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Analogue to design and optimise underground mining methods in some Indian coal mines

We all know that only about 20% coal recovery is possible during development and rest should be extracted during depillaring with 70-90% depending on the feasible method of extraction so selected and applied at the site(s). To optimize the overall coal recovery with better ground control and safety during development and depillaring, the author has a prudent approach with case-studies analogues, presented in this paper. The approach is that the method of extraction per se need to be decided, based not only on techno-economic criteria (as the practice in vogue), but also based on detailed scientific studies right from planning stage. Such studies require evaluation of physico-mechanical properties at laboratories, application of established formulae and norms and scheme of numerical modelling exercises with mechanistic understanding of the stability of barrier/left-out pillars and (if any) ribs. This will not only ensure overall better coal recovery from the seam and higher safety and productivity, but also will mitigate the chances of premature collapses, overriding and other geotechnical problems that may otherwise be encountered during depillaring or final extraction. If we know beforehand that a virgin coal seam is to be exploited below an important surface properties, a suitable method of partial extraction may then be pro-actively designed based on the author's approach. Accordingly, we may have the optimum dimension of pillars during development, keeping an eye on the best-possible recovery during depillaring.

Keeping above aspects in view, this paper describes the total planning approach (TPA) with some case studies application and validation with achieved positive results. The poor recovery with encountered geotechnical problems in some case studies, where TPA has not been followed, is only an eye-opener and therefore presented here for the benefit of the readers. A synergy among the design engineers and rock-mechanics scientists is thus emphasized in this paper.

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Introduction

At present, the underground coal production is being made with the skewed ratio of development to depillaring contribution to be average as 3:1. In many CIL mine-areas, only development is being done and depillaring is not feasible at this moment due to scores of reasons as:

- there are contiguous seams (e.g. 5 in number in Hirakund Bundia mine, Orient area, MCL) with weak partings – high production continuous miner application is not found suitable scientifically, although found feasible techno-economically in the detailed project report (DPR).
- the developed pillars are of such a small size that even splitting as final operation is not found feasible below surface and sub-surface properties e.g. Pipariya mine, SECL.
- the pillars are so irregularly developed with varying size that even with stowing, coal recovery during depillaring is expectedly poor e.g. Ballarpur mine, WCL; KB 10/12 mine, BCCL. In KB 10/12, even splitting with stowing has to be designed by the author with likely strengthening of sidewalls with a pattern of resin bolting, wherever stability of stooks is found to be worsened due to inadequate pillar-dimension developed.
- the stowing cannot be adopted because of high costs involved, making the coal extraction squarely non-feasible and also because of shallow depth of cover (adverse H/L ratio) e.g. Barora mine, BCCL, mines of Mugma area, ECL etc. Many times, there is site-preparation constraint for suitable stowing plants due to important surface properties. However, the rate of stowing can suitably be improved by scientific design and thereby cost can be curtailed down to make the proposition feasible-technically and economically. Depillaring with stowing, if properly implemented, means higher coal recovery and safety at places where caving is not possible.

The above implies onset of a stage, when no more development patch was available for coal production e.g. in many mines of Orient and Talcher area, MCL, mines of Sodepur area, ECL. But, these mines employing teeming personnel have to operate due to non-technical reasons and depillaring cannot be postponed for future in wait of advanced technology for such situations. Finding no other option, partial extraction methods were designed by the author in these mines. Over and above the planned left-out pillars between extracted spans and as barriers, many pillars were designed to be left out, if caving is adopted for goaf treatment. In the mines of Orient area, partial extraction method without stowing has to be discarded in view of poor coal recovery and conservation. On the other hand, the stowing is found to be uneconomical and many panels still await a suitable method of extraction to be implemented.

Partial extraction methods without stowing have been designed in mines of Sodepur area, ECL taking only the ground control aspects into consideration, these aspects could not be considered during or before development of the coal seams. Although the author has working experience of a planning and design engineer in CMPDI, he could not situate a synergy among the techno-economic and rock-mechanics concepts in these mines. The non-replenishable coal was lost forever in the goof of the mines of Sodepur area. There were two primary reasons:

(a) many pillars in the panels were undersized from point of view of a feasible partial extraction method and its application. During development, only provisions of Coal Mines Regulations were followed and there had been no consideration made as to what would be likely depillaring methods and as to what may be optimization of pillar dimension accordingly.

(b) the redistributed load after taking combined effects due to extraction in neighbouring panels has been calculated with the use of extensive numerical modelling exercises. The calculation has provided no option but to leave imperatively these pillars against the concept of conservation. Here, the mining (partial) methods cannot be optimized, which otherwise could have been very easily done by following TPA.

Given the large coal reserves occurring at higher depth, the TPA needs to be proactively and pragmatically applied to optimize methods of coal development, method of extraction and concurrent support, understanding site-specific geo-mining complexities and likely geo-technical problems. The author could sensitize the mine operators of Chinakuri mine, ECL, where workings is proposed to be beyond 650m depth. At the locale, the pillars have been developed to an average size 45m × 45m (centre-to-centre). However, the modelling results showed failed zones in pillar, roof and floor, which were confirmed in underground site-observation. This mine has history of occurrence of severe rock bursts and therefore stowing is must, no matter which method of extraction is found feasible. Changing the dimension of pillar to a bigger size, based on scientific study by the authors, is fraught with difficulties as entries are to be curved, posing problems for travelling and transportation. The recommended bigger size, based on research studies by the authors and their team, is 54m × 54m (centre-to-centre). To it, there are associated ventilation problems to be addressed. A high-production viable method of extraction needs to be designed in the bump-prone Dissergarh seams at depth 650m and beyond, since the mine has coal reserves of about 10Mt of steel grade-II coal to be extracted in future [1].

The above description, necessitating the importance of TPA, shows only some representative case-studies in brief. This paper provides a brief resume of some representative case-studies to settle two questions: (a) when TPA not applied, the problems and poor-recovery faced by the mining industry and (b) when TPA applied, the advantages received by the mining industries.

What happened if 'TPA' not applied

Indian case-studies

A mine of TISCO, located in Jharia coalfields had XV (top and bottom) seam of contiguous nature, 57m below which there lies XIV seam. The lower seam XIV seam was caved with a working height of 4.2m and about 60% extraction. The situation was further worsened as XV top seam was found to be partly extracted with shoving below surface properties and partly extracted with caving. The subsidence strain calculated was found to be in tune of 30 mm/m on the floor of XV bottom seam. The mine management desired to develop only-left XV bottom seam, having high grade coal and also having high subsidence damages. Support design was a challenge even during development [2]. Extensive supports with support-load as $6.5 t/m^2$, *inter alia* with support safety factor of 2.0, were suggested for such development and implemented with recommended strata monitoring put in place for safety.

The current practice is to depillar the top seam and wait for the goaf settlement before extracting the bottom seam, not contiguously situated as XV-top and bottom, mentioned above. At RK-NT incline, SCCL, 1A and 1 seam are being extracted in descending order. Depillaring in the top 1A seam is quite smooth with regular caving. Seam 1 underlines 1A seam with a parting varying from 16m to 20m. Seam 1 is 5.4m thick, out of which the coal band is only 2.7m. This band exists between tow clay horizons. As such maximum height of extraction in 1 seam is restricted to 1.7m, leaving 1m coal against a 1.5m layer of clay in the roof. It has been found that following the caving and surface subsidence in the top seam extraction panels, all the roadways of the bottom seam 1, especially the dip-rise galleries, has experienced abutment stresses, causing shear failure in the roof with large roof convergence and significant floor heaving. A time-dependant deterioration of roadways was observed at many places. The ground control problems can be apprehended/assessed beforehand, if TPA properly applied. However, with an aim to optimize in 1A and 1 seams, detailed scientific study has to be undertaken by CIMFR, Dhanbad.

In the scientific study for RK-NT, the causes for adverse conditions in the bottom seam were analysed. Suitable change in method of extraction in future workings of both seams was suggested. The immediate strata above the developed galleries in 1 seam consist of 1m thick coal, about 1.5m thick clay, and about 0.8m shale in ascending order. A massive grey sandstone layer exists above the shale layer, which extends up to the floor of 1A seam. Multiple seam interactions were analysed with the help of extensive numerical modelling exercises and 4 options were recommended by CIMFR [3]. The mine operators could finally receive the remediation of the geotechnical problems, encountered detrimentally in the past workings and likely to be encountered in future also. The loss of production, time and morale could be avoided if TPA would have been applied.

AUSTRALIAN CASE-STUDY WITH CONTINUOUS MINER

Mechanized (i.e. with continuous miners) bord and pillar (B&P) method was adopted in the study-panel in Blue Mountains colliery. The depth of cover was 230-260m deep with a seam thickness of 1.6-2.1m. The pillars were 20-35 × 37.5m between roadway centers with a roadway width of 6m and a fender (stook) width of 6.5-7m. The mine had a history of overriding i.e. encroachment by the goaf into the working area during depillaring. On almost 90% of instances, goaf would encroach the working area by 5-15m. The immediate roof was generally a competent sandstone, which caved at a low angle of 25^0, this angle with the horizontal being the overall angle of hanging strata after caving [4]. The geotechnical problems of goaf encroachment are commonly faced in a B&P workings, if the immediate roof is massive and/or competent as in case of this old-fashioned mine, not from Indian standard but with regard to other Australian mines using mobile goaf-edge supports and employing advanced extraction methods e.g. Wongawalli method etc [5]. Caving mechanism and geotechnical issues were studied (Fig.1). The pillar dimensions were not of optimum size such that during delayed caving, the formed-stooks/fenders could not sustain the sagging weighting of roof strata and consequent high abutments. The mine was in urgent need to arrest goaf encroachment/over-riding suitably to save men and machine.

The bolted breaker lines were goaf-edge supports (convenient and very cheap), implemented as the first comprehensive field trial in Australia by the first author. Over-riding could be arrested successfully by pattern of rock bolts so designed as detailed elsewhere [6]. The first row of inbye bolts effectively contained the shear-planes, cutting across the bolts due to caving, as observed and measured with a suite of instrumentation including instrumented bolts. Many burials of continuous miners and recovery operations involving money resources could be avoided, if TPA would have been applied scientifically at planning stage.

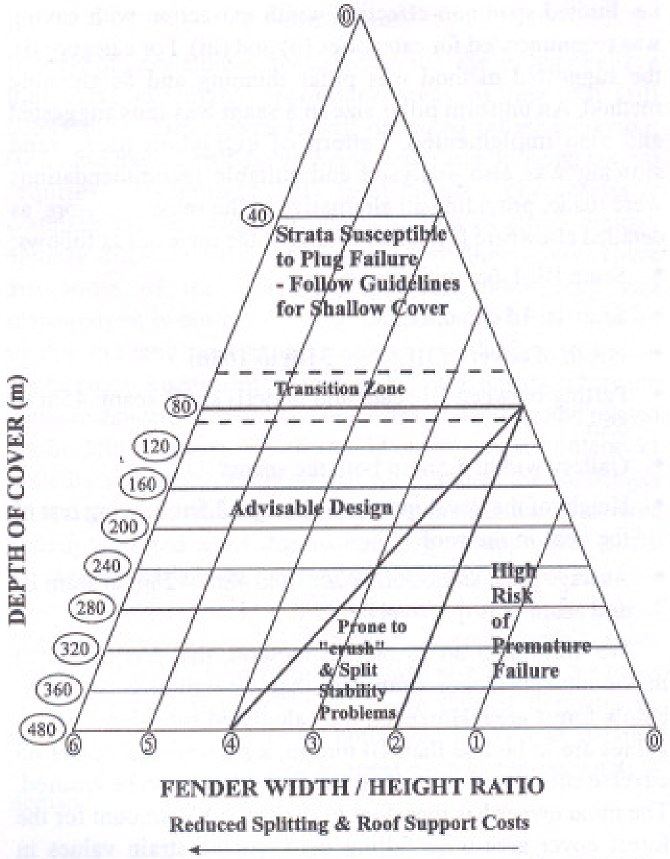

Fig.1 Fender/stook design triangle: nomogram used for TPA [5]

TPA and advantages

CASE-STUDY WITH AN AIM TO PROTECT SURFACE FOREST-AREA

At Monet Ispat coal project, Milupara, Raigarh, there are two seams, namely seam III and underlying seam II. 'TPA' was applied by the authors and their team before development of pillars was started in the mine. The undertaken scientific studies considered the following 4 important categories related to depillaring, in addition to TPA aspects:

i. Seam III – depth of cover <70m, the aspects of pot-holing were analysed by extensive numerical modelling and also the long-term stability of left-out stooks during proposed depillaring by caving
ii. Seam III – depth of cover >70m, with aim to protect forest
iii. Seam II – such that no subsidence effect on the floor of seam III
iv. Extraction in seams, with no *sine qua non* to protect surface forest area, sinec there is no forest above to be protected

The study therefore took into account the whole lease-hold area into of the mine, demarcating into two categories (a) where the forest has to be protected and (b) where the surface area is free from the forest, considering the estimated angle of draw from subsidence point of view. Caving with rib-and-slicing was designed for category (iv). Partial extraction i.e. limited span/non-effective width extraction with caving was recommended for categories (ii) and (iii). For category (i), the suggested method was pillar thinning and heightening method. An uniform pillar size in a seam was thus suggested and also implemented. Pattern of extraction using sand stowing was also analysed and suitable recommendations were made, providing an alternative to the mine operators, as detailed elsewhere [7]. Other details of the mine are as follows:

- Seam III: 1-6m thick (top seam)
- Seam II: 4.5-5m thick
- Depth of cover of III seam: 31m to 163m
- Parting between III seam and underlying II seam: 45m to 55m
- Gallery width: 4.5m in both the seams
- Height of the development workings: 2.5m, leaving rest of the coal in the roof
- Average pillar sizes: 26m × 26m and 48m × 26m in seam III and seam II respectively

We know that an extraction method, that has predicted maximum subsidence strain less than 20 mm/m is permitted below forest area. However, the calculated subsidence strain values are to be less than 10 mm/m, a prescribed limit, if no adverse subsidence impact on the forest land is to be ensured. The mine owner has therefore to deposit NPV amount for the forest cover area-wise falling between the strain values in between i.e. > 10 mm/m and < 20mm/m [pl. refer Env.Cir. MOEF, F.C.Division, F.No.2-2/2000-FC)], considering perhaps the little damage to the forest, that may happen due to the extraction.

The other option is that, if the calculation yields in a geo-mining situation, a strain value more than 10mm/m, either the panel width (in other words, extraction span) or, the extraction height is to be reduced such that the subsidence strain value in every case is brought below the prescribed 10mm/m. Furthermore, even if there is predicted subsidence movement below the prescribed limit due to extraction of the top seam, the underground winning of lower seam(s) may affect the top seam, in the way to damage the thought-as-safe forest areas detrimentally. Subsidence induced inner-burden shearing, stress redistributions and movements may contribute significantly to overlying seams(s). The only alternative left with the planner and executer is to have no subsidence effect on the floor of the overlying seam(s) [here the top seam III].

Based on the study as described briefly above, development in both coal seams was started and now is in progress. The authors are of the view that the reserve forest areas over the proposed extraction in the seams will be protected from subsidence point of view, as validated in many such case studies in SECL, MCL, SCCL and WCL. This case study thus demonstrates the optimization of mining methods after evaluating their feasibility as case-by-case and panel-wise-panel in total perspectives. The mine operator could save money in terms of mandatory NPV payment. In addition, the mine operators can now plan the future extractions in much better manner.

Indian case-study with continuous miner

While applying TPA in terms of feasibility studies, method of development (bord and pillar), extraction (pocket and fender) and supports in Jhanjra colliery have been optimized with wider (6m or 6.6m) and higher (~ 4.5m or 4.8m) development galleries and subsequent extraction, the first such trial in Raniganj coalfields (RCF). Based on the rational logic and relevant research, this method with full mechanisation using continuous miner – variants of that already established in Australia, was regarded safe also by the regulatory authority DGMS in India, despite the mandatory maximum restrictions being 4.8m and 3m respectively and general practice in vogue. In definite term, this means higher production and productivity with faster pace of coal extraction, making underground coal mining economically viable at places where conventional Indian underground mining is not viable – technically and financially. The mine could set a production record in India (max. daily production: 2700 tonnes and average 1800 tonnes/day and 565000 tonnes/annum was achieved at ease, till date highest development record in B&Mines (~ 535 no.). In depillaring, the average production was 2200 tonnes/day and the mine has completed extraction in the designed panel by the author in April 2010, barring the salvaging and shifting operations. Many such future applications are therefore being planned.

The approach of the first author in this regard consists of mechanistic understanding of strata before and after coal extraction, application of his experience gained in Australia (having similar geo-mining parameter) and in CIL production-mines, in planning and design (CMPDI) and in R&D (CSIR, CIMFR). The bolted breaker lines (as detailed in 2.2.) have helped continuous miners to extract with better productivity, ease and safety also in India, e.g. as applied Jhanjra mine, ECL. Two important points may be highlighted:

(a) Due to varying depths 78m to 141m in four panels of R-VI seam at Jhanjra colliery, ECL, an uniform pillar size of 26m × 26m (corner-to-corner) with 6.0 bord width and 4.8m height (or full height of seam whichever less) was suggested and implemented in all the panels [8, 9], although smaller pillar size may be suitable from development point of view only. Such pillar can suitably be extracted following the recommended design of extraction as in Fig.2. The strata monitoring and management was continuing to validate this proposition.

(b) During extraction by conventional rib-and-slicing method, ribs are designed with a factor of safety (FOS) between 0.6 and 0.8 to fail eventually. The CMRI strength formula was therefore, modified suitably under a grant-in-aid project (founded by Ministry of Coal S&T) [10], considering only the collected failed pillar cases. In case of continuous miner deployment for depillaring, the safety

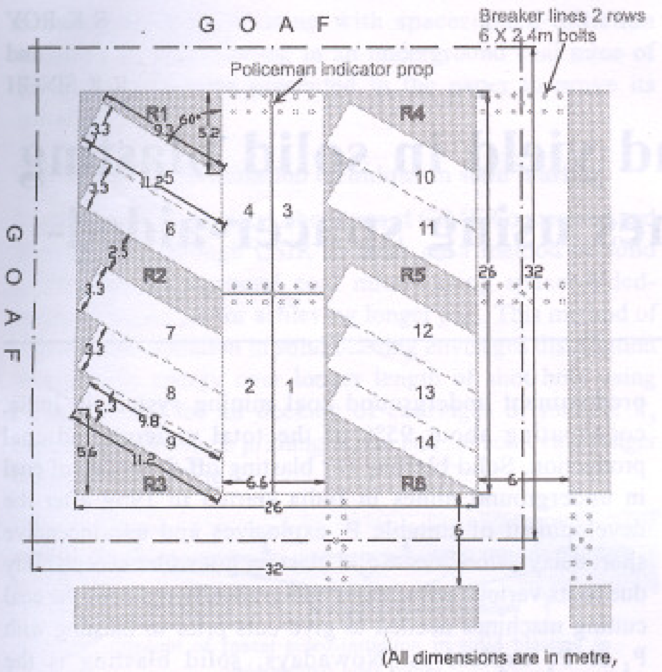

Fig.2 Recommended pattern of pillar extraction indicating split and along with extraction sequences: all ribs having FOS > 0.5

factor of ribs should be 0.5 to 0.7. The lowering of safety factor is due to fast extraction/retreat by continuous miner and no expected damage to the sides compared to solid-off blasting technique used in conventional B&P mining in India.

It may be prudent to discuss here the kernel of scientific deliberations related to Fig.2. The numerical modelling exercises started with lower size ribs (2m), generally common. But, FOS of ribs was found to be less than 0.5. On the contrary, there was a view that the 'ribs' dimension should be 2m as the general practice, but extraction sequence should leave a larger dimension rib (called colloquially in US as fender 'X') as the last rib to prevent any likely accident to continuous miner, (CM) remotely operator. Banking too much on fast retreat by the CM, this view is based on the US experience where the CM comes out from the pillar-under-extraction quickly before discontinuities in the roof may affect unsafely. These discontinuities can be generated due to extraction-induced stresses or geological anomalies. A consortium of experts from DGMS, ECL, Joy Mining (UK), RMT (UK) and CIMFR finally decide not to accept fender 'X' concept, because:

1. Larger-dimension rib might delay the caving detrimentally as the roof was already analyzed to have high caving-index values especially for its 3 identified beds with high RQD.
2. Being the first application in RCF, the already-trialed method of extraction (as in Chirimiri, SECL or in VK-7, SCCL) should be adopted and knowledge gained would help future application of new method of extraction.

Conclusions

In view of case-studies discussed above, the authors believe that there are many secondary areas of research still outstanding. The understanding of 'squat pillar' behaviour (w/h ratio mere than 4-6, 'w' being width and 'h' being height) requires assessment of post-failure characteristic comprehensively and also understanding of stress regime, entirely different from the stresses at shallow cover. These are some of the gray areas. Strata-monitoring and management is not proactively implemented at the sites by us due to many reasons including the availability of Indian geotechnical instruments having poor-craftmanship. There are many technical limitations of numerical modelling and related applicability-aspects. We all should obviate these bottlenecks unitedly and concurrently so that we can meet the challenges of underground mining in India. The mining methods have already suffered a lot due to our laggard approach, partly because we have been meeting our coal demand till last Five Year Plan (2002-2007) by opencast mines. Limited potential of opencast reserves coupled with environmental considerations and available coal reserves at depth will now remain the focus of Indian coal industry. Coal from deeper deposits by underground methods, to be optimized by TPA as detailed above, need to be produced to meet ever-increasing energy-demand.

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