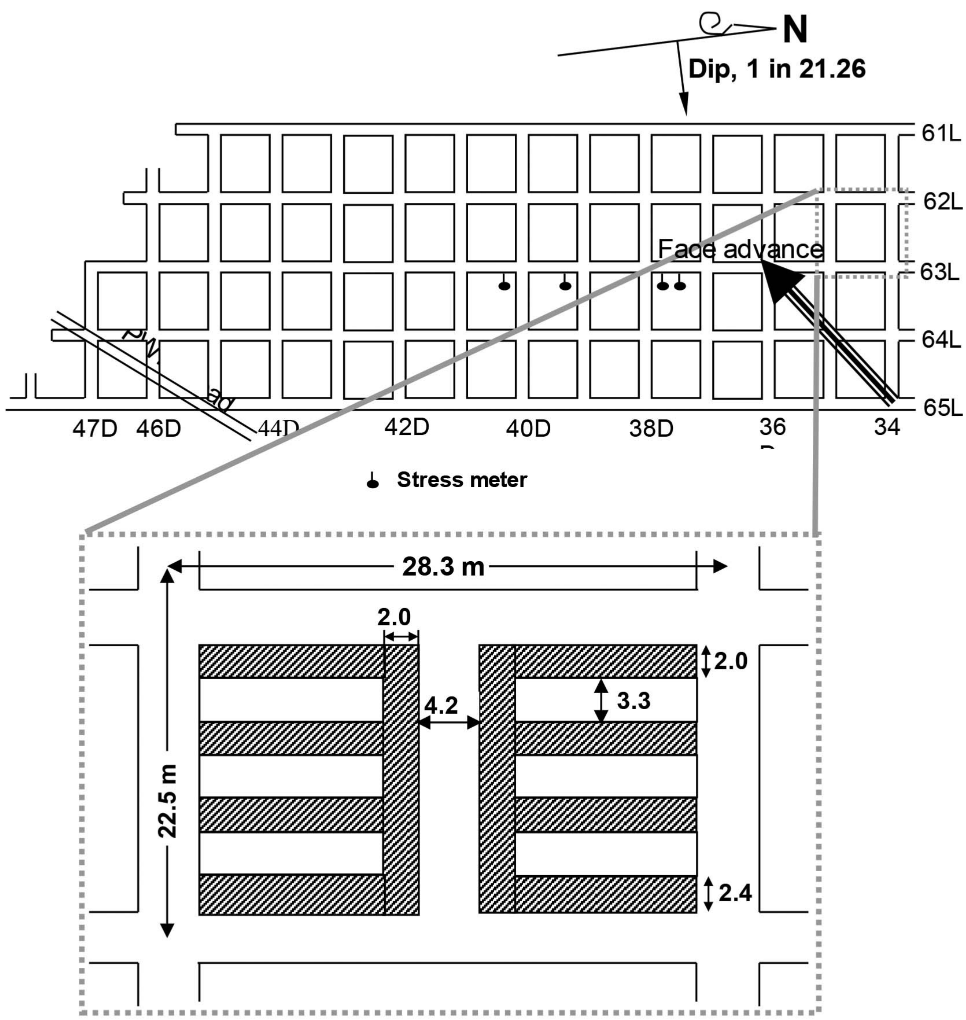


Fig. 6: Location plan of instruments (stress meters) in an observational panel and the manner of pillar

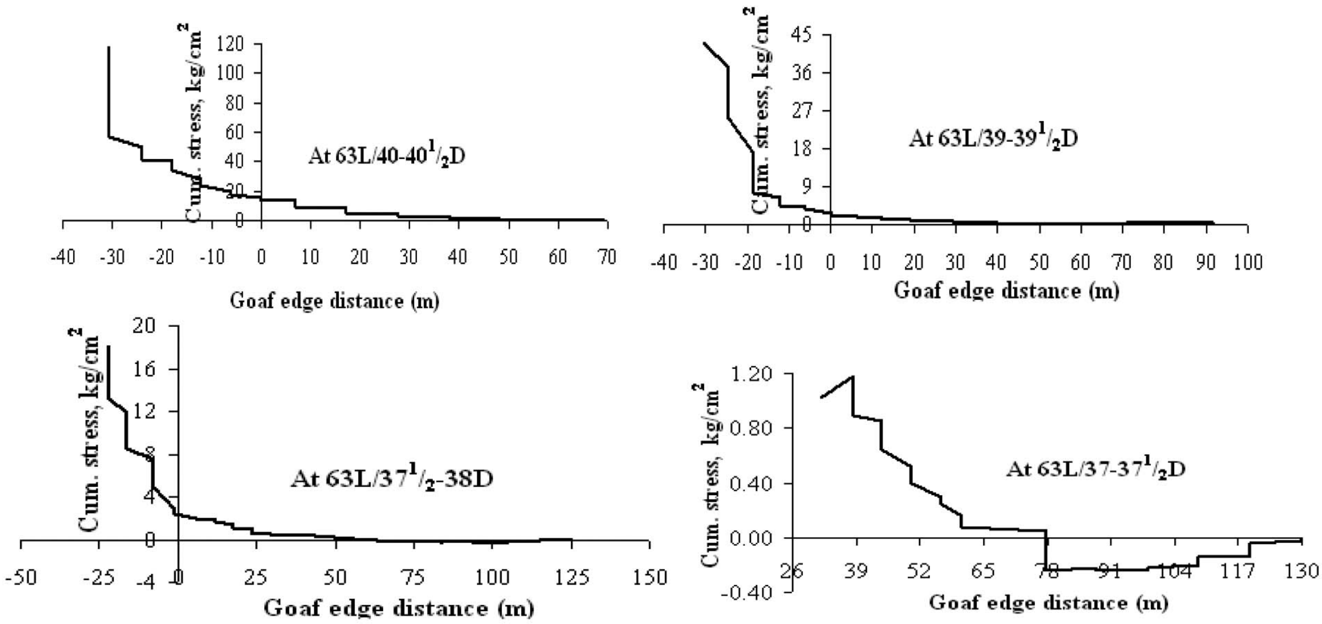


Fig. 7: Observed variation of mining induced stress with goaf edge distance independently for each station of the panel.

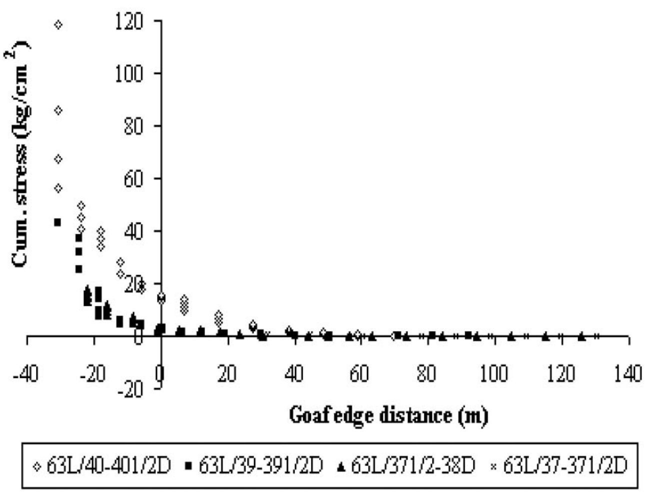


Fig. 8: Combination of data (variation of mining induced stress with goaf edge distance) of all stations of the mine

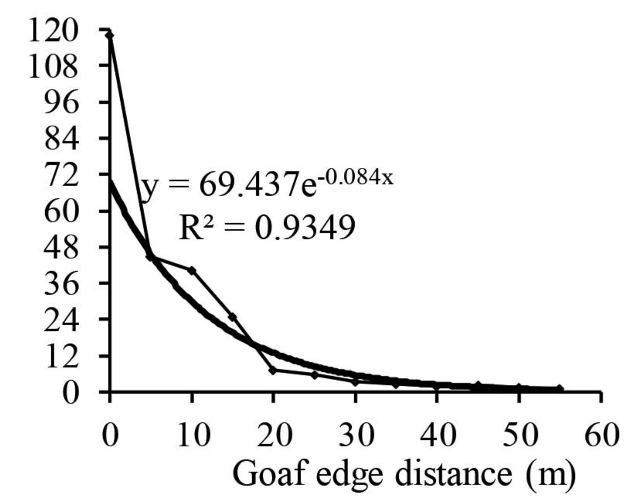


Fig. 9: Final shape of the mining induced stress variation graph after normalization of the position shift, elimination of the observational crowd and interpolation

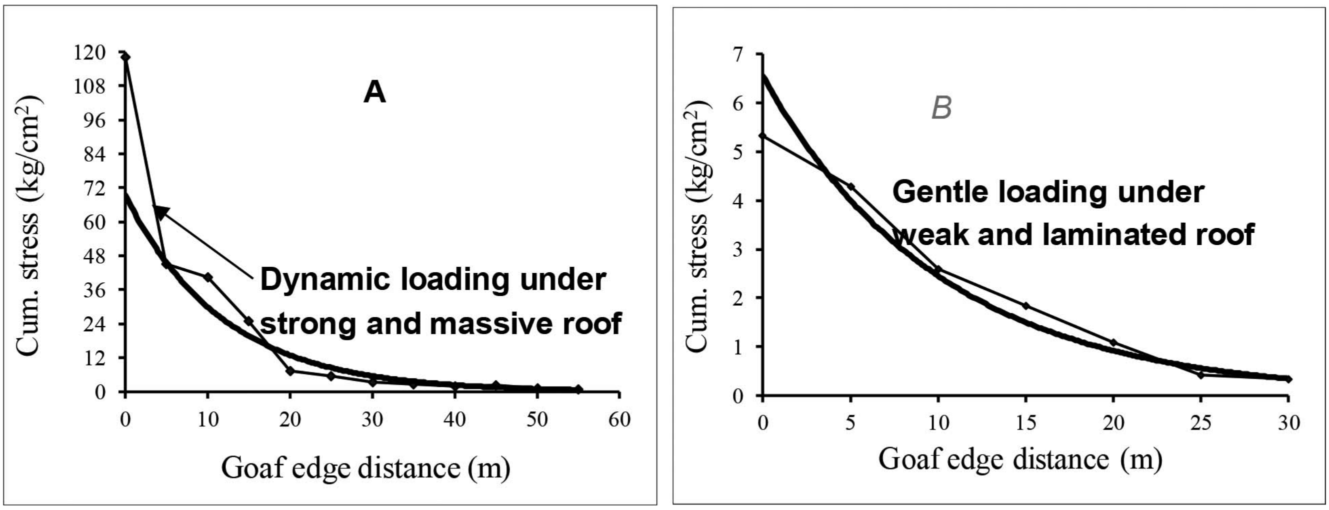


Fig. 10: Difference in pillar loading pattern due to variation in geo-mining conditions of two mines A and B.

& b). Depillaring at A and B mines was done at 77 and 48 m depth cover respectively. A comparison of observations of these two sites shows that the impact of dynamic nature of mining induced stress over the natural supports poses serious threat for the safety of working under a hard and massive roof rock mass.

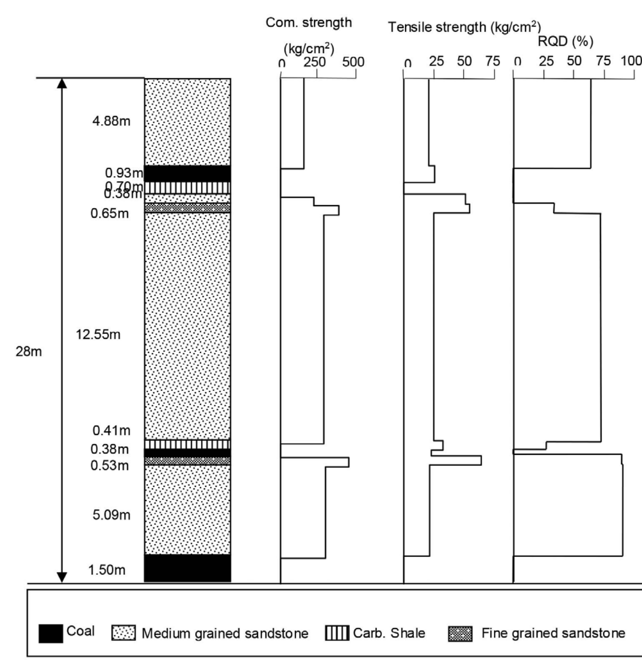


Fig. 11(a): Sections and properties of immediate overlying rock strata of mine A

Convergence observation

Convergence observations in a mechanised depillaring panel at different selected locations are presented in Fig. 12. An exercise, similar to that of mining induced stress observations, was done for convergence observations and final shape of the convergence change is shown in Fig. 13. Again, the sudden increase of convergence near zero line (roof fall) is mainly due to the ***en-masse*** strata movement during the fall. At zero line, there is no effective natural support, therefore, the convergence increases suddenly just before the fall.

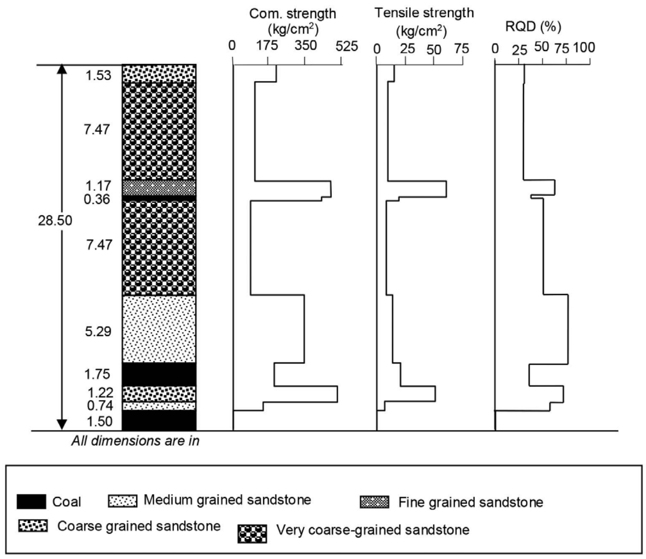


Fig. 11(b): Sections and properties of immediate overlying rock strata of mine B.

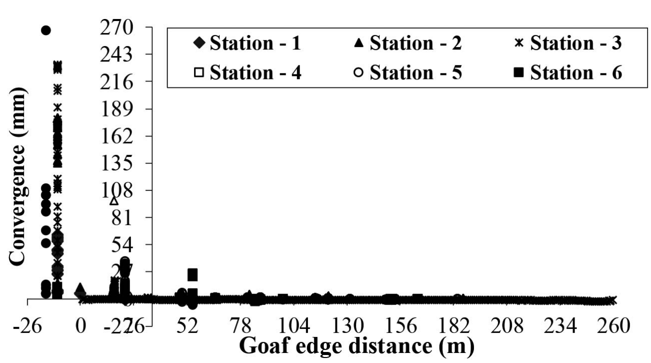


Fig. 12: Convergence observation with goaf edge distances at different station in a mechanised depillaring panel.

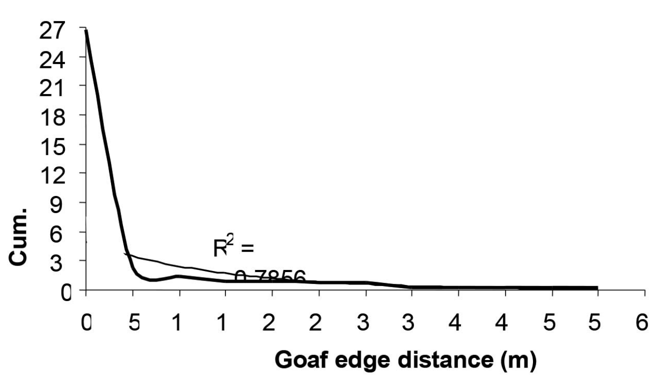


Fig. 13: Projected nature of roof to floor convergence during mechanised depillaring of panel.

Load observation

The stability evaluation of a freshly exposed roof over a gallery is generally done with the observation of load on support. Load cells are generally placed below the applied supports like props/chocks/roof-bolts to measure load encountered during different stages of mining. The load cell performs well to pick up the load generated over the support if the applied support is stiff in nature. However, in actual practice, the stiffness of passive support keeps fluctuating and generally remains poor. To improve safety, industry is adopting stiffer supports, like pre-tensioned roof bolts, to control the roof effectively during excavation. The load cells placed over the base plate of these roof bolts provides only collar load, which may mislead the analysis. If the roof strata parts, then the primary function of a roof bolt is to carry the load of the parted rock blocks. Here maximum load over the bolt is developed near the parting horizon. To understand the actual load distribution along a roof bolt, instrumented bolts are used. Here a number of pairs of strain gauges are embedded along the length of a bolt (Fig. 14) to pick up axial and shear load simultaneously at each point. The readings of all these strain gauges are taken through lead wires, which can be extended to a safe observation station. Stiff and high-capacity roof bolts are being used as breaker line support of a depillaring face (Ram et al., 2017). To optimize the design of roof bolts-based breaker line support, loading of the roof bolts at different stages of depillaring was studied with the help instrumented bolts. An observed typical loading of a front row roof bolt (instrumented bolt) of the breaker line during major roof fall is shown in Fig. 15.

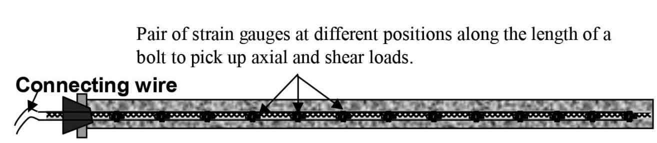


Fig. 14: Instrumented bolt for load distribution study

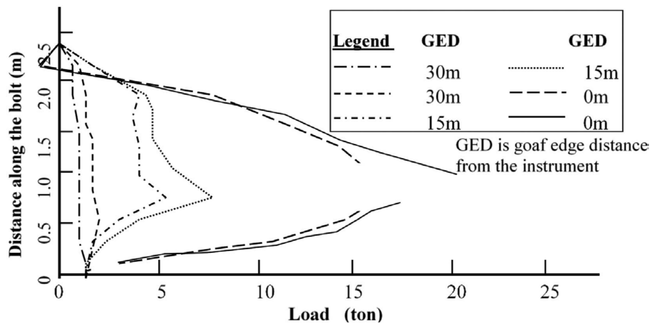


Fig. 15: Development of axial load across an instrumented bolt at different stages of a depillaring

⏩ Conclusions

Mining industry has understood the importance of instrumentation in study of rock mass behavior during different stages of excavation. However, a comprehensive instrumentation and regular monitoring can only serve the purpose for evaluation of the support performance and the rock mass response for safety and efficacy of the mining operation. It is highly challenging and technical to extract valuable information about the strata behavior using different geotechnical instruments during underground coal mining. The competency of overlying roof strata significantly affects the nature and amount of mining induced stress/deformation around an excavation, while the other parameters like underground environment, depth and dimension of excavation are important for optimization of techno-economical aspects of the measurement. As far as possible, all the instruments should be connected through a single cable provided with a thick PVC pipe and extended up to a measuring station for remote monitoring, which may be either on the surface or at safer place in underground mine. Continuous data acquisition system is preferred for continuous and online monitoring. It will be better if this system will facilitate immediate warning signals in case of abnormal strata movements.

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Health Titbits

Cauliflower gives cancer curry Eating vegetables such as cauliflower in a curry may help prevent and treat prostate cancer, according to new research from the US. Scientists say that the spice turmeric, which gives curry its yellow colour, reduced the development of cancers in lab mice, as did a naturally occurring substance called phenethyl is othiocyanate It is abundant in vegetables such as watercress, cabbage, broccoli, Brussels sprouts, kale, turnips and cauliflower.

MGMI encourages its members to induct new young members

Office bearers of all the Local Chapters are always appreciated for their innovative programmes to motivate the young Geologists, Mining Engineers, Petroleum Engineers and Metallurgical Engineers to become Life Member of MGMI and to propose new events: virtual or real!

NUMERICAL SIMULATION FOR DESIGN OF GOAF EDGE SUPPORT DURING CAVING AND STOWING METHODS OF STRATA CONTROL MANAGEMENT

Sahendra Ram[1], Ashok Kumar[2], Arun Kumar Singh[2],
Birendra Kumar Thakur[3] and Himadri Shekhar Mahato[4]

Abstract

The application of numerical modelling in efficient strata control is a proven and established technique to explore insight behaviour of underground structures under influence of mining activities at different stages of mechanised depillaring. This paper discusses the importance of design of roof bolt-based goaf edge support based on numerical modelling and field investigations. Parametric study on numerical models has been carried out on elastic constitutive model and measured the rock load height to be supported based on safety factor contours of 1.5 in immediate roof strata at the goaf edge. Length of required bolt as goaf edge support as defined is decided based on the results of numerical model and field study. Roof bolt-based goaf edge support has been found to be suitable for both mechanised depillaring with caving and semi-mechanised depillaring with stowing. In a mechanised depillaring with caving, 2.4 m length of roof bolt for 6 m gallery width is found to be suitable. In semi-mechanised depillaring with stowing, 1.8-2 m length of bolt is found to be sufficient for 4-5 m gallery width.

Keywords : Mechanised Depillaring; Numerical Modelling; Underground Structures; Safety Factor Contour; Caving; Stowing.

Introduction

India is the largest consumer of coal in the world and produces around 80% of its electricity needs using fossil fuels. India invested a major share of its foreign reserve in import of around 247 Mt of coal in the fiscal year 2019-20 to fulfil the coal production gap of the country. Considering the increasing population and economy of India, the country needs energy to meet the target of planned development in a sustainable manner. Since nationalization of Indian coal mining industry in 1947, a phenomenal growth in coal production can be seen but it remained confined to opencast mining methods. Economic development makes India an energy starving country. Among all the available resources of energy, coal is dominating and it will continue to be the major source of energy for at least 10 decades.

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Rate of coal production has not matched the demand of energy and the country is still lagging behind its objective to produce 1 Bt of coal till 2022. Around 96% of the total coal production in India is currently being produced by opencast mining method and rest by underground mining. The contribution of underground mines in coal production is on a declining trend since last two decades i.e., around 20% during 1990s to 4% during 2020s. Opencast is favoured over underground due to availability of reserves at shallow depth of cover and availability of heavy earth moving mechanised technologies including less expertise of rock mechanics except engineering in slope/dump stability.

Status of underground mining has not improved in India due to less mechanization and strata control developments including strata control management. However, future of opencast mining method is limited due to depletion of shallow coal reserves, limitation of machines at higher depth and environmental damages. Future of Indian coal mining industry is dependent over the development of an efficient underground mining method which is of strategic importance and contribute to the economic development of the nation. Underground coal mining is the way forward towards clean coal production technology and sustainable development.

Underground coal mining involves extraction of sandwiched seam between over- and under-lying coal measure formations (like sandstone, mudstone, clay, shale etc.). At present, coal from underground mine in Indian coalfields is being extracted by Bord and Pillar Mining Method (BPMM) and longwall technology. Some special approach like Bhaska method is being practiced in North East Coalfields (NEC) of Coal India Limited. In absence of surface and sub-surface features, coal is generally extracted with caving system of goaf management, otherwise with stowing. In all underground mining methods, coal is extracted by increasing width of roof span under protection of natural support and applied/artificial support towards working area. The progressive extraction of coal to form underground openings and structures results into decrease in stiffness of immediate roof strata and natural supports. The creation of a void causes redistribution of stress field followed by rock mass movement and dilution in the competency of underground structures in and around the working goaf edges. The rock movement/deformation is governed by the geology, mechanical properties of the rock mass and the existing stress field of the mine.

Roof instability is managed by development of suitable strata control techniques based on available empirical approaches, field and laboratory investigations including numerical modelling. Salamon (1989) reported that numerical modelling is vital in strata control as it is impossible to explore the influences of some variables experimentally during the field study. It is difficult to directly imitate the available empirical approaches to a mine due to inhomogeneous and anisotropic nature of rock mass. It requires extensive field and laboratory investigations to develop a suitable strata control technique in a given geo-mining condition. It is always better to develop a field measurement-based design for the underground structures and strata control technique. However, a systematic parametric investigation is difficult in the field due to the involved operational and safety issues. Further, difficulties in prediction of rock mass behavior and ***in situ*** stress conditions have made empirical formulations (Sheorey, 1992 and Venkateshwarlu et al., 1989) more popular in the mining industry.

Field investigations for the design of underground structures (Ram, 2017) provided a number of valuable information, but a systematic parametric study is prerequisite for development of design norms for underground structures. Numerical modelling is a powerful technique

(Singh et al., 2016; Murali Mohan et al., 2001) for such parametric studies to design underground structures under varying geo-mining conditions for safe and efficient recovery of coal from underground mine. Numerical modelling simplifies the problem by a number of logical and reasonable assumptions for carrying out the parametric study to understand the influence of different geotechnical parameters over stability of underground structures. Growing strength of computational machines and developments of new mathematical procedures, algorithms and computational methods for solving problems have enhanced the scope of numerical modelling approach for a geotechnical problem.

A numerical modelling study for design of underground structures requires valuable inputs from laboratory and field testing of rock samples and rock mass. Most of these inputs are site dependent and difficult to be generated through simple tests. Therefore, experience and skill is important for simulation study of a geotechnical problem. However, as per different reported studies, the numerical modelling techniques have vast potential to simulate geo-mining conditions of a mine site for rock mechanics investigations during mining activities (Yavuz, 2004; Verma and Deb, 2008; Kushwaha, et al., 2010; Ram et al., 2017). The selection of a proper numerical modelling technique for the study of rock mechanics under different geo-mining conditions is a bit tricky (Hudson and Feng, 2010), but again, considerable weight is given to the available experience. This paper describes the application of numerical modelling in design of support system at the goaf edge for strata control during continuous miner based mechanized depillaring with caving and conventional semi-mechanised depillaring with stowing. It also presents the roof-pillar interaction in and around the goaf edge during the two techniques of goaf management.

⏩ Roof-rib interaction at the goaf edge

Goaf edge is a limiting line between the goaf and working areas during depillaring operation which provide protection to the running slice. Underground structures around the goaf edges face the maximum induced stress and deformation due to development of fulcrum of the hanging roof inside the goaf. A complex roof-rib interaction is developed at the goaf edge and extraction of slices are carried out under such conditions. Safe and effective design of a breaker-line support provides controlled caving (Jeremic, 1985) and also prevents goaf encroachment during depillaring with caving. Further, effective roof bolts-based support design at the goaf edge during depillaring with stowing would provide safety to a running slice. Rock mechanics including numerical modelling (Ram et al., 2021) supports the logic to install efficient and effective roof bolt-based goaf edge support.

Pillars/fenders/ribs/snooks at the goaf edge experience complex rock mechanics challenges of high vertical induced stress causing their side spalling due to suspended roof in the void (Esterhuizen et al., 2010; Singh et al., 2011; Ghasemi et al., 2012; Basarir et al., 2015). Amount of vertical stress is directly proportional to the depth (Sheorey, 1993; Singh et al., 2001; Singh, 2010; Suchowerska et al., 2013). Thus, higher mining induced stress causes deterioration (Fang and Harrison, 2002) of the pillars/fenders/ribs/snooks at the goaf edge. The side spalling of pillars/fenders/ribs/snooks at the goaf edge dilutes their strength and resistance against the threatening span of hanging roof in the goaf. The spalling of coal pillar results into non-elastic and elastic zone in it around the goaf edge (Wilson, 1972; Gao and Ge 2016).

⏩ Roof-rib mechanics during mechanized depillaring with caving

Continuous miner based mechanized depillaring (MD) with caving technique of goaf treatment, is one of the fastest methods of pillar extraction existing in Indian coalfields. Here, a slice width of 7.0 m and length of 13-15 m is extracted within 1-2 hours under the shadow of competent inbye rib and outbye snook with application of RBBLS at the goaf edges. Inbye rib and outbye snook are expected to remain intact for a smaller duration till the extraction process is in progress (2-5 hours) (Figure 1a). These left-out competent remnants increase the efficacy of RBBLS installed under their shadow in order to control goaf encroachment (Ram et al., 2021).

⏩ Roof-rib mechanics during conventional depillaring with stowing

Semi-mechanized (Side Discharge Loader/Load Haul Dumper) based conventional depillaring with stowing technique of goaf treatment is relatively a slower method. However, regular back filling (stowing) of void (goaf) improved the strength and efficacy of left-out ribs by providing confinement to the rib (Figure 1b). Generally, regular stowing of the void at different stages of the depillaring operation does not allow hanging of large span of roof around the unstowed area. Thus, improved strength of rib and less span of hanging roof provides a safe and efficient working environment during depillaring with stowing which also lead to less built-up of induced stress along the line of extraction. The advantage of efficient rib can be used to replace the conventional breaker-line support by roof bolts-based goaf edge support (RBGES) analogous to RBBLS which is used during MD with caving. The main role of RBGES is to provide a limiting line to separate the influence of unstowed area towards the working slice similar to the conventional cog/chock support. Application of RBGES reduces the cycle time of mining operation and consumption of timber.

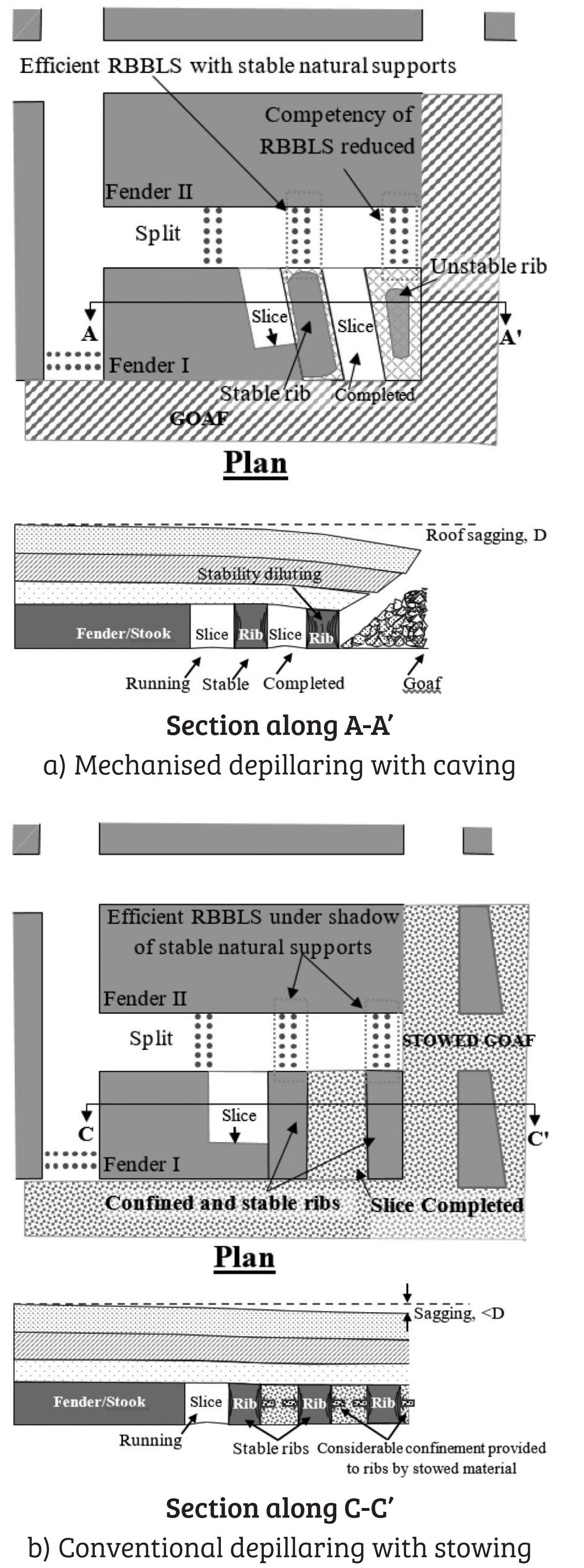

Figure 1. Roof-rib interaction at the goaf edge during different methods of depillaring.

Numerical modelling

There is huge scope of numerical simulation in assessing the behavior of underground structures, which further improves the problem definition and provides valuable insight including route to design and stability assessment. However, inputs of actual rock mass properties and their calibration along with failure criterion is a challenging task (Galvin 2016). Numerical modelling of a geotechnical problem requires the valuable inputs from laboratory and field testing of rock samples and rock mass respectively. There are difficulties in accurate determination of the various strength properties of rock mass, however, a synergy of field and laboratory studies provided the required inputs for numerical models. Most of the inputs are site specific and difficult to be generalized for a geotechnical problem through simple laboratory tests. Therefore, skill of numerical simulation along with field experience is beneficial in solving a geotechnical problem.

Numerical modelling is frequently used to solve a rock mechanics problem, where the problem is converted into simpler one and then combining them through discretization techniques. Total domain area of the problem is discretizing into smaller zones/meshes of different shapes and sizes. After discretization of the area, all the relevant conditions to the specific problem are defined and incorporated. All necessary boundary conditions are applied for the considered specific problem before application of the basic governing equations for each smaller element. Since, all the elements are connected to each other, so the resulting equations are also in relation to each other (Singh and Singh, 2006). Typical parameters to be considered for the analysis of a geotechnical problem are: the geometry of the area, rock properties (elastic modulus, strengths, Rock Mass Rating (RMR) etc.) and ***in-situ*** stress field. Various numerical modelling techniques have been developed (Coggan et al., 2006; Hudson and Feng, 2007), which utilizes a wide spectrum of algorithms and mathematics. Details of these methods along with their application, advantages and disadvantages are briefly discussed below.

Finite element method (FEM)

In this method, the total area is divided into a finite number of elements/meshes. Material properties and necessary boundary conditions, stresses, strains, displacements are applied. This method experienced considerable enhancement in computational techniques and development of different software packages, which attracted many geotechnical engineers (Oraee and Hosseini, 2007; Aksoy et al., 2010). It uses implicit function scheme (Loui and Sheorey, 2001), in which all the elemental information is stored at the same time and the solution is obtained simultaneously for all the elements. Therefore, application of this method to solve a problem of bigger size requires a fast computer with large memory. Further, this method demands a more regular domain (in shape and size) in comparison to other numerical modeling methods and therefore, a complicated geometry requires special effort in this method.

Finite difference method (FDM)

In this method, discretization of the domain area is done in a similar way as it is done in FEM. The method also requires regular shaped elements; thus, it is difficult to use this approach for simulation of complicated geometry. It uses explicit solution scheme (Yasitli and Unver, 2003; Reddish et al., 2005). The formation and solution of the equations are localized, which is found to be more suitable for computer's memory and storage. Therefore, even a bigger problem can be simulated with finer mesh size without much time consumption in computation. FLAC^{3D} gained its status among geotechnical engineers to solve complex rock mechanics problem using FDM approach (Itasca, 2012).

⏩ Boundary element method (BEM)

In this method, only boundary of the domain area is discretized and therefore, it needs less computer memory to store the elemental information. However, the accuracy of the results within the solid region is relatively less and therefore, this method has limited applicability. It is applied for solving three dimensional problems due to its advantage of reduction in model dimensions (Kuriyama et al., 1995). It is used for general deformation analysis due to underground excavations (Pan et al., 1998; Li et al., 2009), soil-structure interactions, groundwater flow and fracturing processes. It is more efficient in solving problems of fracturing in inhomogeneous and linearly elastic bodies.

⏩ Distinct element method (DEM)

All the above discussed methods are based on the principles of continuum mechanics, but the DEM is based on the principles of discontinuum mechanics (Xie and Zhao, 2009). The key concepts of the DEM are that the domain of interest is treated as an assemblage of rigid or deformable blocks. Contacts among these blocks are identified and continuously updated during the entire deformation/motion process and are represented by appropriate constitutive models. Researchers have found this approach more suitable for the analysis of a geotechnical problem because this approach inherits capability to handle geological discontinuities efficiently. Potential of distinct element approach-based Particle Flow Code (PFC) for simulation of synthetic materials (Potyondy and Cundall, 2004) to consider the geological complexity is widely appreciated (Cai et al., 2007), where mechanical behavior of the rock is approximated by representing it as a cemented granular material. The major drawback of this approach is the computational difficulty in handling a large area of interest.

⏩ Discrete fracture network (DFN) method

This method is used for the study of flow in fractured rock mass (Jing and Stephansson, 2007) in which an equivalent continuum model is difficult to be established. It is used for developments for multiphase fluid flow, hot-dry-rock reservoir simulations, characterisation of permeability of fractured rocks and water effects on underground excavations and rock slopes (Lee et al., 2006; Xu and Dowd, 2010). This approach has the potential of calibrating the flow rate as per unit hydraulic gradient field for the fractures in the rock mass through simulation of packer tests.

⏩ Hybrid models

Hybrid models are mostly used for flow and stress/deformation problems of fractured rocks. The main types of hybrid models are the hybrid BEM/FEM, DEM/FEM and DEM/BEM models (Jing and Hudson, 2002; Coggan et al., 2007). The hybrid models have many advantages, but special attention needs to be paid to the continuity conditions at the interfaces between regions of different models. When different material assumptions, such as rigid and deformable block-region interfaces, are involved in the model then compatibility at this interface needs to be addressed properly. The intention is to apply the two coupled approaches to take advantage of each modeling method for an efficient utilization of the computational resources.

⏩ Numerical modelling for strata control at goaf edge during depillaring

Discussed roof-rib mechanics at the goaf edge supported installation of RBGES during depillaring with stowing. But its direct application is difficult due to the different uncertainty with different rock layer formations. Parametric study by numerical modelling provides good understanding of rock mass behavior for a given geo-mining conditions. Influence of goaf on the rock mass in and around the goaf edge could be visualized using numerical modelling investigations. Incorporation of the indigenous rock mass failure criterion for the safety factor and Rock Load Height (RLH) estimations helped in strata control technique. Prior to development of a numerical models for design of support system at the goaf edge, following tasks are to be carried out.

Selection of suitable material model

It is very important to decide the material model as it plays an important role in numerical modelling. Normally, the models are classified into two parts -- elastic and plastic. Elastic model is based on Hooke's law of elasticity. It is the simplest model involving two basic parameters, Young's modulus and Poisson's ratio. It doesn't have a failure plane; it implies that the stresses and strains will increase infinitely with increase in load. In FLAC^{3D} packages, it allows to calculate safety factor of rock mass surrounding an opening, if failure criteria provided in the simulation procedure.

Even though it is simple, the method is quite popular for mining engineering applications. Reasonable results of application of an empirical failure criterion (Sheorey, 1997), established for Indian geo-mining conditions, in the package have created good scope for this approach (Murali Mohan et al., 2001). Further, in an elastic model (3D), rock mass failure can be observed in a better way due to maximum elastic stress developed in the model (Basarir et al., 2015). This approach provides a simple way to estimate safety factor of rock mass for the analysis.

In a plastic model, some degree of permanent path-dependent deformations or failure can be easily shown, which provides consequence of non-linearity of stress-strain relationship. The plastic model comprises of Mohr-Coulomb (MC) models and Mohr-Coulomb Strain-Hardening/ Softening (MCSS) models. These models provided considerably large deformations and loosening of pillars, prior to start of depillaring in the modelling process (Ram, 2016). Under such conditions, it is found to be difficult to analyze rock mass at the goaf edge with the help of a plastic model. Considering all these, the elastic model in FLAC^{3D} is found to be better for design of applied support for strata control during underground mining.

Elastic model

An elastic model provides the simplest representation of material behaviour. In this model, strain increments generate stress increments according to the linear and reversible law of Hooke:

$$\Delta\sigma_{ij} = 2G\Delta\epsilon_{ij} + \alpha_2 \epsilon_{kk}\, \delta_{ij} \quad (1)$$

$$\alpha_2 = K - \frac{2}{3}G \quad (2)$$

$$\sigma_{ij}^{N} = \sigma_{ij} + \Delta\sigma_{ij} \quad (3)$$

where, the Einstein summation convention applies, δ_{ij} is the Kroenecker delta symbol, α_2 is a material constant related to the Bulk modulus, *K* is Bulk modulus, *G* is Shear modulus and σ_{ij}^{N} is new stress value.

Material properties required for numerical modelling using FLAC^{3D} as input parameters for elastic model are density, Bulk modulus and shear modulus of rock mass. Instead of using Young's elasticity modulus and Poisson's ratio directly, FLAC^{3D} uses bulk modulus and shear modulus. The bulk modulus and shear modulus are evaluated using Young's modulus and Poisson's ratio by the following equations.

$$K = \frac{E}{3(1-2v)}\,\text{GPa} \quad (4)$$

$$G = \frac{E}{2(1+v)}\,\text{GPa} \quad (5)$$

where, *E* is the Young's modulus in GPa, *K* is the Bulk modulus in GPa, *G* is the Shear modulus in GPa and v is poisson's ratio.

In situ stresses

The ***in-situ*** stresses are well known factors that influence the stability of an underground structure during mining. It is, therefore, necessary to estimate the stresses as realistic as possible. Mainly, the idea of horizontal ***in situ*** stress condition is an important parameter for designing underground mining structures, especially during development of a coal seam. Based on a thermo-elastic shell model of the earth, Sheorey (1994) proposed an equation for the average in-seam horizontal stress. In this theory, it is observed that the mean ***in situ*** horizontal stress (mean of the major and minor horizontal stresses) depends on the elastic constants (E, v), the coefficient of thermal expansion (β), and the geothermal gradient (G). This theory gives the value of mean horizontal stress as:

$$\sigma_h = \frac{v}{1-v}\sigma_v + \frac{\beta EG}{1-v}(H+1000) \qquad \text{MPa} \quad (6)$$

where, ***H*** is depth cover in meters, σ_v is vertical stress and σ_h is horizontal stress.

Another study by Sheorey et al. (2001) found that this equation fits with the available stress measurement data from different parts of the world. In absence of a measured data from Indian coalfields, ***in situ*** stresses are simulated according to the equation 6.

The vertical ***in situ*** stress, induced due to gravity, is taken as:

$$\sigma_v = 0.025H\text{MP} \quad (7)$$

As per Sheorey (2001), the values of different parameters of equation 6 for Indian coal measures are given as:

v = 0.25, β = 3 x 10^{-5}/°C, E = 2000 MPa, G = 0.03°C/m

Now, for these values, we obtain the mean horizontal stress as:

$$\sigma_h = 2.4 + 0.01H \quad \text{MPa} \quad (8)$$

Although, the available numbers of ***in situ*** stress measurement data for Indian coalfields are only few, this equation has good agreement with those measured data of Indian coalfields. Among these, the latest measurements by erstwhile Central Mining Research Institute (CMRI Report, 2002) are of considerable importance and it is observed that the horizontal stress field is not highly anisotropic and supports Equation 8. Murali Mohan et al. (2001) also showed that Equation 8 provides good results during study for estimation of pillar strength in coal mines. With this value of stress, some initial trial numerical models for development of coal seams also provided reasonable results.

Since, the elastic modulus of coal can vary from about 0.8 to 5 GPa, therefore, some important deviations from Equation 8 can exist. The value of E is 2 GPa, chosen as a rough average on the basis of laboratory measurements, prior reported studies and results of the trial models run. For parametric study, in situ stresses are simulated according to the Equations 7 and 8. The values of both major and minor horizontal stresses are taken to be the same.

Material model and failure criteria

To use the elastic model, it is required to estimate the values of different parameters for determining the failure mode. It is better to estimate these values through laboratory testing, but due to unavailability of proper laboratory testing facility, popular rock mass indices are used for estimation of these values. It is found that the Sheorey's failure criterion is in good agreement with the results obtained by elastic modelling. This failure criterion is based on different case studies and field measurements in Indian coalfields. In this criterion, RMR (Venkateswarlu et al., 1989) is used (Kushwaha et al., 2010) to represent the rock mass characterisation. Considering these, Sheorey's failure criterion is used in this study.

Basically, this criterion uses the 1976 version of rock mass rating (RMR) of Bieniawski (1976) for reducing the laboratory strength parameters to give the corresponding rock mass values. But after application of Venkateswarlu et al. (1989) RMR by different researcher, this indigenous empirical formulation is considered for a rock mechanics study (Kushwaha et al., 2010). This criterion is defined as:

$$\sigma_1 = \sigma_{cm}\left(1+\frac{\sigma_3}{\sigma_{tm}}\right)^{b_m} \quad \text{MPa} \quad (9)$$

$$\sigma_{cm} = \sigma_c \exp\left(\frac{RMR - 100}{20}\right) \quad \text{MP} \quad (10)$$

$$\sigma_{tm} = \sigma_t \exp\left(\frac{RMR - 100}{27}\right) \quad \text{MPa} \quad (11)$$

$$b_m = b^{RMR/100} b_m < 0.95 \quad (12)$$

where, σ_1 is tri-axial strength of rock mass or major principal stress in MPa, σ_3 is confining stress or minor principal stresses in MPa, σ_c is compressive strength of intact rock in MPa, σ_t is tensile strength of intact rock in MPa, b is exponent of intact rock, which controls the curvature of tri-axial curve, σ_{cm} is compressive strength of rock mass in MPa, σ_{tm} is tensile strength of rock mass in MPa, RMR is RMR of Venkateswarlu(1989), b_m is exponent for rock mass corresponding to the intact rock constant. In the above equations, the subscript m stands for the rock mass.

For estimating these parameters, only the value of the compressive strength σ_c is known. Tensile strength was simply taken as one tenth of compressive strength for coal measure rock and one fifteenth for coal and b is equal to 0.5, which is taken as the most representative values as seen from a large number of test data published earlier (Sheorey, 1997).

The factor of safety is defined as:

$$SF = \frac{\sigma_1 - \sigma_{3i}}{\sigma_{1i} - \sigma_{3i}} \quad \text{when} \quad -\sigma_{3i} > \sigma_{tm} \quad (13)$$

$$\text{Otherwise, } SF = \frac{\sigma_{tm}}{\sigma_{3i}} \quad (14)$$

where, σ_{1i} is induced major principal stress in MPa, σ_{3i} is induced minor principal stress in MPa.

Selection of roof bolt properties

The FLAC^{3D} package has capability to incorporate different properties of a roof bolt for the reinforcement of rock mass. It provides structural elements; called cableSELs in FLAC^{3D}. The structural elements are two-noded, straight finite elements with one axially oriented translational degree-of-freedom per node (Itasca, 2012). Generally, manufacturer of the bolt supplies information regarding the area, modulus and yield force resistance of the bolt. However, the properties related to the grout are more difficult to estimate. In FLAC^{3D}, the grout annulus is assumed to behave as an elastic-perfectly plastic solid and the manual describes a process for estimation of grout properties (Itasca, 2012). Properties of different elements of reinforcement used in modelling are derived from the existing norms to design the reinforcement (DGMS Circulars, 2009 and 2010) and also supplied by the manufacturer. Grout stiffness (K_g) and cohesive strength (C_g) are determined using equations 15 and 16 as given in manual of FLAC^{3D}.

$$K_g \cong \frac{2\pi G}{10 \ln\left(1+\frac{2t}{D}\right)} \quad (15)$$

$$C_g = \pi(D+2t)\tau_{peak} \quad (16)$$

where, G is grout shear modulus, t is annulus thickness, D is diameter of roof bolt, τ_{peak} is shear strength of grout/rock or bolt/grout interface.

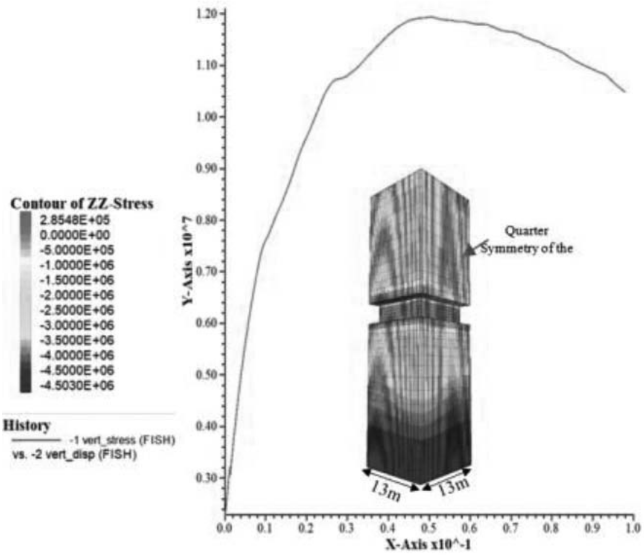

Figure 2: A quarter symmetry of the pillar (26 m x 26 m, center to center) and stress-strain behavior of for strength estimation.

$$S = 0.27\sigma_c h^{-0.36} + \left(\frac{H}{250} + 1\right)\left(\frac{w_e}{h} - 1\right) \text{MPa} \quad (17)$$

where, S is pillar strength in MPa, σ_c is uniaxial compressive strength of coal in MPa, h is working height in meter, H is depth of cover in meter, w_1 is length of the pillar (corner to corner) in meter, w_2 is width of the pillar (corner to corner) in meter, effective pillar width (w_e) = 4A / P_c, area of pillar (A) = w_1 x w_2 and perimeter of the pillar (P_c) = 2 x (w_1 + w_2).

⏩ Calibration of model

The properties of materials obtained through laboratory testing are fine-tuned through the results of different initial test models of a quarter symmetry of the pillar (Figure 2). Here, the obtained values from laboratory are varied by ±10% (at a step of 2%) in different test models. The obtained values of strength (Figure 2) from numerical simulations of a quarter symmetry of a pillar of the panel are compared with the value obtained by the CMRI empirical pillar strength formula (equation 17). A set of properties, which provided matching results when compared empirical with the numerical values of the strength and those properties used in the model are finally selected for the simulation.

⏩ Selection of bolt length for goaf edge support

To estimate the appropriate length of bolts for support design at the goaf edge, different models are run with 1 m, 1.5 m, 2 m, 2.4 m, 2.5 m, 3 m and 4 m bolt lengths. These roof bolt-based goaf edge supports are installed at 2 m outbye from the goaf edge (Figure 3). Two rows of bolts at the goaf edge are installed at 1 m grid pattern in models for the appropriate length of the bolt. For 1 m bolt length, negligible influence is observed on safety factor contour at the goaf edge. This influence became prominent for 1.5 m length of the bolts. The bolt length from 1.5 to 4 m of RBBLS showed almost similar response at the goaf edge. Considering the economy, geo-mining conditions and complex behavior of coal measure formation, 1.8 to 2.4 m length of bolt found to be in good agreement with the actual site practices.

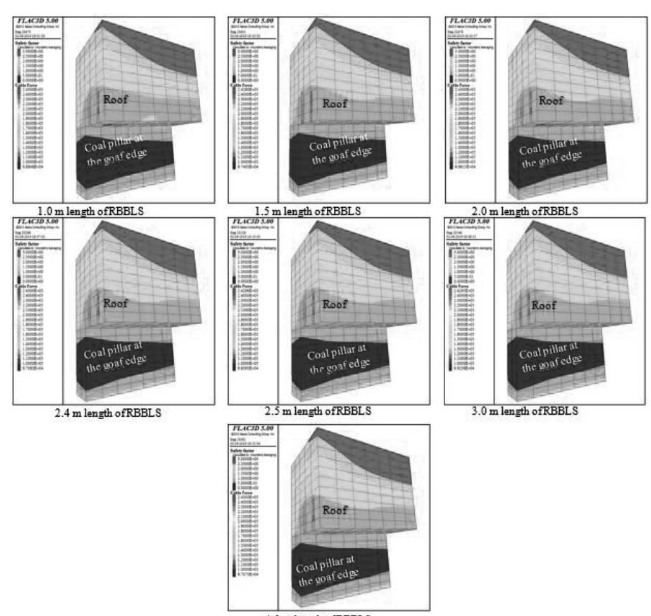

Figure 3: Safety factor contour at goaf edge for different lengths of bolts.

Depth	RMR	Position of RBBLS from the goaf edge	Pattern of RBBLS
100 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
150 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
200 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
250 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
300 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
350 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
400 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern
450 m	30, 40, 50, 60 and 70	0 m, 1 m and 2 m	1 m and 0.75 m grid pattern

Table 1: Range and values of different parameters considered for the numerical simulation study

⏩ Design of RBBLS during mechanized depillaring with caving

An assessment of support density is generally done according to the rock load height (RLH). Accordingly, a detailed parametric study is done through modelling to assess the qualitative and quantitative impact of the selected parameters. The range and value of the considered parameters for the study is given in Table 1. Here, simulation is carried out by changing depth of cover and nature of overlying strata. In this simulation study, a pillar is extracted as per pocket & fender method maintaining straight line of extraction. Properties of rock mass and reinforcement details are given in Table 2.

The simulation studies have revealed that induced stress increases rapidly during extraction of third row of pillar in the mid of the panel (Ram 2016, Ram et al. 2017). After extraction of fourth row of pillars, the development of induced stress is almost same as that observed during third row of extraction in the mid of panel. Further, it was observed in the field that main fall occurred after 17000 m^2 to 21000 m^2 (during third row of pillars extraction) followed by maximum deterioration in natural support at the goaf edge. Therefore, the RLH at the goaf edge is studied after 3rd row of extraction in the model at different depth of cover and under varying roof strata (Figure 4). RLH is observed by cutting a 3D section at 7 m out-bye towards x-axis, 5 m towards y-axis from mid of the gallery (3 m gallery width plus 2 m of pillar thickness) and 9 m in z-axis (4 m working height plus 5 m height of overlying roof) at the goaf edge. RLH estimated at 0m, 1m, and 3 m out-bye side at the goaf edge without application of RBBLS.

Table 2: Rock mass properties used for different formations in parametric study.

Rock mass/reinforcement		Parameter	Value
Sandstone		Young's Modulus (GPa)	7
		Poisson Ratio, υ	0.25
		Density (kg/m^2)	2500
Coal		Young's Modulus (GPa)	2
		Poisson Ratio	0.25
		Density (kg/m^2)	1440
Shale		Young's Modulus (GPa)	5
		Poisson Ratio	0.25
		Density (kg/m^2)	2500
Reinforcement	Grout	Grout stiffness per unit length (N/m^2)	2.94e10
		Grout cohesive strength (N/m)	1.34e6
		Grout exposed perimeter (m)	8.95e-2
		Shear strength of grout/rock or bolt/grout interface (MPa)	15
	Roof bolt	Diameter (mm)	22
		Cross sectional area (m^2)	3.8e-4
		Young's modulus (GPa)	200
		Tensile Yield strength (N)	2.43e5
		Pre-tension (N)	2.94e4
		Length (m)	2.4

Obtained values of RLH from the numerical modelling studies with respect to different RMR and depth of cover (H) is subjected to a multi-variable regression analysis. Our different experiences of core sample logging in different Indian coalfields found that around 60 to 100 m strata from the surface are weathered. At lower depth of cover (100 m), generally, the rock mass is not very compact and, therefore, higher value of RMR is uncommon. Thus, the RMR values above 60 are also excluded for the depth of cover up to 100 m. The obtained relationships for RLH at the proposed three positions of the RBBLS at the goaf edge are given below. This value of RLH is for a safety factor 1.5 and is in tune with the field results. The rock load at the goaf edge can simply be estimated by multiplying the rock density into RLH. Influence of RBBLS at the goaf edge is shown in Figure 5.

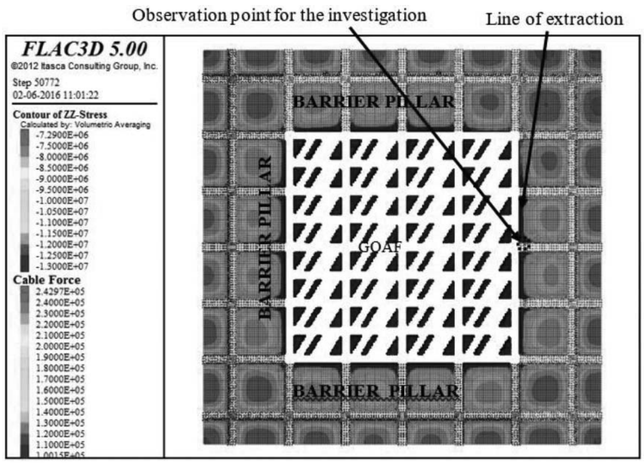

Figure 4: Stress profile after 3rd row of pillar extraction at 250 m depth of cover.

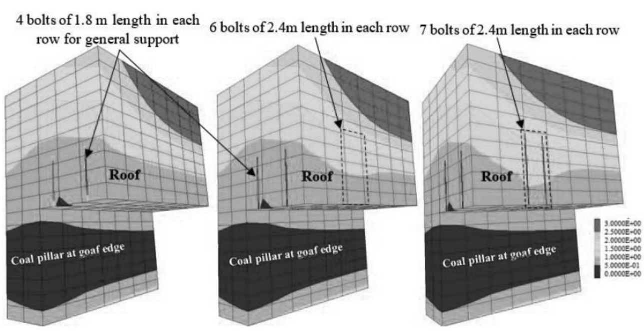

Figure 5: RLH estimated at 0 m,1 m and 3 m at the goaf edge and Influence of RBBLS over the safety factor contour at 2 m distance from the goaf edge.

For 0 m from goaf edge

$$RLH = 11.67 * H^{0.58} * RMR^{-1.14},\ R^2 = 0.89 \quad (18)$$

For 1 m from goaf edge

$$RLH = 66.32 * H^{0.31} * RMR^{-1.26},\ R^2 = 0.90 \quad (19)$$

For 2 m from goaf edge

$$RLH = 115.22 * H^{0.12} * RMR^{-1.20},\ R^2 = 0.90 \quad (20)$$

⏩ Design of RBGES during semi-mechanized depillaring with stowing

Numerical simulation for estimation of rock load heights under varying geo-mining conditions of six panels of Satgram Area of ECL mines is carried out (Ram et al., 2021). The properties of rock mass used in the models are determined in laboratory using procured rock samples from the different mines, reinforcement materials (Deb and Das, 2011) and sand (Bowles, 1997) which are mentioned in Table 3. In-situ model is run till convergence to the equilibrium. The converged models are developed using BPMM with and without application of the rock bolt supports in galleries and the goaf edges. After development of a panel, pillar extraction is carried out in both the supported and unsupported models by splitting and slicing. The voids created in the model are filled regularly after execution of few steps and the average volume of the void is kept around 1500 m^3 at different stages of the working. Finally, the models are run up to equilibrium for different stages of depillaring with stowing for examining the rock load height at the goaf edge in both unsupported and supported condition.

Coal exists in sedimentary rock formation which is inhomogeneous and anisotropic in properties. Considering the uncertainty during actual field practice, RLH in the numerical models is defined as the height of the immediate roof strata up to 1.5 safety factor contour. RLH is measured at the goaf edge without using rock bolt supports in the models. It is examined in the middle portion of the panels when maximum diagonal length of line of extraction (Figure 6) is attained to develop maximum induced stress during depillaring. A section of working height including immediate roof strata is cut along red dotted line as shown in Figure 6. The values of RLH measured at goaf edge without RBGES is shown in Figure 7. Significant improvement in safety factor at the goaf edge is observed after application of RBGES (Figure 8).

Table 3: Properties of rock mass, reinforcing materials and sand.

Structures	Formation/material	Parameter	Value
Rock mass	Sandstone	Young's modulus (GPa)	5-7
		Poisson Ratio, υ	0.25
		Density (kg/m^2)	2200-2500
	Sandy Shale	Young's modulus (GPa)	5-6
		Poisson Ratio, υ	0.25
		Density (kg/m^2)	2200-2300
	Shale	Young's modulus (GPa)	3.5
		Poisson Ratio, υ	0.25
		Density (kg/m^2)	2300-2400
	Coal	Young's modulus (GPa)	2
		Poisson Ratio, υ	0.25
		Density (kg/m^2)	1400
Reinforcement	Grout	Grout stiffness (N/m^2)	9.56e9
		Grout cohesive strength (N/m)	8.2e4
		Grout exposed perimeter (m)	6.28e-2
		Shear strength of grout/rock (MPa)	12.8
	Rock bolt	Cross sectional area (m^2)	3.14e-4
		Young's modulus (GPa)	210
		Tensile Yield strength (N)	2.32e5
Sand stowed	Sand	Young's modulus (GPa)	0.05
		Poisson Ratio, υ	0.35
		Density (kg/m^2)	1600

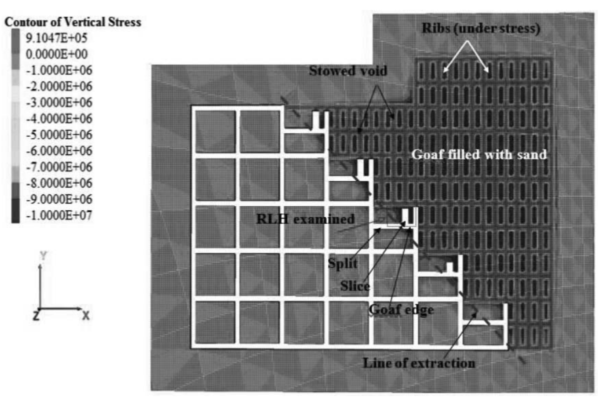

Figure 6. Pillar extraction with sand stowing and locations marked for measurement of RLH in the numerical model (after Ram et al., 2021)

Multivariate regression analysis of the recorded values of RLH in the numerical model at the unsupported goaf edges for different panels is conducted for the development of design of RBGES. It led to establishment of empirical Equation 21 to predict RLH for the considered range of simulation. The values of RLH measured in models and predicted by using the developed formulation is also compared and found to be matching.

The RLH in the studied panels are also estimated using different available empirical approaches, which was developed for depillaring with caving system of strata control management (Kushwaha et al., 2010). The RLH values estimated by using newly developed equation for stowing, is found to be less when compared from the available empirical equation for caving. Difference in the two values of RLHs is mainly due to the fact that caving system encounters relatively more strata movement and dilution in competency of rib and roof near the goaf edge compared to stowing system of strata control management. Rock load for the design of support at the goaf can be calculated by multiplying the density of rock mass with the RLH at the goaf edge (Equation 21). It is also found that 1.8m length of rock bolt in 4-5m gallery width and 2m length for 5-5.5m are sufficient as RBGES during depillaring with stowing system of strata control management.

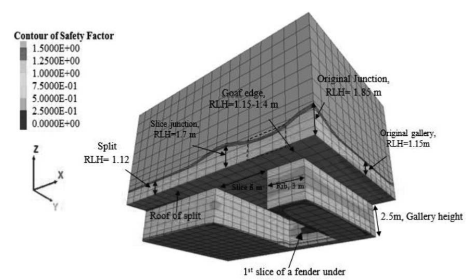

Figure 7: RLH measured in unsupported immediate roof at different vulnerable location around the goaf edge in the numerical model.

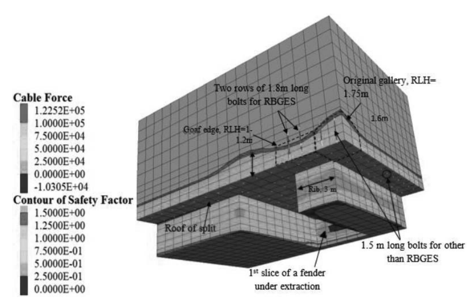

Figure 8. Improvement in contours of safety factor at different vulnerable location around the goaf edge after application of RBGES in the numerical model.

$$RLH_{ges} = 6.94 * H^{0.099} * W^{1.20} * RMR^{-0.96} \quad (21)$$

where, RLH_{ges} is rock load height at goaf edge in meter during depillaring with stowing, H is depth of cover in meter, W is width of gallery in meter, RMR is Rock Mass Rating, K is ratio of horizontal to vertical ***in-situ*** stresses.

⏩ Conclusion

Field studies helped in understanding and development of conceptual model for the roof-pillar interaction at the goaf edge during CM based mechanized depillaring with caving and semi-mechanised depillaring with stowing. The roof-rib interactions during these two depillaring approaches revealed the presence of a competent rib/snook is essential for the efficacy of the RBGES during the methods of strata control management. Parametric studies over simulated models also supported the conceptual model of roof-rib interaction at the goaf edge during two methods of strata control management. The numerical modelling is done considering the geo-mining conditions of the studied sites. Incorporation of the indigenous rock mass failure criterion for the safety factor and estimation of RLH based on 1.5 safety factor contour helped in design of the goaf edge support for the two methods of goaf management.

CM based mechanized depillaring noticed higher value of RLH at 0 m from goaf edge for all considered depths of cover. It is found that the performance of RBBLS is affected with depth and nature of roof, if installed right at the goaf edge. For a better performance, position of RBBLS is shifted towards outbye side of the goaf edge as per the geo-mining conditions of depth of cover and RMR. Further, the values of RLH get almost saturated after 2 m out-bye from the goaf edge. Therefore, position of the RBBLS is varied within 2 m from the goaf edge only. High strength, pretensioned, stiff and resin grouted roof bolts of 2.4 m in length is suitable for RMR 42 to 70 at 100 m to 400 m depth of cover. For lower value of RMR (<42) bolt length of RBBLS is to be 3-6 m.

Developed empirical formula for design of goaf edge support for semi-mechanised depillaring with stowing method of strata control management in goaf is valid for depth of cover from 76-192m, rock mass rating from 42-58.5 and gallery width from 4 to 5.5m. It is also found that 1.8-2.0m bolt length for the RBGES is suitable for the studied range of variation in geo-mining conditions. Further, it would improve the mining cycle time and reduce the consumption of timber with the application of RBGES during depillaring with stowing method of strata control management.

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Technical Note

CARBON QUANTUM DOTS FROM INDIAN LOW-QUALITY COAL: A NEW AVENUE FOR VALUE ADDITION AND ALTERNATIVE USE OF COAL

Binoy K Saikia[1]* and Ajay Sah[1]

Abstract

Carbon quantum dots (CQDs) or fluorescent carbon nanoparticles are a new class of carbon-based nanomaterials that have emerged recently and gained tremendous attention due to enormous potential for optoelectronic applications on account of their characteristic broad emission, tunable fluorescence emission, high thermal stability, and low toxicity. The demand of CQDs has been increasing and subsequently a cheap and large-scale production process of such high-value materials is very essential with proper supply chain for import substitution. In the present report, we report an economically feasible synthesis process for CQDs by using the abundant coal as a source of carbon. The properties of the raw samples and products were evaluated by the chemical analysis and other analytical techniques including UV-visible spectroscopy, high-resolution transmission electron microscopy (HRTEM), and Fourier-transform infrared (FTIR) Spectroscopy. This innovative result will open up a new avenue for alternative use of Indian coal for their value addition.

Keywords:Low-quality coal; carbon quantum dots; coal;ultrasonication; value added products from coal.

Introduction

Carbon Dots (CDs) are the new emerging zero-dimensional photoluminescent carbon nanomaterials (CNMs) that can be broadly divided into two parts i.e., carbon dots with size less than or equal to 10 nm are termed carbon quantum dots (CQDs) and graphene nanosheets (GNs) with a plane size less than 100 nm are termed graphene quantum dots (GQDs). Moreover, GQDs have sp^2 hybridized carbon but CQDs contain both sp^2 and sp^3 hybridized carbon atoms (Saikia et al., 2019). CQDs were first discovered in the year 2004, during the purification of single-walled carbon nanotubes through preparative electrophoresis. But these fluorescent carbon nanoparticles received their name "Carbon Quantum Dots" in the year 2006. This particular discovery triggered further studies to understand the fluorescence properties of CQDs for diverse applications. They also have attractive properties of which high stability, good conductivity, low toxicity, and nature-friendly materials are worth mentioning (Xu et al., 2004).

CQDs are mostly synthesized from carbon-based structures/materials by adopting top-

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down approaches like electrochemical oxidation, laser ablation, chemical oxidation, and ultrasonic synthesis. Bottom-up is also another approach for the synthesis of CQDs from small precursors such as carbohydrates and polymer-silica nanocomposites. Both the pathways are effective in synthesizing CQDs of varied sizes and properties. Although these methods are useful for the synthesis of CQDs, still there is demand for large-scale production and low-cost methods with availability of precursors compared to the present methods available worldwide. CQDs have found tremendous application in the field of chemical sensing, biosensing, nanomedicine, semiconductor devices, photo-catalysis and electro-catalysis (Wang & Hu, 2014;Lim et al., 2015). CQDs are defined in terms of the surface-functionalized carbogenic core. These materials generally contain lots of oxygen-containing functional groups on their surfaces which imparts high solubility in water. The fluorescence property of carbon quantum dots is basically due to their size and functional groups which are present on their surface (Wang & Hu, 2014). The introduction of heteroatoms like nitrogen into the carbon nanostructures increases conductivity due to a decrease in the highest occupied molecular orbital-lowest unoccupied molecular orbital (HOMO-LUMO) gap which can be employed in energy storage devices and solar cells.

Among the carbon sources, coal is a very promising source for the synthesis of CQDs since it is a naturally occurring, abundant, and cheap available natural resource in most parts of the world. It is worth mentioning that carbon in coal structure is easier to displace oxidatively than the carbon in pure graphite structure (Saikia et al., 2019). Herein, we developed a process for synthesis of CQDs along with nitrogen-doped CQD by using ultrasonication and ultrafiltration process. Northeast Indian high sulfur coal was used for synthesis of CQDs and urea was used as the source of nitrogen in N-doped CQDs as shown in depicted in Figure 1.

⏩ Synthetic method for coal-derived CQDs

Coal-based CQDs were basically synthesized by using ultrasonication and ultrafiltration techniques and summarized in the subsequent section. It is acknowledged that ultrasound can generate alternate low-pressure and high-pressure waves in liquid, resulting in the formation and collapse of small vacuum bubbles. Also, ultrasonication is a well-established top-down approach in which mechanical technology is used for sludge disintegration (Wang et al., 2017).

⏩ Synthesis process of CQDs

In summary, the CQDs were synthesized by taking 10-12 g of coal sample mixed with 200 mL of hydrogen peroxide (30%) in an ice-cold condition. The reaction mixture was then ultrasonicated (frequency: 20-40 kHz) in a microprocessor-based ultrasonicator for about 5-6 hours at atmospheric pressure and temperature. The resultant mixture was then cooled to room temperature and followed by the addition of ammonium solution until the pH of the mixture was found to be neutral. This mixture was then filtered by using a polytetrafluoroethylene membrane and further purified with the help of dialysis technique (ultrafiltration). After dialysis, the solution was concentrated in a rotary evaporator to obtain the purified CQDs. The synthesized CQDs were denoted as CC-CQDs. The details of the process are available elsewhere (Das et al., 2019).

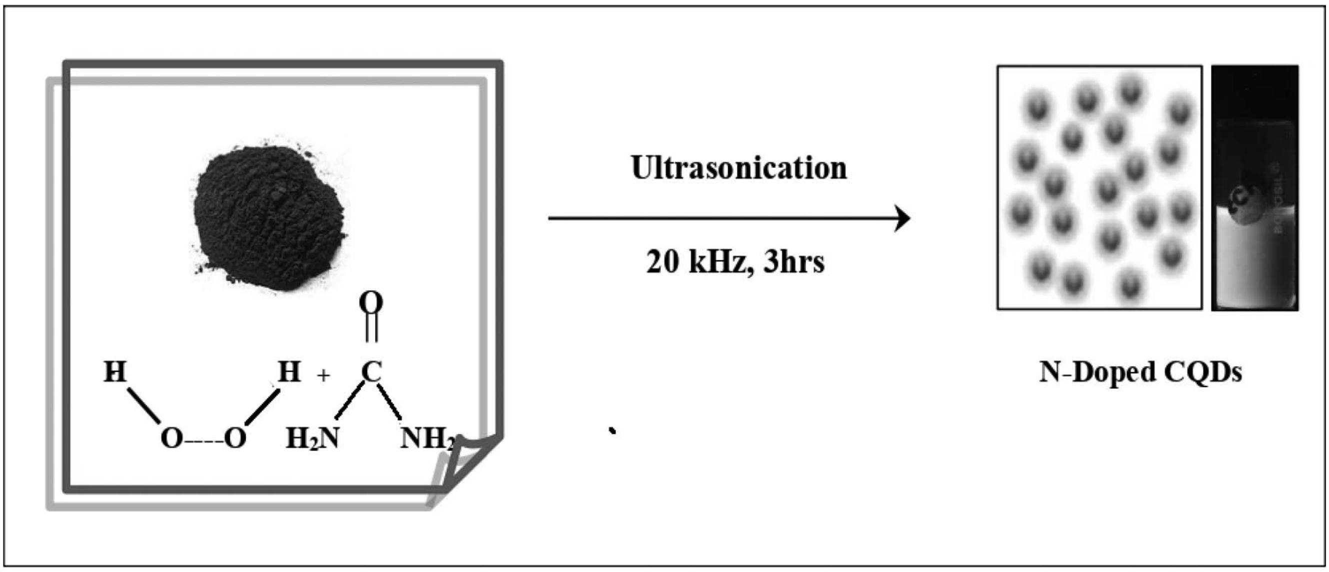

Figure 1: Schematic Diagram for the Ultrasonic assisted synthesis of N-Doped CQDs

Synthesis of nitrogen doped CQDs

1 g of grinded coal sample was oxidized with 100 mL of hydrogen peroxide (30%) in an ice-cold condition in a beaker and was kept overnight. 0.7 g Urea (CH_4N_2O) was added to the reaction mixture and dissolved. The mixture was ultrasonicated in a microprocessor-based ultrasonicator for about 3 hours at a frequency of 20 kHz at room temperature and pressure. The resulting solution was cooled, followed by the addition of ammonium solution until the pH was neutral. The reaction mixture was filtered using vacuum filtration. Both the filtrate and the residues were collected. The solution mixture was purified using the ultrafiltration technique. The obtained N-Doped CQDs from the coal sample were denoted as N-CQDs.

Results and discussions

The physico-chemical characteristics of the raw coal samples and products were carried out using proximate analyzer (TGA). Raw samples contain significant amounts of fixed carbon and volatile matter with a small amount of ash and moisture. The analysis indicated that the residues of coal have different compositions of fixed carbon (20-36%), moisture (3-19%), ash (4-6%), and volatile matter (45-56%). To further confirm the formation of CQDs and the fascinating optical properties of CQDs, the CQDs were characterized by using UV-Visible spectroscopy. The chemical characterization of the as-prepared samples was discussed by using high-resolution transmission electron microscopy (HRTEM) and Fourier-transform infrared (FTIR) spectroscopy analysis.

A fascinating property of the synthesized CQDs was illuminated with a UV light, it shows a bright blue-fluorescence and this can be easily observed in diluted colloidal solutions. The absorption spectra of the filtrate after ultrafiltration are illustrated in Figure 2(a). The special feature of photo-physical properties of the as-synthesized CQDs is to comprehend the presence of conjugated π-domains.

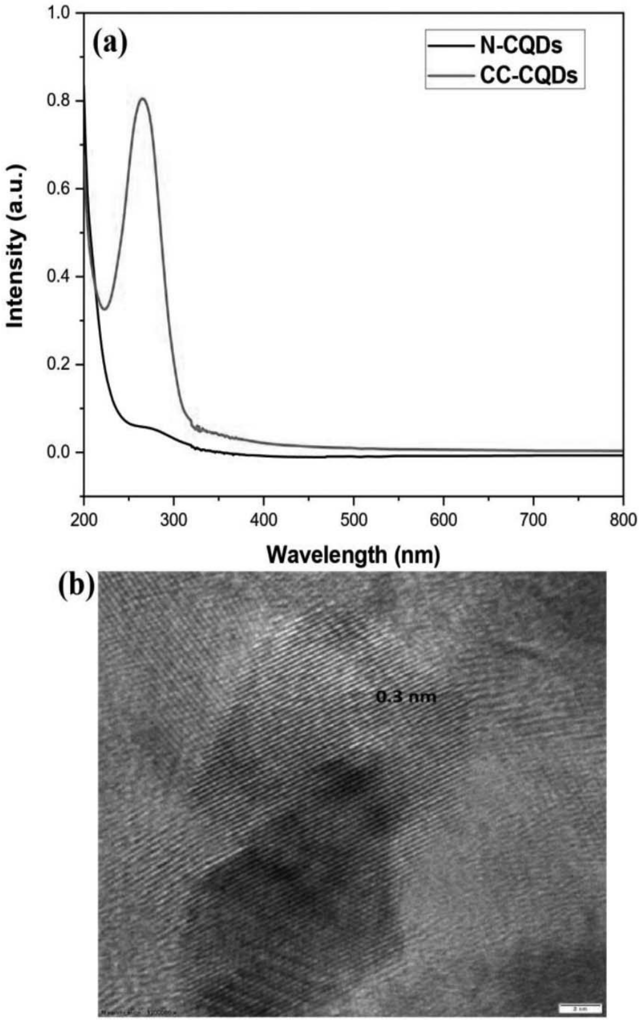

Figure 2: (a) UV-visible spectrum of N-CQDs and CC-CQDs. (b) HRTEM image of N-CQDs showing particle size and lattice parameters.

The tailing band showed up at 300 nm is attributed to the n–π* transition of the functional groups containing oxygen. The band appeared at around 250-350 nm is due to the excitation of π-electrons (π-π*) of the aromatic π system in the CDQs. There was a significant change observed in N-CQDs and CC-CQDs. The peak which was observed at 280 nm in undoped CQDs (CC-CQDs) was reduced significantly after nitrogen doping (N-CQDs)(Saikia, et al., 2019; Das et al. 2019).

During the detailed electron beam analysis, the micro structure/nano structure of the synthesized carbon dots was investigated using high-resolution transmission electron microscopy (HRTEM). N-CQDs showed lattice structure which indicated the presence of carbon nanostructure. The lattice is depicted in the HRTEM analysis with an interplanar distance of 0.3 nm as shown in Figure 2(b). It is to be mentioned that CQDs nanoparticles were agglomerated due to high concentrations obtained from coal in this process, however that can be optimized easily with dilution and by using stabilizer. The TEM-EDX analysis clearly revealed that the agglomerated particles contain carbon (40.3%), oxygen (56.40%), nitrogen (2.10%) and sulfur (1.20%).

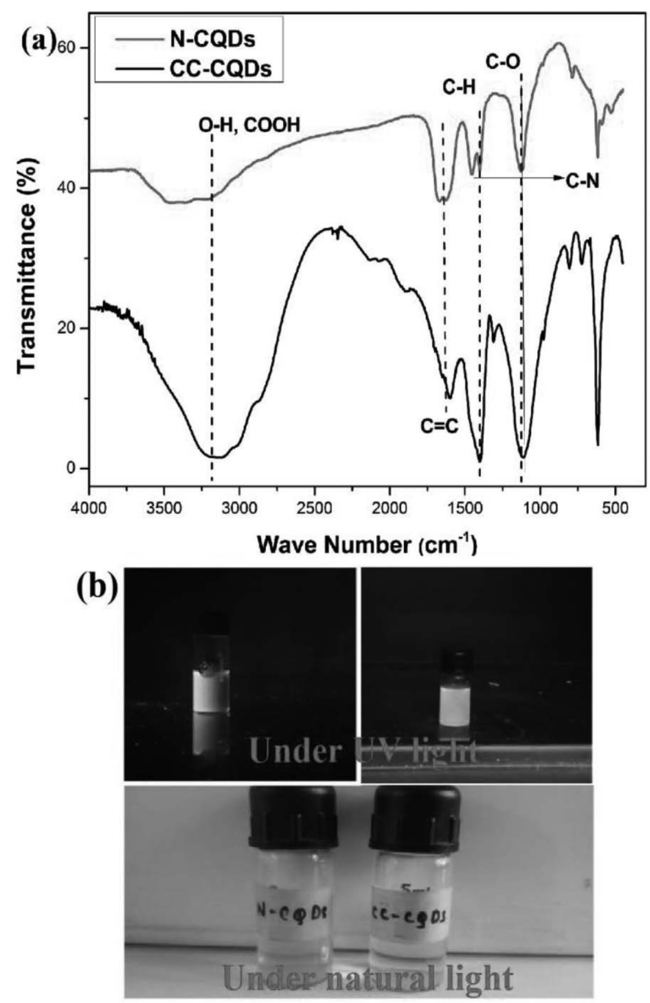

Figure 3: (a) FTIR spectra of N-CQDs and CC-CQDs. (b) N-CQDs (left) and CC-CQDs (right) under UV light (365 nm) and natural light.

FTIR characterization of the CQDs was carried out so as to know the chemical composition and surface functionality. The FTIR spectra of the synthesized CQDs showed the presence of C=C, C=O, C-H, and O–H vibration modes, as depicted in figure 3(a). The sharp absorption peaks at about 1600 and 1200 cm^{-1} are mainly because of the C=C group and C=O group, respectively. These results suggest that CQDs possess aromatic structures with phenolic hydroxyl groups on the surface. Due to the presence of these oxygen-containing functional groups, the synthesized CQDs are found to be water-soluble. A wide absorption peak at about 3400 cm^{-1}, corresponding to the extending vibration peak of O–H bonds was observed. The absorption peak at 3400 cm^{-1}, 1600 cm^{-1}, 1200 cm^{-1} were reduced significantly after doping indicating the change in composition due to doping. C–N stretching vibration was observed at 1392 cm^{-1} as shown in Figure 3(a) (Ma et al., 2012).

Summary and future perspectives

In summary, an efficient and facile process for production of CQDs and N-doped CQDs from abundant low-quality coal sources is reported in this technical paper. We also compared the N-doped CQDs with the undoped CQDs prepared from coal and found satisfactory results for future applications in bio-imaging. FTIR and HRTEM studies confirmed the formation of N-CQDs from coal. The as-synthesized CQDs are found to be water-soluble and non-toxic. In future, nitrogen-doped carbon quantum dots produced from coal can be used to explore specific applications including diagnostic tools via bio-imaging because of its promising fluorescence properties.

Acknowledgments

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HEALTH TIPS : Sugar – the latest culprit

How to find out how much sugar you can eat?

It's not possible to add upto how much sugar you are eating in your diet every day in every meal. But it is possible to acquaint with the recommendations for healthy eating. Such as minimizing eating of processed foods, and eating more whole fruits and vegetables and whole grain products.

The Sugar in the whole apple results in a slow increase in our sugar levels. But apple juice causes a sudden spike in our sugar levels putting a strain on our insulin system. From metabolic point of view, it's much easier for our body to process the sugar when it is in the form of an apple rather than apple juice. When sugar is released slowly, our body is able to metabolize it and does not store it as fat.

LIST OF MGMI SPECIAL PUBLICATIONS

Name of the Publications	Year	US$	Rs.
Progress of the Mineral Industry* (Golden Jubilee Vol.1906-1956)	1956	12	60
Dr. D.N. Wadia Commemorative Volume*	1965	15	100
Small Scale Mining in India and abroad*	1991	45	450
New Finds of Coal In India - Resource potential and Mining Possibilities	1993	30	300
Computer Applications in Mineral Industry	1993	40	400
Indian Mining Directory (4th Edition)*	1993	40	400
Asian Mining 1993	1993	85	850
Mine Productivity & Technology	1994	75	500
Maintenance Management for Mining Machinery*	1995	60	600
High Production Technology for underground Mines*	1996	50	500
Mineral Industry Development in India - Issues, Perspective & Policy	1996	20	200
Disaster Prevention Management for Coal Mines, Vol-I	1996	50	500
Disaster Prevention Management for Coal Mines, Vol-II	1996	50	500
Business and Investment opportunities in Mining Industries (BIMI '96)*	1996	40	400
Indian Mining Directory (5th Edition)	1996	50	500
Information Technology in Mineral Industry (MGMIT'97)*	1997	50	500
Technological Advances in Opencast Mining (Opencast'98)*	1998	80	800
Management of Mining Machinery (MMM 1999)	1999	80	800
Mining & Marketing of Minerals (MMM 2000)	2000	80	800
Mechanisation and Automation in Mineral Industry (MAMI 2001)	2001	80	800
Mineral Industry : Issues on Economics, Environment and Technology (MEET 2002)	2002	80	800
Development of Indian Mineral Industry Looking Ahead (DIMI 2003)	2003	20	200
Emerging Challenges in Mining Industry (ECMI 2003)	2003	50	500
Future of Indian Mineral Industry (FIMI 2004)	2004	80	800
Bridging the Demand Supply Gap in Indian Coal Industry*	2005	30	300
Asian Mining Towards A New Resurgence (Vol. I & II)	2006	175	2400
Indian Mining Directory (6th Edition)	2006	60	600
Turnaround Stories of Coal Companies and Future Strategies	2006	20	200
Reprints of Holland Memorial Lecture	2006	40	400
Glimpses from Transactions	2006	30	300
Coal Beneficiation & Development of Coal Derivatives*	2007	40	400
2nd Asian Mining Congress*	2008	200	2000
Glimpses of Hundred years of MGMI of India (1906 - 2006)	2008	50	500
3rd Asian Mining Congress	2010	160	2000
4th Asian Mining Congress	2012	100	1000
5th Asian Mining Congress (CD)	2014	100	1000
National Seminar on Indian Mining Industry-Challenges Ahead (IMICA)	2015	15	150
6th Asian Mining Congress (Pen Drive)	2016	100	1000
6th Asian Mining Congress (Proceeding Vol)	2016	500	5000
7th Asian Mining Congress (Pen Drive)	2017	100	1000
8th Asian Mining Congress (Green Mining: The Way Forward)	2019	250	2500
Regular publications			
a) News Letter (published quarterly)			
b) Transactions (published Annually)			

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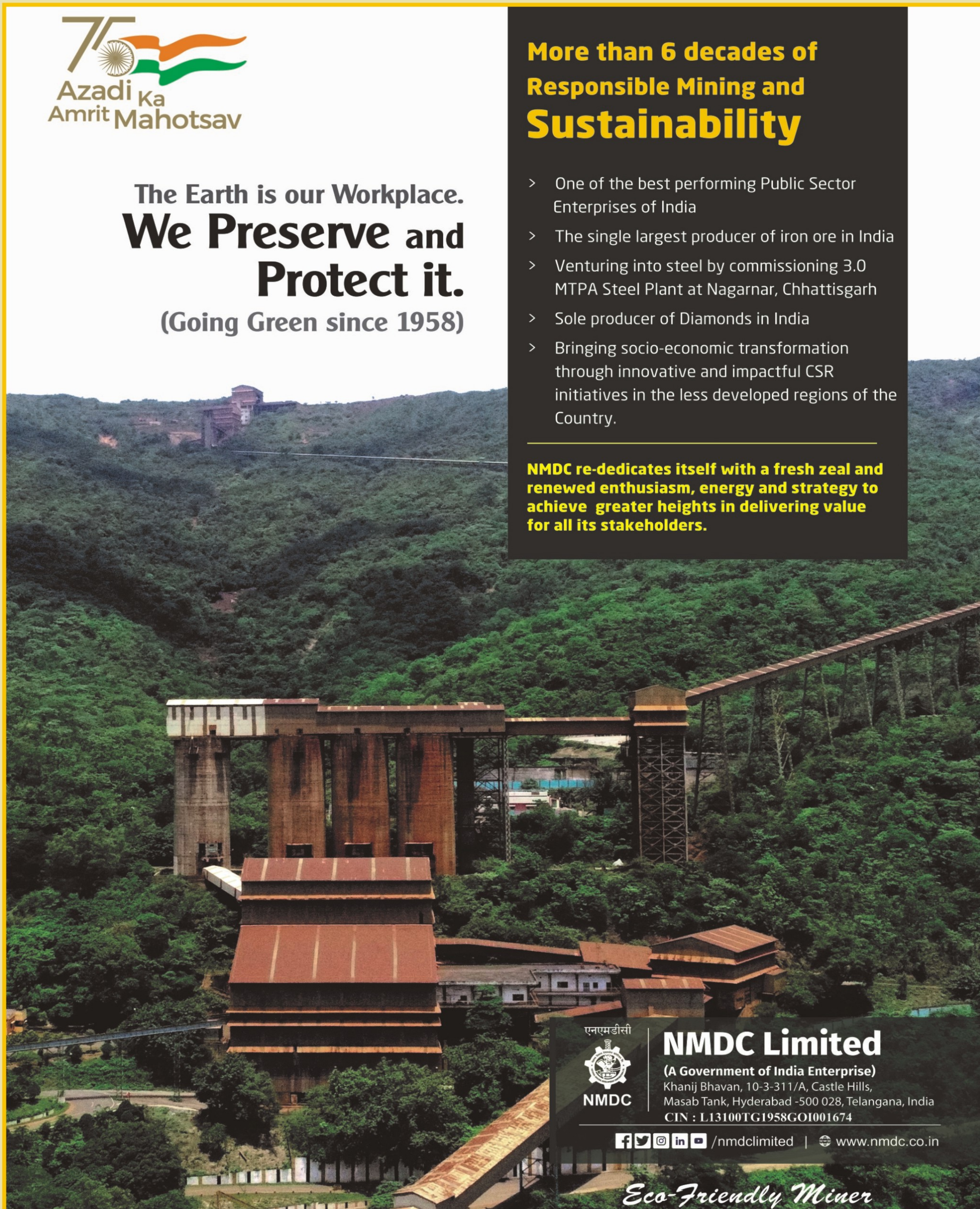

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