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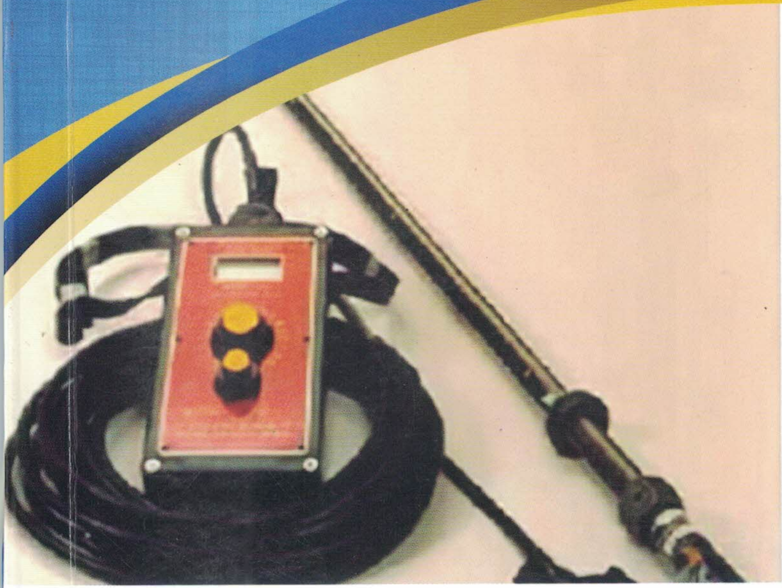

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Estimation of Permeability of Coal Seams Using Well-Logs and Analysis of CBM Gas Content in the Eastern Part of Sohagpur Coalfield, Central India

Manoj Kumar[1], A.K. Tripathi[2], Dr. Sayan Ghosh[3], Ayush[4]

ABSTRACT

This paper aims to analyse the well logs in Sohagpur coalfield to model the permeability of the major seams. Among several factors influencing the gas desorption flow from the coal matrix to the wells, permeability of the coal seams is one of the significant key players which constitutes of the natural fractures termed as cleats (following regular patterns in the matrix) and the fractures developed in the seam due to overburden pressure. Few Indian coalfields are known to have moderate to high permeability ranging from 0.5 mD to more than 10 mD (Chatterjee and Pal, 2010). Three numbers of wells are considered for analysis of geophysical logs to estimate the permeabilities of the major seams V, Index, IV and III encountered. The permeabilities in the seams in Sohagpur is estimated and is observed to range from 0.9 mD to 13 mD which is a very good indication and advantage to the feasibility of CBM production. The permeability of coal is dependent on the face/butt cleats density as well as aperture which affects directly the degree of gas desorption from wells. It is worth mentioning that M/s RIL which owns an almost 1000 sq kms. area (comprising of Sohagpur East and Sohagpur West blocks) for CBM has indicated that the western portion of Sohagpur coalfield is more potential for CBM in comparison to the eastern part. But it is also true, that the coal seams in eastern Sohagpur coalfield are more permeable which may lead to enhanced gas producing wells while production of Coal Bed Methane (CBM) in the blocks. The gas contents (in dry ash free DAF basis) of the coal seams are also analysed from the core samples collected by CBM lab, CMPDI (HQ), Ranchi where the gas content (m^3/ton) of the major coal seams are observed to vary from 0.45 to 2.59 m^3/ton. The proximate analysis results of the coal samples are determined on as received basis in the laboratory which infers low moisture and moderate volatile matter content in the coal seams. The variation of the calculated permeabilities against the gas content in DAF basis is analysed and both are observed to be directly proportional to each other which is a typical character of a coal seam reservoir. Moreover, the assessment of Gas-In-Place (GIP) carried out in the Eastern part of Sohagpur coalfield opens a doorway to study the feasibility for production of CBM in the area in future.

Keywords: *Permeability, Geophysical Logs, Gas-in-Place, Proximate Parameters, Coal Bed Methane*

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INTRODUCTION

Coal bed methane (CBM) is believed to be one of the most utilized unconventional energy resources in the coal bearing areas. This unconventional gas which remains in adsorbed state in the coal matrix was earlier believed to be hazardous in the aspect of mining safety, but detailed research and technology has proved this to be an energy resource technically as well as economically. The storage of the gas is primarily observed to be in the micropores of the coal matrix whereas a small fraction of the gas molecules termed as free gas occurs free in the fractures of the coal seam known as cleats (Vishal *et. al.*, 2013). The pore structure of the coal matrix behaves in a dual nature, the primary storage being the micropores in the matrix which is the primary store house for CBM, whereas the second are the cleats and fractures which also act to be the pathway for the gas desorption while production of gas through wells (Vishal *et. al.*, 2013; Law, 1993). In this study, an attempt is made to evaluate permeability of the coal seams through electrical well log parameters using certain basic principles of rock physics. Several models have been proposed by researchers to define gas desorption mechanism depending upon the pressure variation like Langmuir model, Dubinin Polanyi's model and BET model (Vishal, 2017). Gas content of a coal seam is often observed to be dependent upon the vitrinite reflectance, maceral content, maturity, coal quality and depth of the coal seam (Ghosh *et. al.*, 2016) The gas content in the coal seams is measured through a sequence of steps from determining the desorbed gas from the core sample recovered to recovering the volume of residual gas from the crushed samples (Saghafi, 2017) . Although, few early researches have demonstrated indirect methods of estimating gas content from adsorption gas isotherm of coal and hydrostatic pressure at a depth, but the most reliable technique of measuring the gas content is still the direct method (Saghafi, 2017). The Gas-In-Place (GIP) is related to the volumetric extent of the coal seams in a study area which depends upon the (a) area of the coal beds, (b) thickness of the coal seam, (c) average coal-bed interval density and (d) the gas content of the coal seams. The fundamental principle used in this study is derived as:

GIP= Coal Mass X In-situ Gas Content……(1)

The porosity and permeability of any reservoir governs the deliverability of the gas by the reservoirs. Some researchers have attempted to estimate the variation of permeability of coal seams few coalfields like Jharia where the range is observed to be from 0.05 mD to 10 mD but very few data is available regarding the permeability variation of seams in Sohagpur coalfield. Moreover, many researchers have attempted to map the permeability through various methods using the core samples as well as indirectly through mathematical modelling from well logs This study is basically regarding the estimation of permeability using the electrical logs in three wells in the eastern part of Sohagpur coalfield whose location is shown in Figure-1.

STUDY AREA

Sohagpur coalfield belongs typically to Permian and Triassic basin extensions (Mitra, 1997). Basically Sohagpur coalfield. The geographic limit of Sohagpur coalfield is considered to be bounded between latitudes 23^{o} 05'N and 23^{o} 30'N and longitudes 81^{o}10' and 82^{o}15'E. Sohagpur coalfield spreads about 3100 sq kms within the above said coordinates is divided into two halves by an E-W striking Bahmni-Chilpa fault whose throw varies from 120m to 400m dipping towards North. designated the coal bearing formation as "Barakar and Karharbari " which are succeeded by thick sequence of late Permian and Triassic Supra Barakar rocks. Basically, all the potential coal seams in the area belongs to Barakar formation overlied by a thick strata of Barren measures whose thickness varies from about 200m to 560m in the study area. Barren Measures is represented mostly by medium to coarse grained, occasionally gritty, buff to white sandstone and variegated clay/ siltstone. Sandstone are immature and arkosic in nature and matrix is clayey.

Barakar formation consisting the coal seams is succeeded by the Barren Measures and may be further classified into upper and lower Barakars.

The upper Barakars consisting of medium to coarse grained sandstone, shales, intercalations and the coal seams. Basically, five major coal seams occur across the coalfield named as Seam V to Seam I (being the bottom most) where the depth of the top most seam V varies from 230m to 580m. The lower member generally consist of very fine to fine grained sandstone, siltstone, shale and discontinuous Coal bands / Seams. Sandstone units are arkosic to sub – arkosic in nature and matrix is generally feldspathic.

Basic Intrusive is represented by dolerite. It occur as low angle Sill with Easterly to South-easterly slope. It varies in thickness from 1.35 m to 10.50m with depth ranges from 757.50 m to 667.40 m.

The general stratigraphy of the study area is shown in Table-1.

MATHEMATICAL APPROACH TO EVALUATE PERMEABILITY FROM WELL-LOGS

The basic electrical parameters of well logs namely Single Point Resistance (SPR), Long Normal Resistivity (64N) and Short Normal Resistivity (16N) along with Natural Gamma (in cps) are considered in this study to evaluate few of the key factors like:

a) Fracture density (n per cm^2)

b) Fracture width (w in µm)

c) Permeability (K in mD)

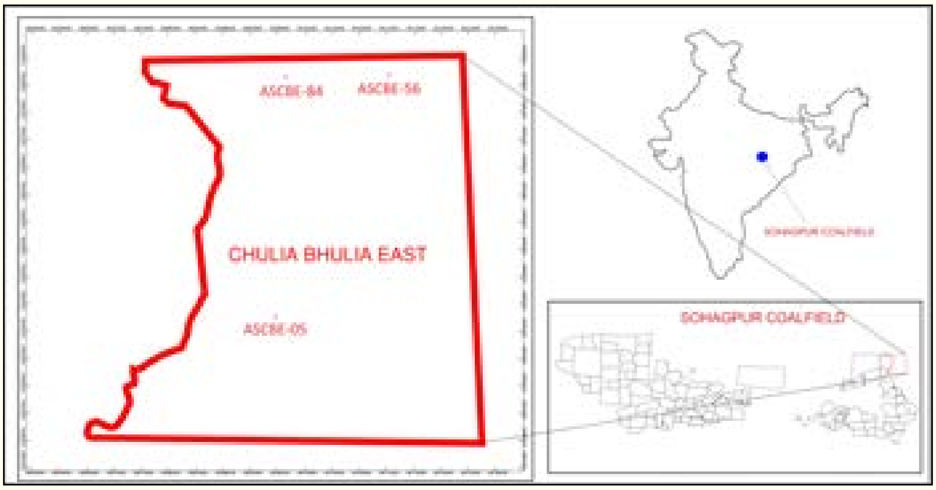

Figure-1: Location of study area in Eastern Sohagpur coalfield MP

The well logs recorded in three wells located in Chulia Bulia East block of Eastern Sohagpur coalfield (as shown in Figure-1) are considered for quantitative analysis using the mathematical approach discussed in this section to arrive at the conclusion of the above three key parameters affecting the desorption rate of gas in the wells. The logs are recorded in open hole environment using PHPA

Table-1: Stratigraphic sequence of Eastern Sohagpur Coalfield, Madhya Pradesh, India

Age	Formation	Strata
Lower Triassic	Deccan Trap	Basic Rock Dolerite
	Pali Middle Member	Medium to fine-grained sandstone grey & carbonaceous shale & coal seams.
Upper Triassic	Pali Lower Member	Medium to coarse grained ferruginous sandstone grey shale & shale bands
Middle Permian	Barakar	Feldspathic fine to coarse grained sandstone, carbonaceous shale & coal seams.
Permian	Talcher	Fine to medium grained moderately Sorted greenish sanstone with green chocolate colored siltstone diamictite, rythmite

drilling fluid which will be taken into consideration later while evaluation.

First of all, its worth discussing here the functionalities of the three electrical logs used in this study where two of them 16N and 64N are resistivities with short and long spacing resistivities whereas the remaining one is SPR which is resistance and we have to convert the same into resistivity using the basic equation:

$$R=(SPR \times L)/A \ldots\ldots\ldots\ldots\ldots(1)$$

where SPR is resistance in ohm, L is length (m) and A is area (m^2).

The Area is calculated of a disc whose centre is that of the sonde, and radius is the sum of radius of the well (NX size is 89cm/2 and depth of investigation(5cm/2) which comes to be around 7 cm from the centre. L is the length of the receiver which is too small and thus assumed to be 2.5mm. This resistivity calculated using single point resistance is assumed to be equivalent to Focussed log parameter.

Before proceeding to the mathematical simulations, we must understand the models which can explain the pattern of a fractured reservoir like coal. As per the study of Reiss (1980), the pattern of a fractured reservoir can be explained by either of the three models. Model I where the coal matrix behaves like parallel sheets separated by fracture planes as shown in Figure-2 whereas the Model II is like vertical match sticks separated by orthogonal fracture planes whereas the Model III is described as cubes separated by three orthogonal fracture planes.

In this study, we shall go ahead with Model I where the coal matrix are assumed to be parallel sheets of planes separated by fracture planes usually cleats.

Several researchers have proposed several models to decipher permeability (Sibbit and Faivre 1985; Li *et. al.*, 2011) but here in this study, the model proposed by Hou (2000), will be utilised given by:

$$K_f=8.50 \times 10^{-4} w^2 Ø^f \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where w is fracture width (in µm), $Ø^f$ is the fracture porosity and K_f is permeability in mD.

In many earlier studies for permeability (), electrical parameters like Shallow Long Laterolog (LLS) and Deep Lateral Resistivity (LLD), but in this study Normal Log instead of Laterolog is used for framing the reservoir properties for CBM in Sohagpur coalfield.

Equation (2) shows that for determination of permeability depends upon the efficiency in estimation of these two significant w and $Ø^f$. These two parameters are to be determined using the Long Normal Resistivity (64N) and the Short Normal Resistivities (16N) along with Focussed Resistivity calculated from Eq (1).

To relate the porosities and fracture width, two different porosities $Ø^{fd}$ and $Ø^{fm}$ are taken into consideration depending upon their depth of investigation from two normal logs (Yao *et; al.*, 2014; Li *et. al.*, 2011).

$$Ø^{fd}=wn_d/\pi(d1+d2)\ldots\ldots\ldots\ldots..(3)$$

$$Ø^{fm}=wnm/\pi(d0+r_w)\ldots\ldots\ldots\ldots.(4)$$

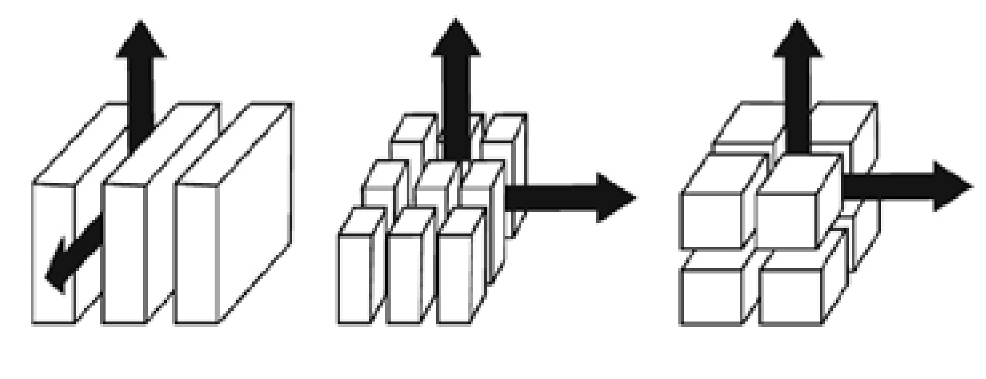

Figure-2: Cleat permeability models proposed by researchers in coal seams (Yan *et. al.*, 2014)

where n_d and n_m are the numbers of fracture in the detection zone of 64N and FOCUSSED LOG, respectively; d_0, d_1, and d_2 are the radial detection depths of FOCUSSED LOG, 16N and 64N log apparatus, respectively; and rw is the radius of the borehole.

The fracture width w (**in µm**) which may be also termed as aperture, is one of the vital estimations which shall severely affect the accuracy of determined permeability. W can be expressed as (Yao *et. al.*, 2014; Sibbit and Faivre., 1985) :

$$\Delta C_{DM}=awC_{mf} \ldots\ldots(5)$$

where ΔC_{DM} is $C_{FOCUL}-C_{64N}$ (mS/m), a is a constant and C_{mf} is conductivity of drilling fluid.

The conductivity in the deep resistivity zone and focussed resistivity zones by Archie's law can be defined as:

$$1/R_{64N}=Ø_{fd}^{mf} S_{wfd}^{nf}/R_{zd} \ldots\ldots(6)$$

$$1/R_{FOCL}= Ø_{fm}^{mf} S_{wfm}^{nf}/R_{zm} \ldots\ldots(7)$$

where R_{64N} is the deep lateral resistivity (Ω•m); R_{FOCL} is the Focussed logging resistivity (Ω•m); Swfd and Swfm stand for the water saturations of fracture network in deep and focussed detection zones, respectively; Rzd and Rzm are the fluid resistivities (Ωm) in deep and focussed detection zones, respectively; mf is the fracture cementation index; nf is the fracture saturation index. If it is assumed that the fractures in the focussed log zone is only filled with drilling fluid whereas the fractures in the deep resisitivity zone is completely debar of drilling fluid then Swfm = Swfd = 1; Rzd = Rw and Rzm = Rmf.where Rmf and Rw are the resistivities of drilling fluids and formation water.

From equation (6) and (7),

$$1/R_{FOCL}-1/R_{64N}=Ø_{fm}^{mf}/R_{mf}-Ø_{fd}^{mf}/R_{w} \ldots\ldots(8)$$

The cementation index m_f can be calculated using equation (Yao *et. al.*, 2014):

$$R_{64N}/R_{w} = 1/ Ø_{fm}^{mf} \ldots\ldots(9)$$

The porosity at focussed zone detection zone $Ø_{fm}$ may be calculated using (Yang *et. al.*, 2005)

$$Ø_{fm} = (R_{mf}/ R_{FOCL})^{1/1.6} \ldots\ldots(10)$$

ELECTRICAL LOGGING RESPONSES OVER COAL SEAMS

The electrical logging parameters constitutes 16N, 64N and Focussed Resistivity Log (FRL) calculated from Single Point Resistance log recorded in the study area. The reservoir permeability shall be determined using the variations in these logs over the various coal seams and hence quantitative analysis of the logs must have precision for efficiently mapping the permeability variation in the study area.

The above mentioned three logs were considered of the wells ASCBE005, 056 and 084 in Chulia Bulia East block of Sohagpur coalfield with major seams encountered being Seam V, IV, IIIT and IIIB. The responses of the logs over the seams are shown in Figure 3 are analysed and the Focussed Resistivity Log (FRL) is calculated from SPR upon certain assumptions discussed earlier. The major seams in the considered wells are taken into considerations and the responses of the considered logs are shown in Table-2.

Its quiet obvious that the depth of investigation tends to increase from FRL to 16N and further to 64N due to the increase in spacing among the detectors. The calculated value of FRL is observed to vary from 44 Ωm to 97 Ωm in the coal seam zones among the three wells whereas the values of recorded 16N and 64N tends to range from 20 Ωm to 700 Ωm and 360 Ωm to 1860 Ωm across the seams in the considered borehole. Although the average resistivity recorded by 16N and 64 N logs are 499 Ωm and 1186Ωm which indicate moderate quality of coal seams in the considered wells.

The Focussed Resistivity Log (FRL) is calculated from the responses of the SPR logs in Ω considering the area where the sonde is at the centre of a disc whose radius is the sum of that the borehole and depth of investigation (which is assumed to be 5cm) as shown in Table-2. The FRL (in Ωm) in this study is believed to be focussed as it is calculated from the log responses of SPR logs.

Table-2: Details of the coal seam samples considered in three wells used for the study and the well log responses recorded over the seams

WELLS	SEAM	FROM (m)	TO (m)	SPR (in Ω)	FRL (in Ωm)	16 N (in Ω m)	64 N (in Ω m)	AREA (in m^2)	LENGTH (in m)
ASCBE005	SEAM V	440.27	441.35	474	76.99	772	1689	0.0153	0.0025
		432.67	433.95	329	53.48	437	1021	0.0153	0.0025
		434.8	435.87	286	46.45	440	832	0.0153	0.0025
		437.4	438.2	277	44.99	100	362	0.0153	0.0025
	SEAM III T	573	574.45	597	96.97	571	1844	0.0153	0.0025
	SEAM III B	582.11	583	468	76.01	18	754	0.0153	0.0025
ASCBE084	SEAM V	469.91	472.97	375	60.91	889	1151	0.0153	0.0025
	SEAM IV	567.51	568.45	313	50.84	164	983	0.0153	0.0025
ASCBE056	SEAM V	455.5	457	442	71.86	756	1247	0.0153	0.0025
		457	458.48	361	58.63	617	1010	0.0153	0.0025
		458.48	460.78	498	80.89	136	1605	0.0153	0.0025
		464	466.18	441	71.63	982	1238	0.0153	0.0025
	SEAM III T	581	583	485	78.78	874	1760	0.0153	0.0025
	SEAM III B	588.02	589.22	441	71.63	294	1236	0.0153	0.0025

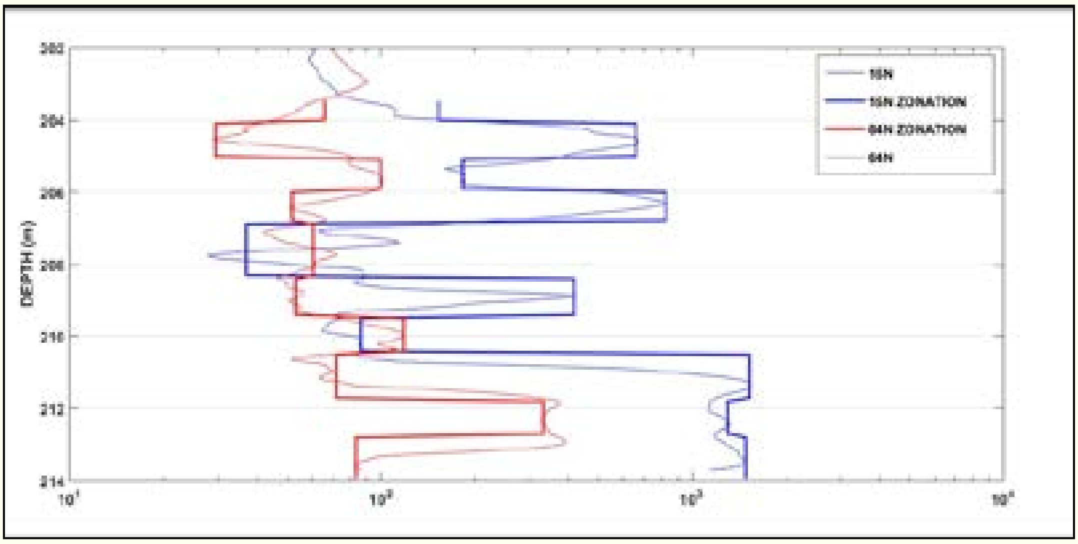

Figure-3: Electrical Log responses and zonation over Seam V in the study area in Eastern Sohagpur CF, Madhya Pradesh, India

A total of six coal bands is considered in each of the boreholes ASCBE 005 and ASCBE056 whereas only two bands are considered from the borehole ASCBE084. The gas content (in m^3/ton) is provided by CBM cell, CMPDI HQ, Ranchi which shall be used to analyse the variation of gas content in the samples depending upon the permeability estimated from the well logs.

As shown in Table-3, ΔC_{DM} is estimated from $C_{FOCUL} - C_{64N}$ from the resistivities recorded by the electrical log and shown in Table-2. The fracture aperture W is estimated using equation (5) using the data ΔC_{DM} and C_{mf}. This leads to estimation of $Ø_{fm}$ using equation (10) in the previous section. Now, the cementation index mf needs to be estimated using equation (9) where the remaining factors are determined from the recorded logs shown in Table-2. Proceeding further, $Ø_{fD}$ which is the porosity of the deep resistivity zone is determined using equation (8) as shown in Table-3. The determination of $Ø_{fD}$ and $Ø_{fm}$ in the considered seams leads to the approximation of $Ø_f$ from the electrical logs in the three boreholes shown in Table-3. The porosity

Table 3: ΔC_{DM} is estimated from $C_{FOCUL} - C_{64N}$, C_{mf} is conductivity of mud filtrate, W is the fracture aperture, m_f is the fracture cementation index, Øfm and Øfd are the porosities of the zones of penetration of deep and focussed logs recorded and K (mD) is the estimated permeability.

WELLS	SEAM NAME	FROM (m)	TO (m)	ΔC_{DM}	C_{MF}	W(um)	$Øm_f$	mf	Øf	K (mD)	Gas Content DAF basis (m3/ton	NEAREST WELLS WITH DESORPTION TESTS
ASCBE005	SEAM V	440.27	441.35	11.69276	0.487805	5.992542	0.016357	1.311958	0.266551	4.977809	0.41	ASCBE033
		432.67	433.95	16.40935	0.487805	8.409791	0.023547	1.287678	0.261541	9.99609	0.45	
		434.8	435.87	19.25301	0.487805	9.867166	0.027109	1.339844	0.266676	13.88901	0.46	
		437.4	438.2	12.22513	0.487805	6.265377	0.02799	0.937496	0.26916	5.634479	0.41	
	SEAM IV	522.17	523.65	0.258748	0.487805	0.132609	0.016267	0.756735	0.270822		N.A	
	SEAM III T	573	574.45	8.560847	0.487805	4.387434	0.012987	1.172846	0.259256	2.645005	0.55	
ASCBE084	SEAM V	469.91	472.97	15.2921	0.487805	7.837202	0.020675	1.42758	0.264535	8.611539	0.91	ASCBE088
	SEAM IV	567.51	568.45	13.57132	0.487805	6.955302	0.02477	1.040291	0.26799	6.8711	0.84	
ASCBE056	SEAM V	455.5	457	12.59307	0.487805	6.453949	0.017525	1.329161	0.26237	5.792162	N.A	ASCBE089
		457	458.48	15.43288	0.487805	7.909353	0.021477	1.34663	0.26516	8.791548		
		458.48	460.78	5.009227	0.487805	2.567229	0.015569	0.879254	0.261735	0.914253		
		464	466.18	12.94167	0.487805	6.632606	0.017581	1.394929	0.262372	6.117321		
	SEAM IIIT	581	583	11.54936	0.487805	5.919048	0.015986	1.334684	0.261264	4.851309	1.50	
	SEAM IIIB	588.02	589.22	10.55864	0.487805	5.411303	0.017581	1.096481	0.262662	4.076394	1.78	

$Ø_f$ is assumed to be the mean of $Ø_{fD}$ and $Ø_{fm}$ whose estimation has been discussed earlier. The porosity in the considered seams are observed to be more or less consistent varying from 0.25 to 0.27.

The permeability of the considered seams are estimated from the determined porosity and fracture aperture values using the equation (2) discussed in the earlier section. The permeability of the seams are one of the key factors governing the rate of desorption of gas as the cleats and fractures are the pathways for the gas flow from the matrix to the well. The estimated permeability shows moderately high values (almost >5 mD) in the seams of eastern Sohagpur coalfield which is going to be an advantage for production of CBM from the study area.

The desorption tests are carried out by CBM lab, CMPDI (HQ), Ranchi on the core samples collected from the drill sites of the three wells in Chulia Bulia East block of Sohagpur coalfield. The results of the gas content in the wells are compared to the permeability obtained from the well logs as discussed in the earlier section.

COMPARISON OF GAS CONTENT (IN M^3/TON) AGAINST ESTIMATED PERMEABILITIES (IN MD)

The estimated permeability of the considered coal seams V, IV, IIIT and IIIB in the wells ASCBE005, ASCBE056 and ASCBE084 are compared with the desorption results obtained from the coal cores in the laboratory. The considered gas content results are of Dry Ash Free (DAF) basis obtained by the team of CBM cell in CMPDI (HQ), Ranchi from three wells in Chulia Bulia East block of Sohagpur coalfield.

The limitation of the study in this sectionis that the gas content results obtained from the core samples are not of the same wells in which the permeability have been estimated due to absence of geophysical logs in the desorption wells. But, here it has been attempted to consider the geophysical logs of those boreholes which are nearest to those of the desorption test wells in the block. Significant care has been taken while correlating the seams for comparison of the calculated permeability and obtained gas content results for inferring a clear portrait regarding the dependency of these two features of coal.

The variation of gas content in a coal seam is typically determined by measuring the volume of gas desorbed from core samples where the permeability through the cleats and fractures acts as the pathways for the gas to flow from the matrix to the wells after lowering of the pressure from the coal seams. Figure-4 clearly reflects the dependency of the gas content measured in the laboratory over the coal seams' permeability (in mD) estimated from the well logs. The gas content in the seams varying from 0.41 m^3/ton to 1.78 m^3/ton typically showing a gradually increasing trend with depth as shown in Figure-4.

A quadratic polynomial was tried to best fit the variation of the gas content values determined in the lab with the estimated permeabilities as shown in Figure-4. The correlation coefficient of the polynomial with the data was observed to be 0.60 which is moderately good. The polynomial can be expressed as equation (11) to relate both the above specified parameters in the study area.

Gas Content (m^3/ton) = 0.0172 x K(in mD)^2 - 0.1233 K(in mD) + 0.7377…………(11)

The estimated permeability from the well logs shows a n average permeability of about 6 mD in the seams considered in this study which is believed to be better than moderate permeability for coal seams for production of CBM gas.

CONCLUSIONSANDRECOMMENDATIONS

The estimation of permeability may be done using either of the direct or indirect methods for evaluation of the deliverability of gas by a reservoir. The gas assessment studies in eastern Sohagpur coalfield is the preliminary step towards the development of CBM gas in the CIL command area. The estimation of permeability using electrical well logs has been established by many earlier researchers and the similar model is used to determine the permeability in this study also. The average permeability estimated from geophysical electrical logs in the study area is about 5-6 mD which is conventionally considered to be moderately high permeability in CBM reservoirs, whereas the permeability determined from few samples of Chulia Bulia East block in the CBM laboratory, CMPDI (HQ), Ranchi is about 4.5 mD.

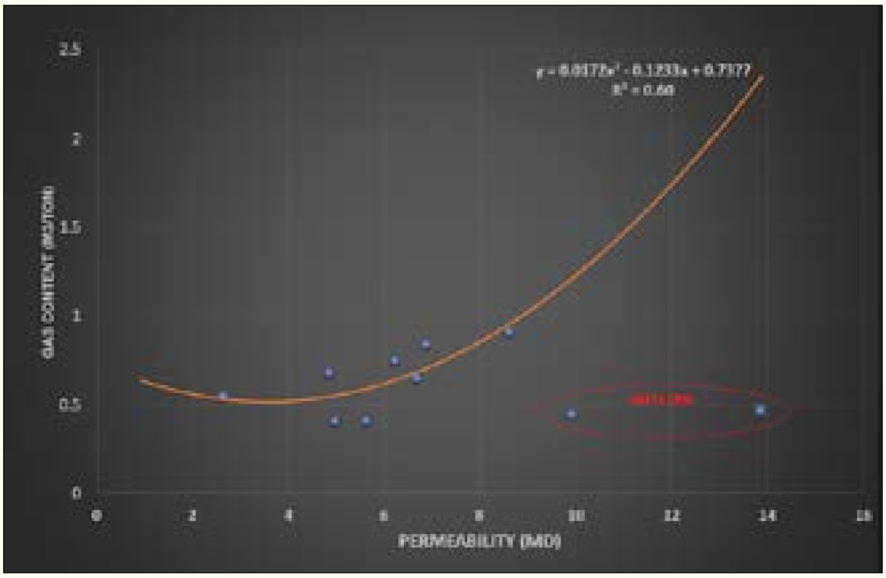

Figure-4: Variation of estimated permeability (mD) against the determined Gas Contents (m^3/ton) Eastern Sohagpur CF, Madhya Pradesh, India

The maximum gas content determined from the core samples in the study area is observed to be about 1.78 m3/ ton at a depth of more than 600m in a well in the study area which may be considered to be of moderate gassy seams in comparison to the relatively higher gassy seams in the Damodar Valley coalfields in Jharia and Raniganj coalfields. But the high permeability of the coal seams delivers an additional advantage during the development and production stage in future. It is also recommended to analyse the triaxial permeability and image the in-situ fracture orientation using Borehole Imaging methods like Acoustic Televiewer or Focussed Micro Imaging (FMI) tool in the wells in the future stages of study in the area.

LIMITATIONS OF THE STUDY

The estimation of permeability with efficiency is very significant for planning of project feasibility for any CBM gas field. This study focussed on the overall permeability using the well logs data acquired in the field which can also be measured from the coal core samples in the laboratory. But, the limitations of this study can be specified as:

1) Lack of geophysical log data in the wells in which desorption tests were carried out.
2) Basic electrical parameters (namely 16N, 64N and SPR) were used in the study where the logs used is affected by matrix as well as fluid filled in the pores.
3) Limited quantity of gas desorption results in the study area.

ACKNOWLEDGEMENT

The authors are highly obliged to the CBM cell & CBM lab, CMPDI (HQ), Ranchi for providing the desorption results of Sohagpur coalfield for completion of the study. The authors are also grateful to Shri I. D. Narayan, Regional Director, and Shri Subhas Surin, HOD (Expl), CMPDI, RI-V for their consistent support and valuable suggestions to accomplish the gas assessment studies in Sohagpur coalfield. The authors delivers thanks to Shri A. K. Mohanty, GM (Exploration), Dr. A. K. Panda, GM (Geology), Shri N. P. Srivastava, CM (Geology), CMPDI (HQ), Ranchi and Geophysics Section of CMPDI, RI-V for providing their views and suggestions for improvement of the study.

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Monsoon Preparations in larger Opencast Coal mines-A study based on Northern Coalfields Limited

Jai Prakash Dwivedi[1], R. B. Sindhur[2], Himanshu Wadhwani[3]

MONSOON IN INDIA

Monsoon is a familiar, though a little known climatic phenomenon. Many attempts have been made to discover the exact nature and causation of monsoon, but so far, no single theory has been able to explain the monsoon fully. During April and May when the sun shines vertically over the Tropic of Cancer, the large landmass in the north of Indian Ocean gets heated and causes the formation of an intense low pressure zone in the northwestern part of the subcontinent. Since the pressure in the Indian Ocean in the south of the landmass is high as water gets heated slowly, the low attracts the southeast trade winds across the equator. These conditions help in the northward shift in the position of Inter-tropical convergence zone. The southwest monsoon as the continuation of southeast trades and easterly jet streams after the withdrawal of westerly jet streams is held responsible for the burst of monsoon in India. The southwest monsoon sets in over the Kerala coast by 1st June and moves swiftly to reach Mumbai and Kolkata between 10th and 13th June. By mid-july, southwest monsoon engulfs the entire subcontinent. (IMD, 2018)

Anxiety over delayed rains is nothing new. This anxiety is like the rains themselves: a staple of Indian life. The monsoon isn't just the key climatic or agricultural event in the Indian subcontinent — it's the key economic event. Its effects reach far beyond agricultural output, shaping political dynamics on both the regional and national levels. Agriculture accounts for 18 percent of India's growth domestic product (GDP) and employs around half of its total workforce. The monsoon rains are the main source of water for 55 percent of the country's arable land. This means the rains are crucial — not only for India's farmers, but for its economy as a whole.

But for a Mining Engineer at opencast mines, he sees monsoon as hardship. The monsoon keeps him on toes- maintaining stability of dumps, water management, pumping out water, slippery haul roads, risk of drowning of machines, disruption in power, flow of silt in adjoining areas- villages, public wrath keeps him worried and over worked for he has to maintain coal production levels. In mines water has always been a source of danger

Fig-1: Monsoon Onset Map of India

[1] General Manager, [2]Chief Manager (Mining), [3]Asstt Manager (Mining), Amlori, NCL, Singrauli

and many inundation have occurred due to heavy rainfall, change of water course, constriction on water courses, in accurate survey, incorrect mine plans, ineffective evacuation system, geological disturbances, water charged strata.

NCL- a company with difference for having all the mines with opencast mines and also operating with high stripping ratios (above 1:4). It not only moves mountains but also create mountains (of 400 Mcum qty annually). 90% of its produce goes to pit head power plants and the company is responsible for 15% of nation's coal production and 10% power generation. Consistent Coal supply to power plants is essential. The area has an average rainfall of 1200 mm, but due to high stripping ratios vast open and excavated areas, even a small quantity of rainfall disruption in production is likely to happen. Effective steps ahead of monsoon and during monsoon need to be taken. (Akala, 2018)

EFFECT OF MONSOON INTRA SEASONAL VARIABILITY ON OPENCAST MINE PLANNING

1. Drop in coal production: Pegged at 22% in Q2 in planning process, may dip further to 3-4% below also.
2. Deterioration in quality of coal: Due to flow of silt to coal faces and increase in moisture content, the quality is likely to dip to around 5-10%.

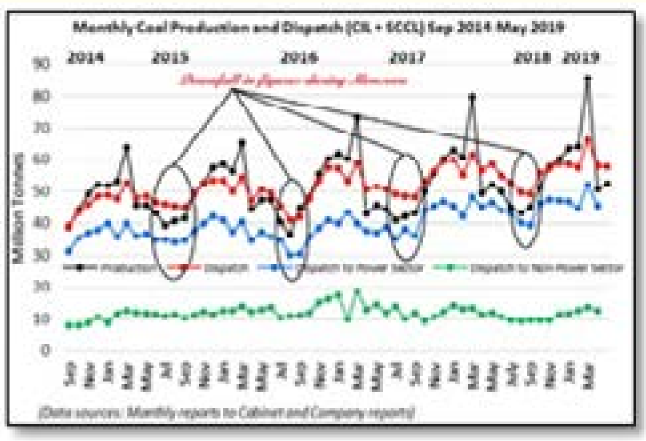


Fig.-2: Drop in Monthly Coal Production & Dispatches during Monsoon Period. (Monthly reports to Cabinet and Company reports, May 2019)

3. Increase in risk of stability of dumps: Very often the hydro-static pressure inside the dumps increases due to incessant rains, this in turn may unstable the dumps which otherwise were stable pre-monsoon: A list of incidences that happened in past is enclosed in Table-1.
4. Breach of retaining walls, gabion walls, flow of silt in adjoining areas, blockage of railway tracks and disruption to power supply. Fig pic in Annexures.
5. Drowning of costly HEMMs.
6. Slippery haul roads leading to reduced tire life.
7. The more dangerous and out of control situations arise is when dump silt flows into property not belonging to mine owner, especially villages, houses and agricultural land. This will incite public wrath and huge compensation will be demanded from them. Protection against these properties should be on top priority. Atleast mine management should plan and be ready to face torrential rains of the quantity double than the highest rainfall. All drains should be wide enough to course water to its proper destination.
8. The toe of dump if not maintained at safe distance and if not protected by drainage and retaining walls, the silt is likely to rush on haul-roads and disrupt mine operations.

UNDERSTANDING THE DRAINAGE SYSTEM, RIVERS, DAMS, NALLAHS OF ADJOINING AREA

General topography of the coalfield shows plain country to the South. East & West has a gentle slope towards the Rihand river in south of the coalfield forming main drainage of the area. Kachni river, Ballia nala, Bijul nala and Tippa-Jharia nala are the important streams for drainage of the coalfield. Kachni river drains a major part of the area in the west, Ballia nala drains the eastern part, Bijul nala drains the northern part and Tippa-Jharia nala drains the north-eastern part.

Dumps which are least compacted are likely to flow in the event of heavy rains, gullies, raincuts are formed. To avoid this, proper water management has to be made. Dumps have to be kept properly

Table -1: List of incidents of opencast mines due to instability of dumps (DGMS 2019)

Year	State	Name of Mine	Name of Company	Date of Accident	No of Persons Killed	No of Persons Seriously Injured
2007	Jharkhand	Chasnalla	IISCO	21/08/2007	1	0
2008	Madhya Pradesh	Jayant	NCL	17/12/2008	5	0
2009	Maharashtra	Sasti	WCL	4/6/2009	2	0
2010	Maharastra	Umrer	WCL	28/09/2010	1	1
2011	Jharkhand	Chasnalla	IISCO	9/3/2001	1	1
2011	West Bengal	Dalurband	ECL	14/06/2011	1	0
2013	Odisha	Bharatpur	MCL	21/04/2013	1	1
2013	Odisha	Kulda	MCL	10/8/2013	13	0
2014	Madhya Pradesh	Dhanpuri	SECL	1/6/2014	2	0
2016	Jharkhand	Rajmahal	ECL	29/12/2016	23	0
2019	Odisha	Bharatpur	MCL	23/06/2019	4	9

benched at 30m x 30m bench. A galena or any other software may be used for assessing the FOS, but in no case dumps should be steeper than 28°. It takes nearly 25 years for complete consolidation- a report abstract is given in Fig.-6.

MONSOON PREPARATORY ACTIVITIES

The following steps are required to be taken to reduce the impact of heavy downpour during monsoon:

A. Activity Schedule: Scheduling of activities under monsoon action plan shall commence from the start of the calendar year so that the execution of activities are completed before the onset of first rainfall. It would be appropriate to prepare a calendar program of all the monsoon activities. A timeline should be followed to keep the monsoon preparatory activities on track as in Fig-7 (Pg-16).

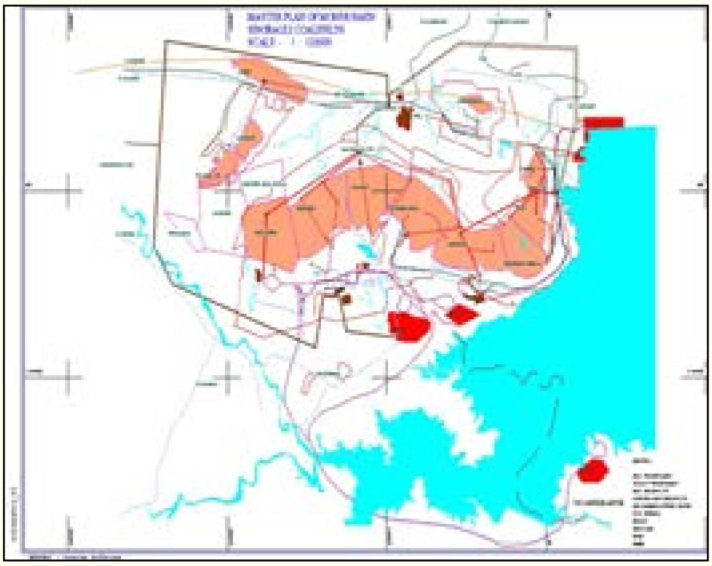


Fig.-3: Drainage System of Singrauli Coalfields

B. Mine Planning and Operations:

Monsoon Preparation Plan :

Monsoon preparation plan of the mine is required to consider :

a. An extensive study of the catchment area,
b. Expected position of dragline cut in both the sections
c. Estimation of available sump capacity in and around the mine.
d. Expected volume of OB dump and its extent demarcated on plan,
e. Direction of water flow during rainfall, inside and outside of mine,
f. Material properties of OB dump.
g. Position of siltation ponds with specifications along the water flow route.
h. Stabilization of dump slopes before monsoon.
i. Position and details of garland drains and mine drains.

Monsoon preparation plan shall include location and details of all the drains with specifications, siltation ponds, hume pipe and box culverts, stretch of gabion walls, alignment of drains etc.

CONSIDERATIONS FOR MONSOON PREPARATIONS

Fig.-4: Considerations for Monsoon Preparation

DUMP SIZE AND DUMP PARAMETERS VULNERABLE TO SLIDE

Fig. -5: Year Wise OB Removal in MCuM in NCL

Table-2: Period-wise remarks on stability of dumps

Period	Average OBR/ year (M.Cum)	Remarks
1990-91 to 2010-11	129	Compacted
2011-12 to 2014-15	205	Moderately compacted
2015-16 to 2016-17	320	Less Compacted
2017-18 to 2018-19	318	Fresh and Least compacted

Calculation of catchment area and sump capacity shall be considered on the basis of peak rainfall within a short span of time and shall be vetted by CMPDIL and ISO. Assessment of catchment area may consider 100% for solid area and 60% for Dump/loose. Layout and size of garland drain shall be such as to manage peak rainfall.

Monsoon action plan shall include mine developmental activities considering the scale of mine extension and volume of OB handling and activities required for dealing the effect of rainfall in monsoon. (S. J. Sibal, 2016)

Sump Preparation

a. Method of advance Sump preparation, wherever feasible, in the successive cut shall be adopted. This will enhance the sump capacity and safety of installations.

b. Mine operation shall include preparation of sump with pumping facility in Purewa bottom and Purewa top floor, according to topographical suitability, in order to avoid the diversion of total rain water to the Turra seam sumps. Mine should be advanced in main dip direction first prior to June so that sump could be prepared in the dip most area.

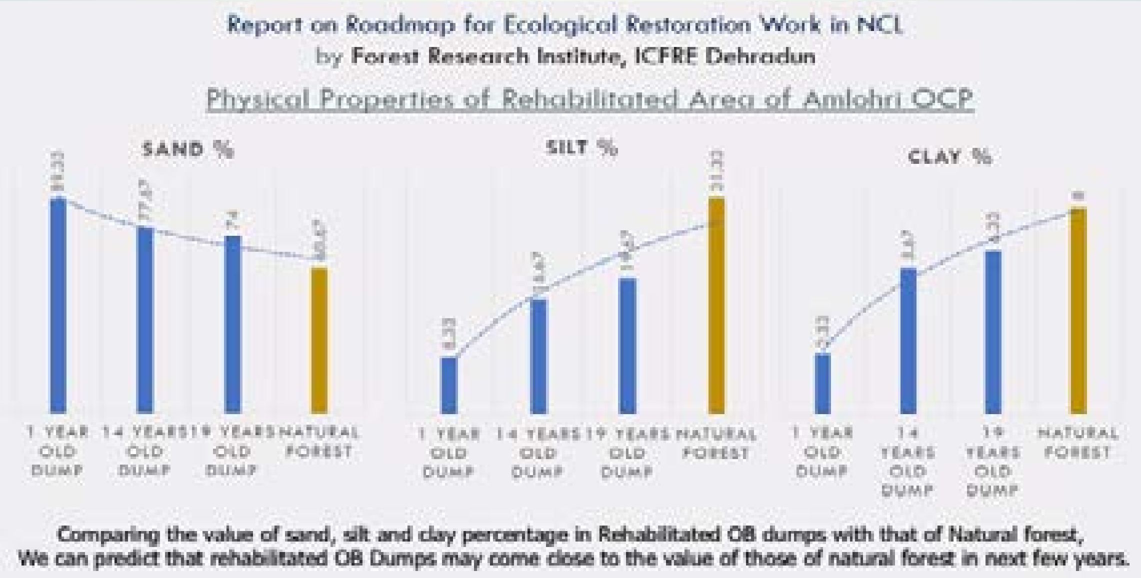


Fig.-6: Physical Properties of rehabilitated area of Amlohri OCP, NCL (ICFRE, 2018)

c. Mine operational plan shall consider the scheduling of coal faces in such a manner that coal production by shovels and surface miner from dip side area of Purewa bottom and Purewa top seam, during the monsoon period is avoided and the same shall be considered for sump preparation.

Dump Management

a. Mine operation shall ensure proper benching of OB dumps. The operation shall also consider the direction and gradient of table top of the dumps in order to regulate the direction and flow of water during the rains.

b. A Dump Management organization should be established in the project which will be responsible for design and maintenance of dumps so that proper benching & slope is maintained, water flows along the designed path, slope stabilization is done by technical and biological reclamation.

c. Mine operation shall ensure that storage of top soil do not add to the flow of silt during the rains. If possible, table top of the dump shall be considered for topping by second bench material, in order to restrict the silt flow.

d. Stabilization of dump slopes, by benching, erection of gabions, appropriate plantation and preparation of water pathways in the dump slopes shall be considered in the mine operational plan.

C. Plantation

a. Plantation work should be taken up wherever dumps have reached their ultimate height and this should be well coordinated by Manager, planning department and Environment, so as to avoid submergence of plants later on.

b. Washed out plantation in OB dumps shall be considered for replantation by appropriate technical reclamation.

c. Different methods involving High performance Flexible Growth medium for Erosion control or reinforced geo composites shall be considered for stabilization of dumps.

Fig.-7:Timeline for Monsoon Preparatory Activities

D. E&M related works

Pumping system :

a. Sufficient no. of pump and motor assembly along with Switches and starter panels shall be made available before the onset of monsoon period, with a view to counter any emergency situation.

b. It is also advisable that standby pump and motor assembly shall be mounted on the pontoons and placed near the sump area for dealing with emergency circumstances.

c. Flexible pipes of matching dia and longer lengths shall be fitted on the delivery side, for flexibility of operation during sudden increase of water level.

d. High capacity diesel pumps shall be considered for deployment in emergency condition.

Pipelines:

a. Fixed pipe lines near the main sump area shall be elevated to appropriate level, so as to deal with sudden increase water level.

b. Refurbishment/replacement of existing pipelines shall be done before the onset of first rainfall.

c. Pipelines shall be set on the pedestal along the main entry to the Turra seam.

Power Supply:

a. Alternate of power supply shall be made so as to immediately resume power in case of emergency.

b. Power supply to panels and starters shall be done by overhead lines erected at an higher altitude, so that it is not affected by water accumulation or silt.

c. It is also considered that standby starter panels and switches of the pontoon pumps, if applicable, shall be mounted on the pontoons, to avoid its submergence / damage during the heavy rains, which shall be used in case of emergency.

d. To prevent the possibility of theft of conductors and thereby stoppage of power, towers should be established, if feasible, for provision of uninterrupted power supply.

E. Civil related works

Retaining Walls :

a. Existing retaining walls - their strengthening and additional requirement should be identified, planned and executed, irrespective of monsoon dates.

b. Existing RRM wall shall be replaced by RCC walls, as per the requirement.

c. De-silting backside of existing retaining wall at various locations are required to be completed on time

Silt protection :

a. Identification of infrastructure at lower levels, close to drains which might get damaged/ affected should be identified and planned to either shift or raise levels if possible or provide sufficient protection to guard against silt/water.

b. Embanking by earthwork and side slope pitching stone, is required on different slopes including the dump slopes at vulnerable locations.

c. Extensive installation of Gabion wall shall be considered for arresting of silt and stabilization of slopes , and the work shall be undertaken throughout the year.

RCC culverts & Hume pipes:

a. Requirement of RCC culverts shall be assessed on the basis of experienced gained in the current year monsoon and proposed under mine development program.

b. Hume pipe culvert of 1800mm diameter, shall be considered for deployment. (Shivir, 2016)

Effects of Heavy Rains in Larger Opencast Mines

Fig.-8: Silt flow from dumps

Fig.-9: Damaged RRM Wall

Fig.-10: Damage to Railway track

Fig.-11: Rise of water level in coal face

Fig.-12: Heavy Rain cuts

HOW MUCH RAIN WE CAN WITHSTAND

From Year 2011-15, there was not any major damage to mine infrastructure as the average rainfall was around 250 mm in a span of 8 days. Whereas in Year 2016, with the maximum rainfall, there was a huge infrastructural damage to mine. It is more about short span of heavy rainfall that cause devastation. Suppose we have rain of 100 mm on a day and next day it continues to rain another 100 mm then the silt start flowing and damages can happen.

It may not be feasible in a large opencast mines to have a single large sump at its present deepest portion of excavation. Normally the main sump is located at the deepest portion of the present excavations (which is likely to remain throughout the current year. Once Coal excavation is done, depending upon the site situation the floor may be deepened to the extent possible (so that muck is removed). Additional sumps in other areas depending upon the catchment area they are likely to cater should be made accordingly. In the above example. 3 Sumps – one in purewa and two (east and west) sumps may be created. If space permits stage pumping may be be also done, pumping from one sump to other sump at higher level, thereby avoiding high pumps and also improving face pumping efficiency.

Pumps and pumping

Depending upon the water effecting coal evacuation program, pumps need to be installed

Table-3: Year wise Rainfall in Jayant & Nigahi OCP (S.J Sibal, 2016)

Year	Jayant OCP			Nigahi OCP		
	Rainfall from June-Sept (mm)	in a span of 8 days		Rainfall from June-Sept (mm)	in a span of 8 days	
		Max Rainfall (mm	Period		Max Rainfall (mm)	Period
2011	1912	393	5-12 Aug	1741	395	5-12 Aug
2012	1315	232	28 Jul-4 Aug	1206	225	28 Jul- 4 Aug
2013	1204	161	21-28 Jul	971	156	25 Jun- 2 Jul
2014	980	201	1-8 Sep	869	230	3-10 Aug
2015	755	259	6-13 July	705	243	6-13 July
2016	1963	505	11-18 Aug	1901	441	11-18 Aug

in such a way that they can dewater in 3/7/15 days' time (15 days where no coal production is likely to be affected). Selection of head, capacity of pumps is also an important criteria as we have to keep number of pipe ranges to minimum. Spare pumps, alternate power arrangements should be kept in readiness. In large opencast most suitable are pumps on pontoons, so that they can rise upto 8-10 m.

For draining out water beyond mine area

RCC drain of inner dimension 3m x 2m will be capable to handle water of catchment area 1 to 2 sq km. A minimum slope of drain should be 1 degree. If a slope of 2 degree is provided, the water flow rate will be higher and it will cater the water handling requirement from much higher catchment area.

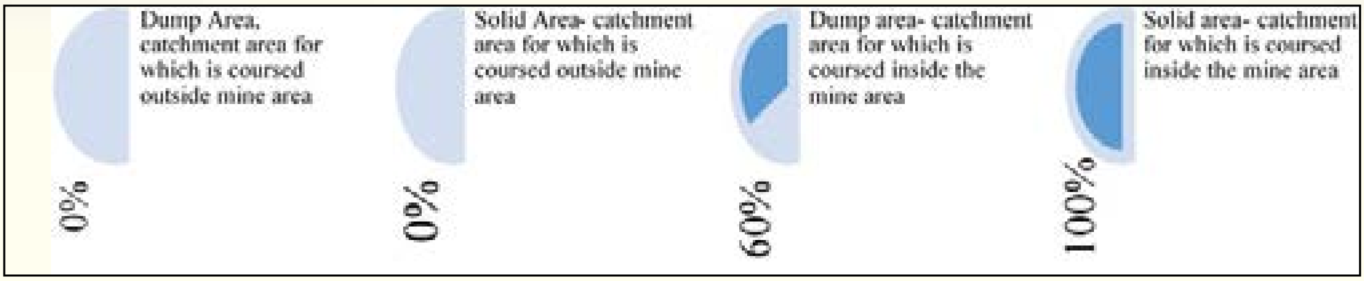
RCC drain of inner dimension 3.5m x 2.5m will be capable to handle water of catchment area 2 to 3 sq km. A minimum slope of drain should be 1 degree. If a slope of 2 degree is provided, the water flow rate will be higher and it will cater the water handling requirement from much higher catchment area.

Other Protection Measures

1. Gabion walls
2. Garland drains
3. Siltation ponds
4. Retaining walls
5. Culverts
6. Kutcha drains
7. Hume pipes
8. Geosynthetics, Geo bags
9. Jute bags
10. HDPE pipes
11. Geomembrane Roll
12. Coir
13. Flexion wall designed by CIMFR

Fig.-13: Calculation of Catchment Area, Amlohri OCP, NCL

THE CATCHMENT AREA CALCULATOR AND REQUIREMENT OF SUMP AREA AND PUMPS



AN EXAMPLE OF CALCULATION OF SUMP MAKE UP OF WATER (MAX) AND SUMP AREA TO BE PROVIDED

Table-4: Calculation of Makeup water (Monsoon Preperation Plan, 2018-19)

Solid		Catchment area in Sqkm.	Draining in	Coeff of precipitation	Max Rainfall @20 years in mm	Make up of water in Cum
	Above Turra (Purewa area)	2.37	100%	100%	200	474000
	In Turra Area	3.4	100%	100%		680000
Dump	West	2.15	22%	60%		56760
	East	1.28	57%	60%		87552
Total make up water in the vent of 200mm rainfall in a day						1298312

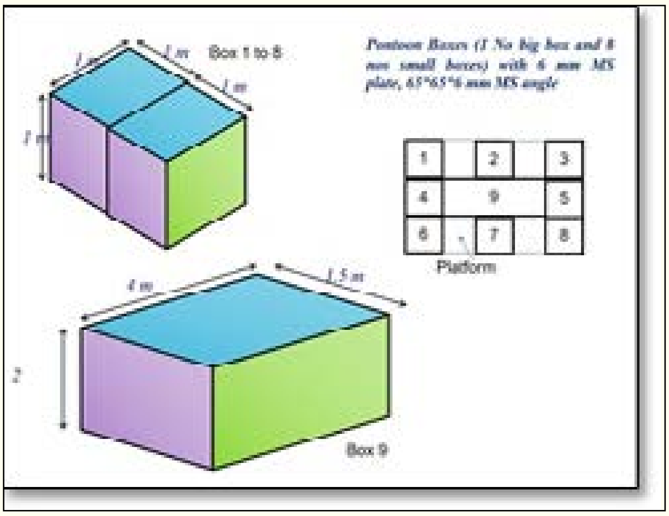


Fig.-14: Pontoon Boxes

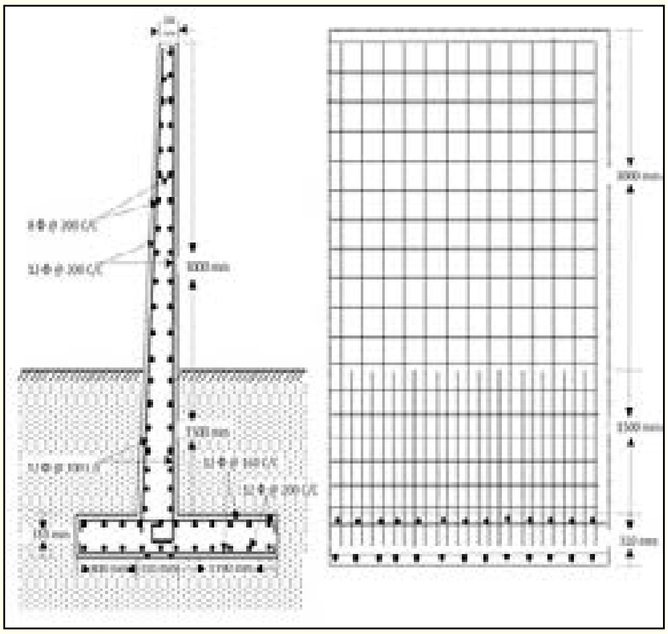


Fig. -15: Design of Retaining wall (CIMFR, 2017)

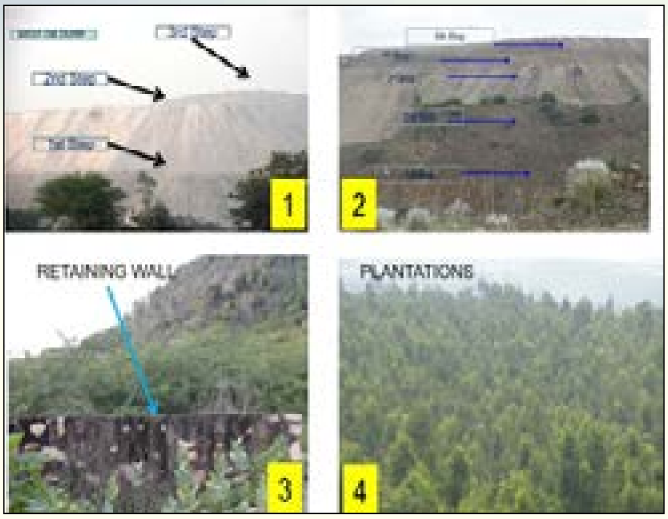


Fig.-16: Stages of Overburden Dump Management

CONCLUSION

More than 95% of coal production in India comes from opencast mines and more than 60% of this production comes from larger opencast mines ranging from 10-40MT annually. Coal production in the country usually slows during the monsoon season. This can increase the problem of fuel availability for the thermal power plants, unless electricity demand slackens or renewable energy, especially hydropower generation, steps up to the plate. Any drop in coal production hampers generation of electricity from Thermal power plants. Although these power plants have been asked to keep a stock to operate plant for 21 days, but often during monsoon these stocks get evacuated and a hue and cry is seen, challenging the nation to go with less electricity. Monsoon preparation hence become not only important but a priority so that coal production from these mines is regular.

The paper describes the intricacies of monsoon preparation and hope in long way help the mine planners and mine operators to gear up for monsoon well in advance. The paper covers wide range of topics related to opencast mine such as sequence of mining, catchment areas, sump requirements, pump requirements, drains, retaining and gabion walls and effects of monsoon if proper action is not taken timely.

ACKNOWLEDGEMENT

NCL faced abnormal rainfall during 2016. Concentrated heavy rainfall for 8 days (11 to 18th August) was 437 mm which was 15% more than the rainfall experienced in any year earlier. (S. J. Sibal, 2016) Due to this very high precipitation in short duration, all the 4 Mega Projects of NCL suffered considerable loss in terms of production, equipment and infrastructure due to huge inrush of water and silt inside the mines. Various committees were constituted with a view to prepare a roadmap for avoiding repetition of such incidences in future. **Shri Gunadhar Pandey, Director (Tech./Operations), NCL** was the guiding force behind the proceedings of the committees and also the driving force behind the implementation of recommendations of the committees. Further in his able leadership, NCL reached the benchmark 100 MT in FY 2018-19.

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Social Issues in Opencast Coal Mining Projects seeking Forest Clearance

Dr Manoj Kumar[1], Pravin K Singh[2] , S. K Jha[3]

ABSTRACT

Opencast coal mining projects require a huge quantity of land – either forest or non forest land. It requires Land to be cleared for mining process. The land includes Notified forest, Revenue Forest, Gair Majarua Jungle Jhari, chota Jhar, Bara Jhar, Gair Mazarua Aam, Gair Mazarua Khash, Tenancy, Kesar Hind, Bhuari etc. Amongst them, Notified forest, GMJJ, Chota Jhar, Bara Jhar are grouped as forest land and requires approval from MoEFCC for its diversion for non-forest purposes as per section 2 of Forest Act 1980. In the Forest application process, various challenges are faced. In this paper an attempt has been made to group the challenges being faced in obtaining forestry clearance and are focused on social issues arises pre In-Principle Approval for proposals for diversion of forest land for its non forest use as per FCA 1980. The challenges in forestry clearances of opencast coal mines includes different social issues raised during the process of obtaining certificate under Scheduled Tribes and other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006. This Paper also explores the organic link amongst different hurdles during land authentication processes.

A conceptual framework for solving forestry clearance issues related to social matter is proposed in this article. ALS is the primary document for preparation of forestry application, which eases the process of land acquisition, FRA certification process, obtaining no objection certificates, and other land records. Building trust amongst the inhabitants of the area under forest proposals helps to establish and improve social relationship and further helps in getting different details. These social issues are found very prevalent in FRA certification, NoC process and preparation of R&R plan. Effective community engagement could, in turn, benefit a opencast coal mining operation. User agency need to demonstrate, through action, that they are taking people's concerns seriously and are fulfilling their promises. Under these circumstances moping of the issues raise in implementation of similar nature of projects will help UA understanding of the issues.

Keyword : *Forest Clearance, OCP, FRA, Notified Forest, WP(C)*

INTRODUCTION

Opencast mining operations (Fig.-1.1) involve huge quantities of clearing of land, overburden removal, dumping and backfilling in excavated areas. The first task in open-cast mining is to remove the topsoil, subsoil and overburden rocks in sequence. The overburden is dumped separately. It can revert back for replacement in reverse order.

The overburden is dumped as heap as external OBD at a suitable location beyond the ultimate pit limit. The OB is spread both horizontally and vertically. The preferred location would be at the shortest distance over non agricultural, non-forest land and non-drainage slope. The dump material can be backfilled to the abandoned pit as the pit progresses or at the closure of the mine. The mine backfill process is the environmental reclamation of the worked out area.

[1] Mgr(M), E&F DEptt., CCL, [2]Sr Mgr(M), Ts to DT(P&P), [3]Sr Mgr(P), L&R, CCL, CIL

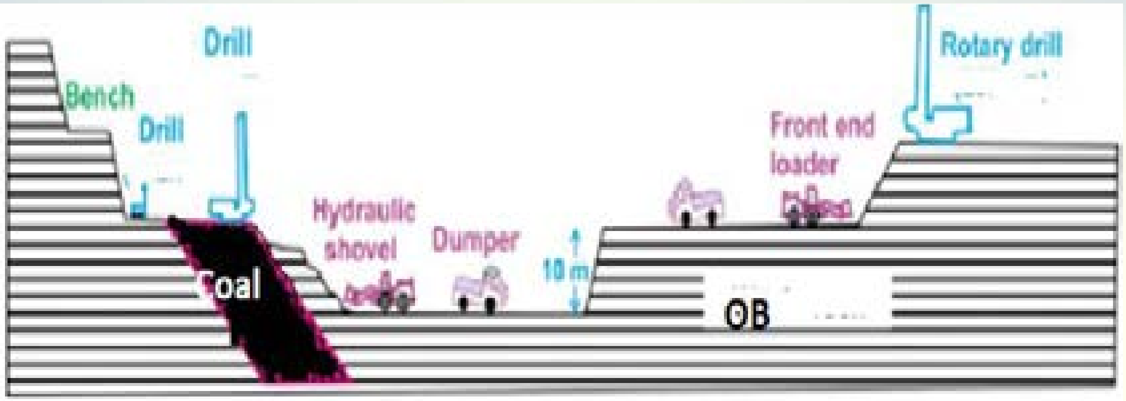

Fig-1.1: Typical Layout of Opencast Coal Mines

Thus for opening an open cast mine requires a huge quantity of land for different land uses termed as component of opencast mine land usages. These land may categorized as forest land or non forest land and requires permission for its diversion for non forest use as per the provisions laid down at section 2 of Forest (Conservation) Act, 1980 (FCA). FCA came into operation initially through the Forest (Conservation) Ordinance, 1980 with effect from 25th October, 1980. The said Ordinance was repealed and subsequently the FCA came into effect on 25th December, 1980. Section 2 of the FCA provides that no State Government or other authority shall make, except with the prior approval of the Central Government, any order directing, inter alia, that any forest land or any portion thereof may be used for non-forest purposes.

VIOLATION

In the judgment in Writ Petition (Civil) No . 114 of 2014 & Writ Petition (Civil) No. 194 of 2014 filed under Article 32 of constitution mining company of Odisha were held responsible in violating the provisions of the Forest (Conservation) Act, 1980, Rules & guidelines and directions issued by the Hon'ble Supreme Court of India [SC judgement 2-8-17].

Hon'ble SC passed order on 12th December, 1996 followed by the order dated 4th March, 1997 namely that mining must cease forthwith in forest areas. In regard to this violation, the only benefit (at best) that can be granted to the mining lease holders that we are concerned with, is till 6th January, 1998 when the affidavit was filed in this Court in I.A.Nos. 2746-2748 of 2009 in T.N. Godavarman. With effect from 7th January, 1998 any mining activity in forest and DLC lands would clearly be completely illegal and unauthorized and the benefit that the mining lease holders have derived from this illegal mining would be subject to Section 21(5) of the MMDR Act. Violation of the FCA is condonable on payment of penal compensatory afforestation charges. But this would not apply to illegal or unlawful mining under Section 21(5) of the MMDR Act, but mining lease holders would be entitled to the benefit of any Temporary Working Permission granted.

Violation as per Hon'ble SC order dtd. 2.8.17 on the issues of mining without an EC or FC or both

- Any mining activity carried on after 7th January, 1998 without an FC amounts to illegal or unlawful mining in terms of the provisions of Section 21(5) of MMDR Act attracting 100% recovery of the price of the extracted mineral that is disposed of.
- In the event of any overlap, that is, illegal or unlawful mining without an FC or without an EC or without both would attract only 100% compensation and not 200% compensation. In other words, only one set of compensation would be payable by the mining lease holder.
- No mining lease holder will be entitled to the benefit of any payments made towards NPV or additional NPV or penal compensatory afforestation.

OBJECTIVE

The objective of this study is to pin point the challenges being faced and to develop the organic link amongst different hurdles by exploring ways to combat the gaps while making application under Sec 2(ii)/2(iii) of FCA till its site handover to the user agency.

DIFFERENT TYPES OF LAND

Opencast coal mining processes is an intensive process. It requires Land to be cleared for coal mining extraction. The land includes Notified forest, Revenue Forest, Gair Majarua Jungle Jhari, chota Jhar, Bara Jhar, Gair Mazarua Aam, Gair Mazarua Khash, Tenancy, Kesar Hind, Bhuari etc. Amongst them, Notified forest, GMJJ, Chota Jhar, Bara Jhar are grouped as forest land. The definition of forest though laid at Section 2 of FCA, further Hon'ble SC in its decision of 12th December, 1996 defined forest as forest must be understood according to its dictionary meaning and it would cover all statutorily recognized forests, whether designated, reserved, protected or otherwise. Forest would also include any area recorded as a forest in the government records irrespective of the ownership. This Court further directed each State Government to constitute within one month an Expert Committee, inter alia, to identify areas which are 'forest' irrespective of whether they are so notified, recognized or classified under any law and irrespective of the ownership of the land of such forest.

CHALLENGES / ISSUES

There is an old proverb: "The forest is the poor man's overcoat." From our earliest times, our country has depended on forests for so much—for food and water, for shelter and clothing, for energy, for medicine, and so much more. Forest resources needs to be judiciously used. But country needs growth for which setting up industry needs energy for its sustainability. Fossil fuels is the main source of energy for the country like India, though non renewable energy is coming very fast. Coal being one of the fossil fuel and having huge reserves to meet the country demand coal company is heading to focus in opencast technology. This system of coal production has certainly increased the productivity in terms of coal production and has added towards meeting the country requirement of energy for different industry. The opencast coal mines require a big chunk of land which may be classified into forest and non forest land. The forest land requires clearance (Table 5.1) from MoEFCC as per provisions of FC Act 1980 for its non forest use. As per Rule 6 of the Forest (Conservation) Rules, 2003, every user agency, who wants to use any forest land for non-forest purposes shall make his proposal. **Form 'A'** for proposals seeking first time approval under the Act and **Form 'B'** for proposals seeking renewal of leases where approval of the Central Government under the Act had already been obtained earlier, to the concerned nodal officer authorized in this behalf by the State Government, alongwith requisite information and documents, complete in all respects.

Unless planned properly obtaining forest clearance for forest land for opencast coal mining is full of Challenges. Different issues involved (Table-5.2) and the challenges faced are having Social facets, Environmental facets and Documentation. In the paper an attempt has

Table-5.1 : Steps of forestry Clearance

1	Submission of proposal	Proposal submission by user agency to state forest department
2	Scrutiny & processing	Proposal scrutiny conducted at various levels of forest conservation division of MoEF
3	Grant of in-principle approval	Grant of approval by state government subject to compliance to certain conditions
4	Submission of compliance report	Compliance by user agency as required for compliance to stage I approval
5	Issuance of diversion order	Grant of diversion order by state government for forest clearance
6	Site Hand over	After Compliance of Stage-II

been made to group the challenges being faced in obtaining forestry clearance and focused on social issues arises pre In-Principle Approval for proposals for diversion of forestland for its non-forest use as per FCA 1980. The challenges in forestry clearances of opencast coal mines includes different social issues raised during the process of obtaining certificate under Scheduled Tribes and other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006. This Paper also explores the organic link amongst different hurdles during land authentication processes.

Social issues - pre in-principle Approval

Social Issues :

The different social issues in the process of diveripon of forest land under FCA 1980 includes Authenticated Land Schedule, certificate under FRA for Forest Land (Notified Forest , GMKJJ), Translated Copy of Proceedings of FRA , No objection Certificate for GMKJJ and R & R Plan – Duly approved from Ministry of Tribal affairs of State.

Authentication of Land Schedule (ALS) :

ALS is the primary document for preparation of forestry application. In fact it is also important documents which is very much required for preparing land details chapter of a mine plan or Project report.it is also a basic info documents for making land acquisition under CBA 1957, L A Act 1952 or other Acts vide which land is acquired for opencast coal mining purpose. Various steps in ALS includes:

a. Fixing Physical Boundary (PB) :

After User agency has demarcated its intension of making application the first and foremost task is to draw PB for which FC application is to be

Table 5.2 : Tree Diagram of Issues – Forest Clearance Process

	Social	Economic	Environmental	Plans & Section	Documentation
I. Pre in-principle approval	• Authenticated Land Schedule • FRA for Forest Land (Notified Forest, GMKJJ) • Translated Copy of Proceedings of FRA • NOC for GMKJJ • R & R Plan – Duly approved from Ministry of Tribal affairs of State • Other issues	• CBA Report – As per MoEF Guidelines dtd. 01.08.2017 • Tree Enumeration Report • Payment for NPV, other levies	• Transportation & Linkage Details • EC letter • Stage – I/ Stage-II letter and Latest Compliance (Word format in case of applying for renewal/ Stage-II)	• Marking of forest proposals on Toposheet (1:50000) • Cadastral Map (1:3860 miles) • KML Plan & DGPS of forest Proposal • Land Use Plan (DGPS or Total Station basis) [1:4000] • KML Plan & DGPS of Compensatory Afforestation Land • Uploading of CA Scheme	• Authorization for Online Application • Mine Plan and its Approval • Leasehold Area Details • Justification of Forest Proposal (Fresh/CLU/ • 3-D Analysis Report for UG Project • Undertakings • Inspection by forest officials (DFO/CF/NO) • Inspection by MoEFCC
II. Post in-principle approval	• Implementation of R&R Plan • Claim Settlement as per FRA, 2006	• Claim Settlement as per FRA, 2006 • Payment for CA, other levies	• Reclamation Plan • Soil Erosion Report • Avifauna Study, • Wildlife Management Plan	• Demarcation of Pillar	• Land Surrender Schedule • Tree Cutting Permission

made. PB is a closed loop enveloping forest as well as non-forest land contain forest land which needs to be diverted under the provisions of FCA 1980. This envelop (Fig 5.A.1.1) acts as PB for the forest application. The physical boundary includes forest and non-forest land.

b. Plotting PB on cadastral Plan (CP) :

After ascertaining the PB, it is plotted over CP (Fig 5.A.1.2) usually available in scale 1: 3860 miles. CP for different mauza of the village contains information of village, mauza, khata no. thana no. and nature of land as shown in 1901 etc. Some times there are 3-4 sheets of CP for one village. A FC application often comprises of 3-4 sheets of CP for small requirement of area and even comprises of 7-10 sheets of CP.

Non-availability of CP often causes delay in LS preparation. Now a days the land records are being computerized by state governments and land records / CP are available on web portals but still these works are not complete for several districts and these records / documents are still not available. Sometimes CP are available with mukhia/surpanch or old aged people. Contacting them and taking them in confidence may sometimes helps in obtaining CP.

c. Land Schedule preparation:

On the basis of information on the CP the information related to village, mauza, khata no. thana no. and nature of land (Kism) is tabulated (Table 5.A.1.1) and the process is called land schedule preparation.

The documents so prepared must gets verified with the land records available in form 2 available with Circle Inspector in Circle office. This documents also contains forest information, which should be get tallied/verified specially the records related to notified forest, with the records available with district forest officer. The details can be obtained on request by an application mentioning the intension of making forest application for diversion of forest land for non forest use. This tallied records will help in future conflicts being raised at forest offices while processing the forest application.

The plot wise information along with thana no. kharsra no. etc is required to be prepared which requires skilled ameen/survyor. For the brownfield/ old projects ammens/ manpower are almost available which make this job easy but for new projects/ greenfield projects availability of manpower/ ammeen posses difficulty in preparing land schedule. User agency has to rely on the local ammeens / job is completed by contractual means which (authenticity of data is the threat). Engaging the job contractually often possess difficulty and awaits for the company approval for engaging them often is the reason for delay in land schedule preparation. For this making roaster /panels of good ammeens on company basis may reduce time.

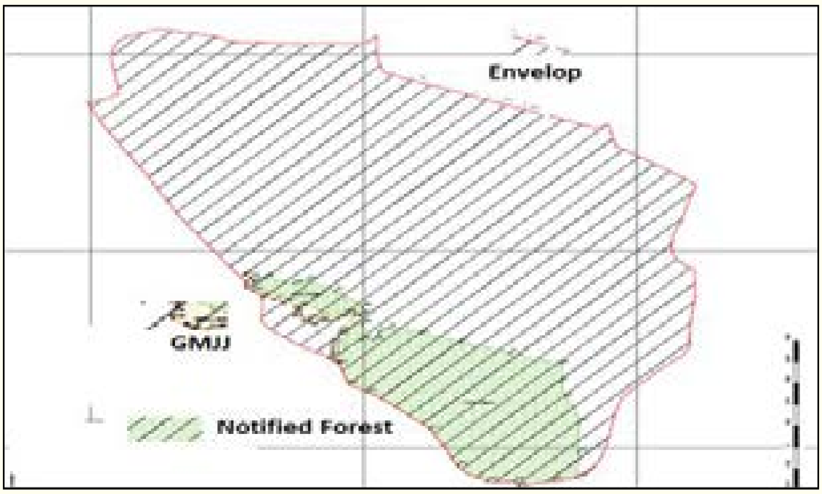

Fig -5.A.1.1 : Envelope/PB of Forest Application

- Land records are available as per survey made in 1908 / 1932 – which is not correct.
- Non availability of land records at Circle office :
  - Lack of land records
  - Non updation of Register-II
  - Torn out khatiyan
- CS / RS Survey

Some of the GMK land has been settled in the name of Raiyat in due course of time by different government. Revision survey has been made in 2005. But sometime it has been observed that it has not been reconciled often poses

Fig -5.A.1.2 : Typical Cadestral Map of a Mauza

found at that time. Forest proposal then only can be considered for diversion of forest land as per FCA 1980. Some of the authorities have responded to it but the response from district authority was not in favour of project proponent/ user agency and thus seems to not materializing. PP were though given relaxation, and certificate issued from some plots by DC, but it were not admissible by forest officials and till date not proposals have been processed as per this new system.

Now PP's are seeking upon authenticated land schedule of revision survey 2005 in Latehar district to be accepted for forest application. PP's are still seeking help from state government for providing land details in accordance with letter no. 4715 dated 27.11.2018 of Forest and Environment Department GOJ. in respect of GMK JJ.

problem in land authentication. Revision survey records are often not accepted by forest officials of the state.

- Govt. issued guidelines

Government of Jharkhand came up with a circular no. 05/S.Bhu. Latehar(Vividh)-181/18 (Chaya Sanchika)-4715, Ranchi dtd. 27.11.2018, vide which a certificate about nature of land in form-I is to be issued from District Collector on the basis of revisional survey after 25.10.1980, for diversion of the forest proposals in which nature of land as per cadastral survey or last revisional survey made before 25.10.1980 is not clear for the want of land records. In addition project proponent has to furnish an undertaking in form-II that PP will be bound to divert the land if that land is found as forest land in future on the basis of any other record

Other issues :

- Unauthorized occupancy on Govt. Land : it has been observed that people have arranged rent receipt of land and get their name registered without reconciling the government record often poses problem in land authentication of non-forest land involved in forest application.
- Land under CNT Act has been purchased and sold : This causes problem while making payment to the beneficiaries and that time

Table - 5.A.1.1 : Typical Land Schedule

Village	Khata No.	Plot No.	Area acquired	Forest land	Notified GMK JJ	Non Forest land	Nature of Land
PAREJ	1	1	40	6.07	33.93	0	Jungle
PAREJ	1	2	36	14.47	21.53	0	Jungle
PAREJ	2	3	0.45	0	0	0.45	Rasta
PAREJ	7	4	0.04	0	0	0.04	Makan
PAREJ	7	5	5.41	0	0	5.41	Tand II
PAREJ	21	6	6.03	0	0	6.03	Tand II
PAREJ	1	7	53.02	35.38	17.64	0	Jungle
PAREJ	1	8	2.94	1.55	1.39	0	Jungle
PAREJ	1	9	2.91	0	2.91	0	Jungle
PAREJ	1	10	3.8	0	3.8	0	Jungle
PAREJ	16	11	0.02	0	0	0.02	Dhan Khet I
PAREJ	14	12	0.09	0	0	0.09	Dhan Khet II

these records need to be checked and land authentication comes in jeopardy.

- Encroachment of land – It has been found that people encroaches land and do poses problem while land authentication process are in progress. People demand R&R benefit, employment etc.
- Interference of Ministry : Now a days while making application for Land acquisition ministry of GoI suggest to include Name, Fathers name and mobile number and to be as per 1908/1932 khatyian. Since these Khatian is not updated, its reconciliation is bit a daunty task.
- Non authenticity of record in Register II : Land authentication process requires reconciliation of records of Register II. But in the land authentication process it has been found that name is recorded in register II but some case is filed under sec 4 (H) of BLR Act.
- Delay in authentication by State, Non cooperation of State Missionaries , Massive Corruption are the other issues in land authentication process.

Resolving issues :

Laisioning at all level from Karmchari, CI, CO, AC, DC, Secretary, Minister/ CM

- Showing similar documents issued from other officers often works for issuance of certificate/ orders required for FC application.
- Correct or near correct Land schedule will often pave way for smooth and correctly preparation of key hole markup language (KML) file, differential global positioning system (DGPS) map of forestland, Land use od forest application, request for certificate under FRA-2006, request for issuance of no objection certificate (NoC) for GMJJ/Revenue forest etc.

FRA for Forest Land (Notified Forest , GMKJJ)

Tribal communities in India and forests was characterized by their co-existence. These rights were not recognised and recorded by the government while consolidating state forests during the colonial period as well as in independent India The resulting insecurity of tenure and the threat of eviction led to the alienation of tribal communities from their ancestral forest lands. Scheduled Tribes and other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006 (the 'Act') were enacted to 'undo the historical injustices' suffered by tribal communities and was an effort for locating tribal rights in institutional responses. Section 3 of the Act provides for the grant of several heritable, inalienable and non-transferable 'forest rights' to the beneficiaries. It is shifting of reforms of locating tribal rights in institutional process.

In compliance of MoEF, GOI's letter no. 11-9/98-FC(pt.) dtd. 3.8.09 read with OM dtd. 05.07.2013, wherein the MoEF issued guidelines on submission of evidences for having initiated and completed the process of settlement of rights under the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006 a certificate is to be obtained from district commissioner/Magistrate in Form II for linear and Non linear projects respectively. The detail of typical information in form II/ Form I is as shown at Table - 5.A.2.1.

In this certificate the District commission has to furnish about completeness of the process along

Table 5.A.2.1: Typical details in FRA certificate

Sl. No.	Date of Gram Sabha	Rev Vill	Thana No.	Khata No.	Plot No.	Land/Area in Ha		Total Area (in Acre)
						NF	GMJJ	
1	2	3	4	5	6	7	8	9
....								
....								
....								

Table 5.A.2.2 : Chronology	
Dtd.	**Details**
30.07.09 & 03.08.09	• State/UT Governments to certifying complete process for identifying & settelment of rights under FRA carried out & it is as per Sec 3 (2) of FRA • Letter from each gram sabha indicating that all formalities / process under FRA carried out • FRA proceedings in vernacular/local language placed before gram sabha - certificate & Quoram of minimum of 50% of membership
05-02-13	Gram sabha may not be required for projects like roads, canals, laying of pipe lines/optical fibres & transmission lines etc where diversion is in several villages involved unless recognised rights of PTG (Primitive Tribal group) and (PAC) Pre Agricultural communities are being affected.
05-07-13	FRA certificate in form I for Linear & Form-II for other projects
09-10-13	All certificates of FRA issued before the issuance of Format I & Format II Submission of fresh certificate should not be insisted upon, provided the certificate issued by DC meets the requirement of OM 3-8-09 & 5-2-13
20-12-13	Stage-I will be considered only after obtaining evidence of FRA
15-01-14	Details of Form-I & Form-II- Exemption of Gramsabha for liear projects except those involving recognised rights of primitive Tribal groups (PTG) & Pre agricultural Communities (ref 5-2-13)
30-03-17	Clarification Regarding Forest Application - with No FRA for part of Forest Land
26-02-19	For the purpose of MoEFCC, as per the provisions under Forest (Conservation) Amendment Rules 2016 for FRA purpose the compliance under FRA is not required for consideration of in principle approval. And the State govt. were requested to adhere the rules. (F no. 11-43/2013-FC)

with annexing the copy of records of all consultation and meetings of Forest Rights Committee(S), Gram Sabha(s), Sub-Division Level committee(s) and District level Committee. A certificate stating that full details of the project and implication was placed before each concerned Gramsabha of forest dwellers, who are eligible under FRA in vernacular/ local language. It is to be ensured that each of the gram sabha has certified that all formalities/ processe under FRA have been carried out, and that they have given their consent to the proposed diversion and compensation and ameliorative measures, if any, having understood the purpose and details of proposed diversion. The discussion and decision on such proposal had taken place only when there was a quorum of minimum 50% of the members of Gram Sabha present. District commissioner has also to furnish that the rights of primitive tribal groups and pre-agricultural communities, where applicable have been specifically safeguarded as per section 3(1)(e) of FRA. Further DC has to furnish that the diversion of forest land for facilities managed by Government as required under section 3(2) of FRA have been completed and gram sabha have given their consent to it. Some of the relevant chronology for the purpose is tabulated at Table - 5.A.2.2.

This Act is silent to clarify whether those who reside outside the forests but are dependent on forests for fulfilment of livelihood needs are also eligible beneficiaries of the Act. The Act is also silent on the definition of 'bona fide livelihood needs'. These are creating additional difficulties in the determination of claims.

State Government shall complete settlement of rights, in term of the Scheduled Tribes and Traditional Forest Dwellers (Recognition of Forest Rights) Act, 2006, if any, on the forest land to be diverted and submit the documentary evidence as prescribed by this Ministry in it's letter No. 11-9/1998-FC (pt.) dated 3rd August 2009 read with 05.07.2013, in support thereof.

Translated Copy of Proceedings of FRA

Forest Appraisal Committee (FAC) often asks for translated copies of proceedings of FRA. From the minutes of meeting of FAC held on 11.06.17, it were observed that some of the project was returned due to non availability of translated copies of proceedings along with forest proposal and it took about 4-5 months for its consideration in next FAC. Thus to avoid further delay in the process of the forest application user agency must ensure that minutes of the proceedings of the FRA certificate issued are translated.

NOC for GMKJJ

NoC for deemed forest or revenue forest or GMJJ is one of the requisite documents required for making forest application. DC of respective district issues this certificate after making application by PP as per information furnished as per Table no. 5.A.4.1. The land records is based on authenticated land schedule and non-availability of land records sometimes poses problem. Demand of pattas by unauthorized occupants is one of the reasons for delay in issuance of NoC, which further delays the FC process.

R & R Plan – Duly approved from Ministry of Tribal affairs of State

The User Agency shall implement the R&R Plan as per the R&R Policy of State Government in consonance with National R&R Policy, Government of India before the commencement of the project work and implementation. The said R&R Plan will be monitored by the State Government/Regional Office of MoEF&CC along with indicators for monitoring and expected observable milestones. Form A and Form B of the FC process warrants R&R plan submitted along with forest application to be duly approved by Ministry of Tribal Affairs. In this regard UA are advised to act accordingly in advance preferably at planning stage of mine plan itself to avoid delay.

Documents signed in / attested

MoEFCC F. No. 11/360/2016- FC dtd. 17th Nov. 2016 says that forest proposals must contain original documents and photocopies if annexed with forest application needs to be authenticated from record by the authority and submitted with the signature and official seal.

It is a good practice that authorized person to put his/her signature and put seal containing his/her name to avoid delay in processing of forest application. It has been observed that one of the proposal of a major coal producing company of India was retuned back from state government level and it took more than 120 days to again come back to State government level ie that project got delayed by 4 months due to non-attestation of the documents. Some of the DFOs are very stringent to it. They even demand to update the signature for all documents either fresh or previously submitted by the previous authorized person, if the authorized person is changed. There are several examples due to which several FC proposals are struck up and being delayed. Proactive approach and preparedness will help UA in cutting short the processing time. UA agency gets the documents attested by the agency/offices from where it has been issued at the time of issuance of such certificates like FRA certificate, NoC from DC, Land authentication from Circle office etc. Further authorization to be issued to such person of long tenure to the place so that frequent change in profile and signature on documents be avoided and further cutting short the FC processing time.

Table 5.A.4.1: Typical details in NoC

Sl no.	Rev Vill	Thana No.	Khata No.	Plot No.	Total Area of GMJJ in Ha	Total Area (in Acre)
1						
....						
....						
....						

Leasehold Area Details

The forest application to include leasehold details which comprises of information related to total land (TL) in the leasehold for which the present forest application is the part, which further includes notified forest (NF), Revenue Forest/Jungle Jhari/Chota jhar/ Bara Jhar (GMJJ), Non forest land (NFL) for already released forest, forest diversion application under process either under Sec 2(ii) or Sec 2(iii) of FCA 1980 or applied under 'change in Landuse(CLU)' or for renewal and rest part to be applied in future. (Table-A.7.1). the sum of NF and GMJJ is total forest land for which application of diversion of forest land has been initiated for its non forest use under Sec 2(ii)/2(iii) of FCA 1980.

This information to be matching with the land acquisition details. The lands in the lease hold are either acquired under Coal Bearing Areas(Acquisition & Development Act 1957 (CBA, 1957), Land Acquisition Act , 1894 (LA 1894) or any other Act. LA Act 1984 has been replaced by Right to fair compensation and Transparency in Land Acquisition, Rehabilitation & Resettlement Act 2013 (RFCTLARRA-20103) and is effective from 01.9.2015. The details of acquisition to include information like acquisition SO No. with Date, Area, and Village involved Thana & its number. (Table A.7.2). It includes village wise plot details along with boundary description. Total area in Table A.7.1 & A.7.2 should match. Any difference in area from the forest application to be suitably justified.

The land details furnished under different notification was on the basis of data gathered at the time of making application for land acquisition, many times differs from the records available in register II kept at circle office. This poses difference in the area as made in the forest application. This is so because of that of authenticated land schedule based on which the present application is made of. This issue needs immediate attention, as this is one of the basic documents for reconciliation of the land records during the process of disposing forest application at initial level at different forest offices of the state. The details of leasehold became

Table -A.7.1 : Land Details in Leasehold Area

		NF	GMJJ	TF	NFL	TL
		(A)	(B)	(C=A+B)	(D)	(E=C=D)
Already Released Forest	(a)					
	(b)					

Already Applied	Sec 2 (ii)					
	Sec 2 (iii)					
	CLU					
	Renewal					
This Application	Sec 2(ii) / Sec 2(iii) / CLU / Renewal					
To be Applied	Sec 2(ii) / Sec 2(iii)					
Total						

Table -A.7.2 : Land Details As per Acquisition

		Acq. No. & Dt.	Village	Thana/ Thana no.	District	Area in Acres	Remarks
(A)	CBA 1957						
(B)	LA Act 1952						
(C)	Nationalization Act 1972/1973						
(D)	Already before FCA 1980.						
(E)	Transfer from Railway						
(F)	Direct Purchase						

more important after guidelines for diversion of forest land for non-forest purposes under the Forest (Conservation) Act, 1980 issued by MoEFCC vide OM dtd. 17/11/2014, which says about submission of proposals to obtain approval for diversion of entire forestland, located within the mining lease and grant of environment clearance to mining projects. The details of forest land falling in the leasehold area for which the application is the part has to be part of forest application.

Most of the forest land which has been released a long back has not been acquired under any land acquisition process. However, some of it has been acquired under provisions of the prevailing Act. This needs attention by project proponent to get it acquired under the provision of the prevailing Act, otherwise this creates problem while processing the forest proposals.

Project proponent often faces difficulty in processing the land which has been acquired by different subsidiary under nationalization Act either 1972 (Coking Coal)/ 1973 (Non-coking coal). This disparity as per author's view arises due to acquisition of some of land under CBA, 1957 & some not. For the land, which has been transferred to different subsidiary by Nationalization Act 1972/73, PP have acquired the land under following conditions:

a) That land for which Mining Right (MR) is available and being used for underground mines (UG), now requires for conversion of technology ie from UG to opencast (OC) for which surface right (SR) is required.

b) That land which do have surface right only and mining is required below ground / OC.

The Coking Coal Mines (Nationalisation) Act, 1972 entails about acquisition of the rights of owners of coking coal mines and coke oven plants wherein The Coal Mines (Nationalisation) Act, 1973 entails acquisition and transfer of the right, title and interest of the owners in respect of the coal mines specified in the Schedule with a view to re-organizing and reconstructing such coal mines so as to ensure the rational, co- ordinated and scientific development and utilization of coal resources consistent with the growing requirements of the country, in order that the ownership and control of such resources are vested in the State and thereby so distributed as best to sub serve the common good, and for matters connected therewith or incidental thereto.

Now a days these lands are being acquired as and when necessary and requirement of PP. This further necessitates the PP to draw the attention to the management for the Land which have been acquired under Nationalization Act (1972/1973), and not acquired under any land acquisition Acts or have been directly purchased, to get it acquired under the provision of the prevailing Land Acquisition Acts.

CONCLUSION

Opencast coal mining projects require a huge quantity of land – either forest or non forest land. While companies are better at managing issues, relating to the environment, health and safety, the social, economic and community issues remain the biggest challenge. ALS is the primary document for preparation of forestry application, which eases the process of land acquisition, FRA certification process, obtaining no objection certificates, and other land records. Building trust amongst the inhabitants of the area under forest proposals helps to establish and improve social relationship and further helps in getting different details. These social issues are found very prevalent in FRA certification, NoC process and preparation of R&R plan. Grievances of the inhabitants living inside the forest land are to be redressed. There have been increasing amounts of company guidance on the topic of grievance mechanisms. However, effective community engagement could, in turn, benefit a mining operation. Field officers can play a very important role. User agency need to demonstrate, through action, that they are taking people's concerns seriously and are fulfilling their promises. Gram Sabha being the 1st platform vide which UA can convey its planning and build trust amongst the inhabitants. Under these circumstances moping of the issues raise in implementation of similar nature of projects will help UA understanding of the issues.

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Ameliorating Water Scarcity by Augmenting Minewater for Potable Purposes from the Coal Mines of Jharia Coalfield- A review

Pritam M. Baruah[1], Gurdeep Singh[2]

ABSTRACT

The dense and highly industrialized populace in the coal mining areas of Jharia Coalfield are plagued by severe shortage of water supply. Providing access to potable water supply in these regions is a growing challenge. Its inaccessibility risks the outbreak of epidemics due to water-borne diseases. Large quantities of minewater are discharged from the coal mines of to facilitate safer mining. The unutilised minewater is prone to contamination from industrial effluents or other anthropogenic sources. There is a growing deterioration of water quality, which poses health risks to consumers unless there is a reduction in contamination sources or efficacy of water purification systems is improved. Realising this situation of water catastrophe, Government of India has recently constituted Ministry of Jal Shakti by merging the Ministry of Water Resources, River Development & Ganga Rejuvenation and Ministry of Drinking Water and Sanitation to optimise sustainable development, maintain quality and regulate efficient use of water resources to cater to the growing demand of water in the country. This review attempts to give an insight on mitigation of water-stressed conditions by augmenting minewater for drinking purposes.

INTRODUCTION

The demand for water resources is set to increase over the years with the increasing population coupled with a rise in industrial growth, urbanization and agricultural activities. Large parts of India have already been declared as water stressed and face a critical situation which has been attributed to mismanagement of water resources. Accessing safe potable water is a problem that continues to persist in many areas. Skewed water availability between different regions and between different people in the same region compounded by intermittent and unreliable water supply system risk causing social unrest. The optimal utilization and management of available water resources thus assumes significance. Minewater is discharged in large quantities from the coal mines and only a small percentage of it is used in reclamation and dust suppression while the remainder of the minewater discharges find its way into natural drainage systems (Singh *et al.* 2012). Minewater discharged during mining operations is a valuable water resource but it runs the risk of getting contaminated from domestic and industrial effluents. If left unchecked, the contaminated minewater jeopardises natural ecosystems supporting human health, biodiversity and food production (Salem and Amin, 2012). Gao *et al.* (2017) observed that avoiding non-compliant minewater discharges is one of the major water resource management challenges faced by the coal mining industry. Through adoption of integrated water management strategies and suitable treatment processes, unutilized minewater discharges may be utilized to cater to the water

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demand of the region, fulfilling irrigation, domestic and industrial requirements (Singh 1994). The quality of minewater discharges is dependent on hydrological, geological and mining conditions and show substantial variation in the concentration of contaminants (Singh *et al.* 2010; Younger and Wolkersdorfer 2004). The drinking water quality standards in some areas fall within the recommended levels (Singh *et al.* 2010) while in other areas, the discharged minewater may contain very high concentrations of heavy metals, toxic anions and biological contaminants (Singh *et al.* 2012; Khan *et al.* 2005; Gupta 1999), making it unsuited for its direct release into the aquatic systems, while also limiting its potential usage downstream. Drinking contaminated water effects human health, aquatic life, development and prosperity of the region (Milovanovic, 2007). This necessitates the need for treatment and disinfection of contaminated water for the removal of pollutants which pose a serious threat to human health. To mitigate the risk of unregulated discharges, innovative measures need to be adopted, including water quality monitoring. In this review we shall seek to give an insight on augmentation of minewater from coalmines of Jharia for potable purposes to mitigate the problem of water scarcity in the region.

Need for Augmentation of Minewater

Despite comprising more than 18% of the total world population, India constitutes only 4% and 2.4% of the world's renewable water resources and world's land area, respectively (National Water Policy, 2012). The development of this water resource and its integrated management is vital for agricultural production, sustaining the environment, reducing poverty and sustainable economic development. The National Water Policy also envisages the development and management of water resources of the country in an integrated manner.

There are limits on quantitative water utilization owing to skewed distribution of water resources over time and space, compounded by the challenges of incessant floods and droughts in different parts of the country. Drought-like conditions prevail during summers in mining areas, forcing the mining community to get increasingly dependent on the contaminated minewater for drinking purposes which adversely affects the public health. Health studies from earlier investigations have revealed that people residing in mining areas suffer from various water-borne diseases like typhoid, jaundice, dysentery, cholera along with other skin diseases (Singh 1994). With the rapid growth in population and increasing demands of a fast-developing nation, compounded by the impact of climate change, the availability of water utilizable for potable purposes will be put under further strain in the near future, deepening water conflicts among people. Lack of consciousness about water scarcity, its vitalness to life sustenance and its economic value result in mismanagement of water resources, wastage, inefficient use and reduction of flows below minimum ecological requirements. The existing skewed distribution of water resources and the lack of a unified perspective in planning, management and use of water resources adds to the water crisis scenario. The National Water Policy (2012) takes cognizance of the existing situation and proposes a framework for creation of an action plan with a unified national perspective. It emphasizes the need to augment water from various sources- such as minewater discharges, to meet the water demands of the local population. Augmentation of minewater offers a positive approach to overcome the problem of water scarcity and affected water quality.

JHARIA COALFIELD: AN INTRODUCTION

Jharia Coalfield (JCF) is situated in Dhanbad district in the Indian state of Jharkhand. It is a sickle-shaped terrain that spreads across a 450 km^2 area between 23º37' N – 23º52' N latitudes and 86º 09'E–86º 30' E longitudes with an average elevation of about 220 m above mean sea level (msl) (Saini et al. 2016). The geological and structural details of the area may be found in Verma et al. A map depicting the coal belt, mining areas along with river/ drainage through it is shown in Fig.-1.

Jharia Coalfield (JCF) is the largest repository of prime coking coal in India, and has been extensively mined and exploited for over a century (Singh *et al.* 2012). It is situated at the centre of Damodar valley, south of Dhanbad city. It is a part of the

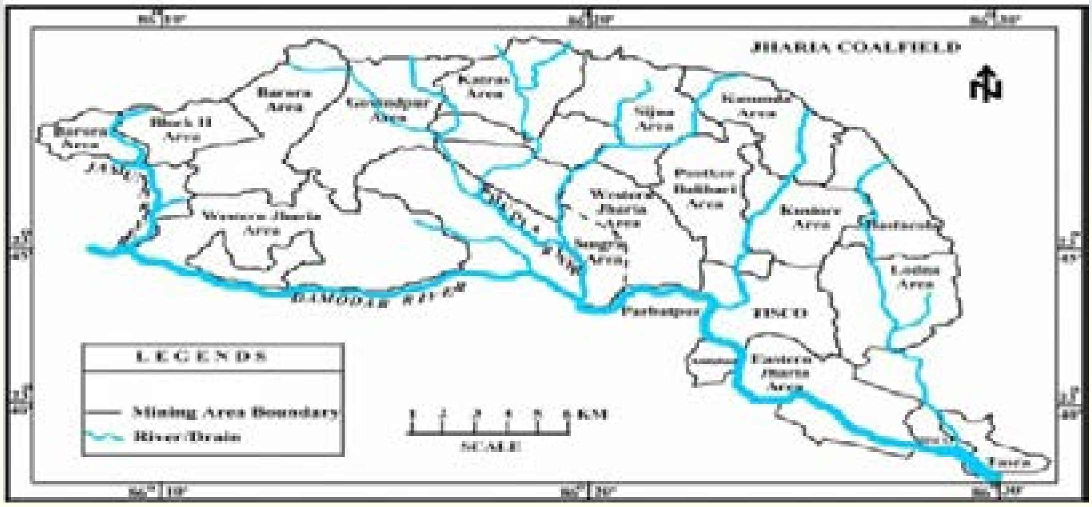

Fig.-1: A map of Jharia Coalfield with its mining boundary and surrounding drainage

Source: Panigrahy *et. al,* 2015

Gondwana Coalfield and has undergone a vast array of anthropologically-induced changes over the last century that has affected the environment around it (Chandra 1992). Several open voids are created in the form of abandoned mines due to open cast mining in Jharia Coalfield. Pot hole and crack formation are a regular feature in this region as a result of extraction of thick seam by caving at shallow depths in the past. This has led to significant damage to the ground surface. At many places these cracks reach the surface and elevate the chances of spontaneous heating of coal seams, triggering mine fires. The hydraulic gradient changes with mine development at the surface and underground mining below piezometric level, thus affecting the quality and quantity of the surface and groundwater flow regimes (Choubey 1991; Sarkar *et al.* 2007; Singh et al. 2007, 2008; Tiwary 2001). Unscientific mining of coal has affected air, water and soil resources, topography, land use and land cover and has triggered coalmine fires that have been active for over a century. Gupta and Prakash (1998) have observed around 70 mine fires covering an area of 17.32 km^2. Investigations revealed around 34.97 km^2 of the area is under subsidence (Singh *et al.* 2012). Apart from mining activities, huge quantities of water effluents from coal beneficiation and preparation plants in Jharia Coalfield are released into the river, posing a serious threat to the health of the aquatic ecosystem and the biodiversity (Tiwary and Dhar 1994; Singh and Gupta 2005).

STATUS OF WATER AVAILABILITY IN JHARIA COALFIELD

The total groundwater availability in any area is the sum of dynamic groundwater resources, the static/in-storage ground water resources in unconfined aquifers and the dynamic and in-storage resources of the confined aquifers and semi-confined aquifers in the area. As per the Central Ground Water Board Report, 2016, the net groundwater availability of Jharia is 79,20,000 m^3 while the existing gross groundwater draft for domestic and industrial water supply is 86,90,000 m^3. The existing gross groundwater draft for irrigation and all other uses is 2,10,000 m^3 and 89,10,000 m^3 respectively (Central Ground Water Board Report, 2016).

STATUS OF POTABLE WATER SUPPLY IN JHARIA

Jharia with a population of 81,979 is the fifteenth-largest town in the state of Jharkhand (Census Report of India, 2011). Jharia, earlier a census town, was combined with other urban units to form Dhanbad Municipal Corporation in 2006. According to the most recent Census Report of India (2011), Dhanbad Municipal Corporation (DMC) has a population of 11,62,472 with 2,20,783 households. Out of the 2,20,783 households, 47,641 households have access to piped water. Dhanbad Municipal Corporation has 21.57% of water supply coverage, (increased from 21 % in 2015), through piped water connections. Water supply in the Dhanbad Municipal Corporation area is undertaken by Mineral Area Development Authority (MADA) and Drinking Water and Sanitation Department (DWSD). MADA provides bulk water while DWSD distributes piped water to areas under Dhanbad Municipal Corporation. Bharat Coking Coal Limited (BCCL) also provide piped water to the residential colonies of its employees. Water supply for the entire mineral areas within the district is done by MADA (bulk water supply and distribution), while DWSD undertakes distribution of water supply to all areas under Dhanbad Municipal Corporation excluding the areas covered by MADA. Water supply by DWSD is either through piped water or hand pumps. MADA supplies bulk water to BCCL for distribution and BCCL supplies water to their collieries and colonies. However, in some areas, BCCL itself extracts and supplies water to their collieries. Dhanbad Municipal Corporation has water treatment facilities to treat raw water and cater to the regional demand. Capacities of WTP at these sources are listed in Table-1.

Water is supplied to consumers through direct pumping and through elevated reservoirs. DMC has total water storage capacity of 109.73 MLD and a total water treatment capacity of 110.50 MLD. Other than piped water supply, hand pumps, wells and ponds are the other sources of water for the citizens.

GROUNDWATER MANAGEMENT STRATEGIES

To employ an effective groundwater management strategy for any study area, a separate plan needs to be prepared on the basis of the stage of groundwater development into over-exploited blocks (where the stage of water development is > 100%), semi-critical blocks (>70% and < 90%) and safe blocks (< 70%) based on the groundwater resource availability and draft condition of the area. The stage of groundwater development is a ratio of annual groundwater draft and net annual groundwater availability in percentage. The prime management objective is proper utilization of groundwater, implementation of rain water harvesting & artificial recharge techniques and adoption of advance irrigation practices & change in cropping pattern.

Management plan for Over-Exploited block

Jharia comes under over-exploited blocks. These blocks are characterised by intensive domestic and industrial draft. The brief descriptions of block-wise management plan for over-exploited blocks are discussed in Table-2.

Proposed Water Management Strategy for Jharia Coalfield

The proposed water management strategy for Jharia is reduction of groundwater draft for municipal and industrial use by using minewater seepage. Volume of minewater required to be used for Jharia is 31,50,000 m^3. This amount of water is additionally required to maintain stage of development 70% and it's already fulfilling through minewater seepage. Volume of minewater required to be used is given in Table-3 and matching of demand and availability is given in Table-4.

Table-1: water treatment plant capacities installed by dhanbad municipal corporation

Name of the WTP	Installed Capacity (MLD)	Utilized capacity (MLD)
Bhelatand WTP	77 under DWSD (DMC)	35 to 40 treated water
Jamadoba WTP	95.4 under MADA	50 treated water
Jamadoba WTP	143 under DWSD (DMC)	Under construction
Khanudih WTP	14 under DWSD (DMC)	13 treated water
Sindri (Chasnala) WTP	13.6 DWSD (DMC)	12.5
Topchanchi WTP	13.6 under MADA	Not running
Total	**356.6**	**110.5**
Source: *Dhanbad Municipal Corporation, Issuer rating, BWR BB (Outlook: Stable), 2018*		

From the matching of demand and availability scenario, it was revealed that unutilized minewater seepage is a huge reservoir itself to meet the present requirement and to maintain stage of development 70%. Therefore, strict water management practices should be adopted for the coal mining belt. Abandoned mines can be treated as a big rainwater harvesting and artificial recharge structure.

ASSESSMENT OF MINEWATER QUALITY IN JHARIA COALFIELD

Recent investigations in Jharia Coalfield (JCF) have revealed several water bodies in the area to be severely polluted (Saini *et al.* 2016). Large volumes of minewater discharged from the coalmines of JCF get contaminated over time and drain into the Damodar river, polluting it. Drainage and sediment runoff from mining sites, leakage from tailing ponds and overburdened (OB) dumps, oil and fuel spills and sewage effluents attribute to water pollution in this region. Studies in JCF have indicated high hardness of minewater discharges due to dissolved sulphates and chlorides (Tiwary 2001; Saini *et al.* 2016). Singh *et al.* (2012) carried out drinking water quality assessment of minewater collected from the coalmines of JCF. Analysis of the minewater revealed high concentrations of total dissolved

Table-2: Groundwater requirement pattern in over-exploited blocks of Jharia

Sl. No.	Items	Volume of water in Jharia (m^3)
1	Net dynamic groundwater availability	79,20,000
2	Existing gross groundwater draft for irrigation	2,10,000
3	Existing gross groundwater draft for domestic and industrial water supply	86,90,000
4	Existing gross groundwater draft for all uses	89,10,000
5	Proposed gross groundwater draft for all uses	55,40,000
6	Reduction in ground water draft from mining & irrigation for stage of development to 70%	31,50,000

Source: *Report on National Aquifer Mapping and Management Plan in Parts of Dhanbad District, Jharkhand. Central Ground Water Board Report, Ministry of Water Resources. Government of India, 2016.*

Table-3: Volume of Minewater required to be used

Sl.no	Items	Jharia Coalfield
1	Existing groundwater draft for municipal & Industrial Use in m^3	86,90,000
2	Proposed groundwater draft (m^3) for municipal & industrial use for maintaining stage of development to 70%	55,40,000
3	Additional water requirement (m^3) to be met from mine water seepage for stage of development to 70%	31,50,000

Source: *Report on National Aquifer Mapping and Management Plan in Parts of Dhanbad District, Jharkhand. Central Ground Water Board Report, Ministry of Water Resources. Government of India, 2016.*

Table-4: Matching of demand and availability

Sl. No.	Items	Jharia Coalfield
1	Unutilized minewater seepage (m^3)	41,10,000
2	Requirement to be met from minewater seepage (m^3)	31,50,000

Source: *Report on National Aquifer Mapping and Management Plan in Parts of Dhanbad District, Jharkhand. Central Ground Water Board Report, Ministry of Water Resources. Government of India, 2016.*

solids (TDS), total hardness and sulphate (SO_4^{2-}) and treatment is necessary before its utilization. High concentrations of sulphate in the minewater could be due to the weathering of pyrites that are associated with coal seams and shales, whereas weathering of ferromagnesian minerals result in higher concentrations of Mg^{2+} and high Mg^{2+}/Ca^{2+} ratio. Studies revealed Ca–Mg–SO_4 and Ca–Mg–HCO_{3-} to be the dominant hydrochemical facies in the minewater discharges from the coalmines of Jharia Coalfield (Singh *et al.* 2012). Previous investigations in JCF have revealed trace metal concentration to be above the desirable levels prescribed for drinking water. The minewater quality was deemed suitable for irrigation in most cases. Its suitability for irrigation was restricted in some areas due to high salinity, Mg-ratio and residual sodium carbonate.

MINEWATER TREATMENT TECHNIQUES CURRENTLY IN USE IN JHARIA COAL-FIELD

Treatment facilities in Jharia employ the use of *Pressure Filters, Slow Sand Filters, and Rapid Gravity Sand Filters* based on the quality of minewater to be treated as well as the demand for drinking water. Reverse Osmosis (R.O.) filters have also been employed in a pilot scale at Pootkee-Balihari (PB) Area to augment minewater for potable purposes. A case study of the minewater treatment facility at Pootkee-Balihari Area has been carried out as it was one of the first treatment plants set up by BCCL on a pilot-scale to augment minewater for drinking purposes.

Minewater treatment facility at Pootkee-Balihari Area: A case study

The treatment facility at PB Area (Fig.-2) is of 4000 litre per hour (LPH) capacity and is modular in nature and can take care of suspended particulate matter, dissolved heavy metals, hardness and microbiological contaminants. This technology has been translated into a pilot scale and a mine water treatment plant for supplying of drinking water to about 500 households. The developed technology is useful in planning the water management plan for the mining areas and solving the potable water problem in such areas. This technology proposed by CIMFR in collaboration with National Metallurgical Laboratory prescribes the use of coagulants- FEOL, ALOL and flocculent-Polyelectrolyte used to increase particle settling efficiency, each stored in separate vessels for the treatment of mine water. FEOL (Coagulant) is prepared by adding 3 kg iron ferric chloride in 250 L water and then adding 3 kg sodium carbonate to maintain the pH above 3. In this process, required temperature is 40-50 ºC. ALOL (Coagulant) is prepared by adding 1.5 kg aluminium hydroxide in 250 L water and then adding about 900 ml HCL to maintain pH near 7. Flocculent is prepared by dissolving 250 gm polyelectrolyte in 250 L water. Ozone has been successfully used as the disinfecting agent in this plant. At present the plant converts 25,000 litres/day of mine water into safe drinking water.

A survey of the minewater treatment facilities in operation across Jharia Coalfield (JCF) revealed the use of *Pressure Filters, Slow Sand Filters,* and *Rapid Gravity Sand Filters* (Table-5). The units of operation and treatment techniques were observed to be similar for most of the treatment plants. A study of two treatment facilities at Ramkanali (Kusunda) and Block II Area of BCCL was carried out to assess the conversion of minewater into potable water.

Minewater treatment facilities at Ramkanali and Block II Area of BCCL: A case study

The treatment facilities at Ramkanali, and Block II Area use Rapid Gravity Sand Filters (RGSF) for the treatment of minewater. Alum powder is the coagulant used in these treatment facilities while bleaching powder (Calcium hypochlorite) is the disinfecting agent commonly used Bleaching powder though widely used has its disadvantages. It generates solid sludge and adds calcium hardness to the water. Also, the transfer of chlorine into aqueous phase from bleaching powder to the water when suspension is made is time consuming. The water treatment facility at Block II Area (Fig.-3) uses water from Jamunia river during monsoon season. The abstracted river water is then treated with alum and bleaching powder at different stages of the treatment.

Table-5: Water treatment facilities that are in operation across JCF with their respective Filter types

Area	Filter type	Location
Sijua	Pressure Filter	Mudidih
Katras	Rapid Gravity Sand Filter	West Mudidih
		Ramkanali
Govindpur	Slow Sand Filter	Kharkharee
	Rapid Gravity Sand Filter	Sinidih
Barora	Pressure Filter	Muraidih
		Shatabdi
Bastacolla	Slow Sand Filter	Bastacolla
	Pressure Filter	Victoria
		Bera
	Slow Sand Filter	Kuya
Lodna	Pressure Filter	S. Tisra
Kusunda	Slow Sand Filter	Khas Kusunda
Pootkee-Balihari	R.O. Filter	PB Area
Block II	Rapid Gravity Sand Filter	Jamunia
Source: *BCCL*		

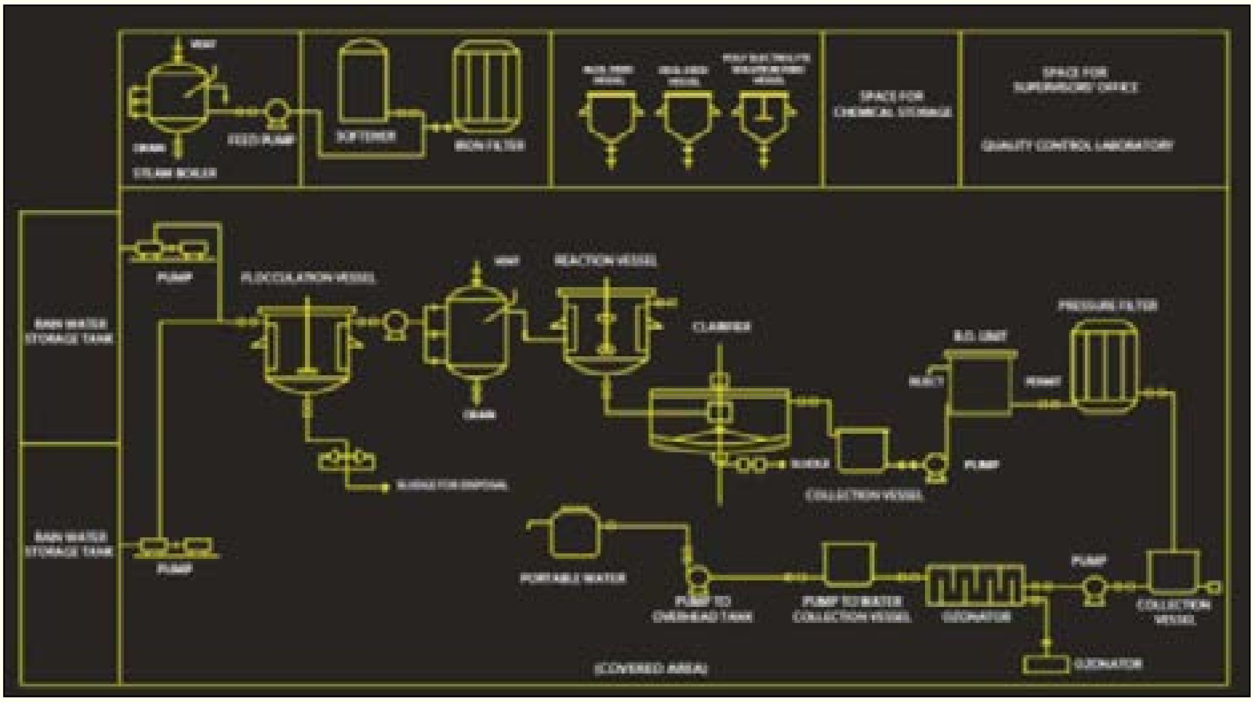

Fig.-2: Layout of Mine Water Treatment Plant of BCCL, P.B. Area. Source: (BCCL)

Dosage of Alum varies between 40-200 kg per day depending upon the colour of raw water. After subsequent filtration, 30-35 kg of bleaching powder is added per day over 3 shifts of 8-hour duration each. The Mine Water treatment facility at Ramkanali (Fig-4) treats pumped out underground mine water which is then subjected to aeration to remove iron and other dissolved gasses like H_2S, CO2. The aerated water is taken to the clarifier unit where 3-4 kg alum powder is added every 2 hours throughout the day. 35-50 kg alum is used up in a day. Bleaching powder is used for disinfection. 10-12 kg bleaching powder is added in a storage drum of 120 L capacity and allowed to settle for 12 hours in the primary drum after which it is transferred to the secondary drum, from which it is added to the filtered water at a flow rate of 100 ml per minute.

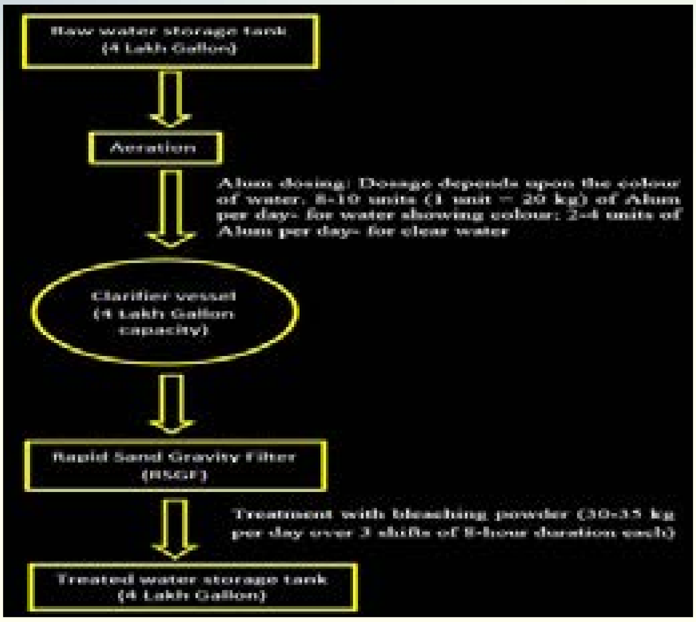

Fig.-3: Flowchart of Mine Water treatment facility at Block II Area

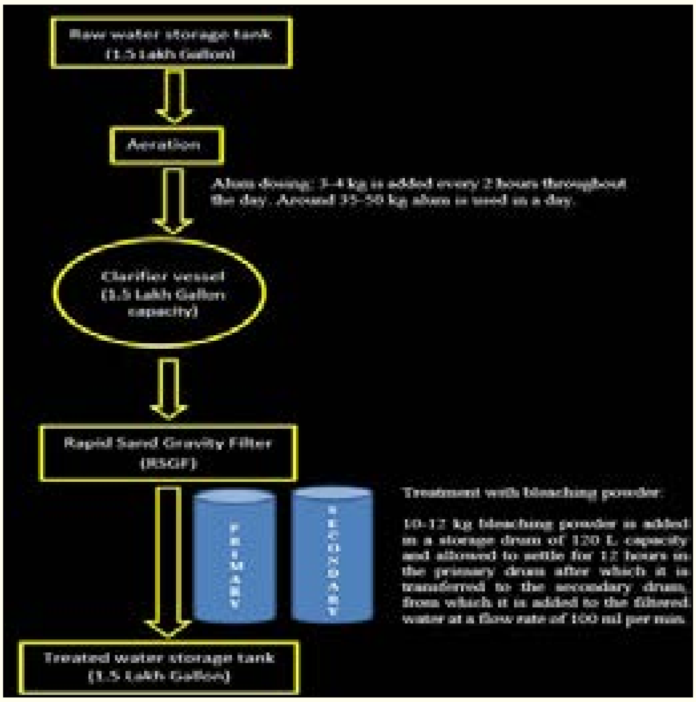

Fig.-4: Flowchart of Mine Water treatment facility at Ramkanali

MINEWATER UTILIZATION IN JHARIA COALFIELD

Scheme for multipurpose utilisation of abandoned minewater

Minewater discharged from the abandoned coalmines of Jharia Coalfield may be gainfully utilised by implementation of this scheme, which has been executed at a cost of Rs 11.72 cr. Under this scheme, a pipeline network of approximately 45 kms has been laid. On implementation of this scheme, 47 million gallons (MG) of surplus minewater from Block-II, Barora and Govindpur areas of Jharia Coalfield that is currently discharged into natural water courses will be stored in two reservoirs of storage capacities 16 MG and 31 MG respectively, covering areas of 4 hectare-area (ha) and 4.5 hectare-area (ha) respectively. These reservoirs are located in Behrakudar and Khonathi villages of Bagmara Block of Dhanbad district. The villagers residing in this region shall directly benefit from the scheme as water demand for cultivation and other agricultural needs shall be adequately met throughout the year. The dependence on monsoon rains for cultivation shall decline on implementation of this scheme. The minewater from the reservoirs is used for potable purposes after adequate treatment. Pisciculture can also be done in these reservoirs with help of self-help groups to elevate livelihood of the local populace.

Scheme for domestic/ community uses of surplus minewater

The flow of mine water from the coal mines of Jharia Coalfield draining into natural water courses may be arrested by diverting and channelizing the flow into the existing ponds of villages lying in close proximity to JCF. 2.16 MGD of surplus mine water from West Jharia Area flowing into natural water courses has been arrested under this scheme and diverted into ponds in the peripheral villages through pipelines. These ponds harvest water as they remain over-flooded even during peak summer season. The villagers residing near these water sources may cater to their agricultural needs on all seasons which at present is totally dependent on rain water from the monsoons. Under this provision, the socio-economic status of the region may be uplifted by improving self-employment scope. The implementation of such schemes in other areas of BCCL are under consideration to arrest flow of minewater into the natural water course.

Assessment of minewater utilization from selected clusters of Jharia Coalfield

In the backdrop of water shortage faced by the local population residing in Jharia Coalfield, some clusters of Jharia Coalfield under BCCL, through implementation of the aforementioned schemes in addition to the setting up of water treatment facilities have improved the extent of minewater utilization. Previous studies in Cluster VIII, Cluster IX and Cluster X have revealed that a total of 36,180 m^3 of water is being pumped out from the coalmines in these clusters for trouble-free mining operations daily. Out of 36,180 m^3 per day, 24,914 m^3 is utilized, while 11,266 m^3 water per day is discharged as runoff (Central Groundwater Board Report, 2016). These figures indicate that a substantial quantity (nearly 69% of total minewater discharge) is utilized. However, a framework needs to be set up to tap into the unutilised minewater which constitutes nearly 31% of the total minewater discharge. Details of mine discharge of Jharia coalfield is given in Table-6.

Table-6: Utilization of minewater discharged from the coal mines Jharia Coalfield

Cluster X (Jharia)	Mines	Minewater discharged per day (m^3/day)	Utilization (residential & related) (m^3/day)	Other uses (m^3/day)	Manufacturing requirement (m^3/day)	Total Utilized (m^3/day)	Total Unutilized (m^3/day)
1	Bhowrah North UG	1485	328	328	0	656	829
2	Bhowrah North OC	640	329	329	0	658	-18
3	Bhowrah South UG	2300	330	330	0	660	1640
4	3 Pit OCP	620	331	331	0	662	-42
5	Chandan OCP (Bhowrah)	580	332	332	0	664	-84
6	Patherdih UG	2000	333	333	0	666	1334
7	Chandan OCP (Patherdih)	700	334	334	0	668	32
8	Sudamdih Incline UG	1160	335	335	0	670	490
9	Sudamdih (Shaft) UG	2340	336	336	0	672	1668
10	Amlabad Closed	0	337	337	0	674	-674
11	Sudamdih Coal Washery	0	338	338	0	676	-676
	G. Total	**11825**	**3663**	**3663**	**0**	**7326**	**4499**

Cluster IX	Mines	Minewater discharged per day (m^3/day)	Utilization (residential & related) (m^3/day)	Other uses (m^3/day)	Manufacturing requirement (m^3/day)	Total Utilized (m^3/day)	Total Unutilized (m^3/day)
1	N.T/S.T Expansion OCP (Prop)	2330	636	0	1681	2317	13
2	Lodna UG	1600	723	360	203	1286	314
3	Bagdigi UG	2230	409	800	40	1249	981
4	Bararee UG	2050	425	500	56	981	1069
5	Joyrampur UG	1640	534	300	212	1046	594
6	Jealgora UG	1600	1600	0	0	1600	0
7	N. Tisra UG	1140	385	600	123	1108	32
8	Jeenagora OCP	700	300	100	300	700	0
9	N/S Tisra OCP	1745	950	135	660	1745	0
	G. Total	**15035**	**5962**	**2795**	**3275**	**12032**	**3003**

Cluster VIII							
1	Bastacolla UG & OC	1840	875	310	0	1185	655
2	Bera UG & OC	1470	530	240	0	770	700
3	Dobari UG	1550	595	120	0	715	835
4	Kuya UG & OC	1870	782	325	0	1107	763
5	Goluckdih OCP	1180	160	345	0	505	675
6	Ghanoodih OC	590	540	425	0	965	-375
7	Kujama OC	820	82	227	0	309	511
	G. Total	**9320**	**3564**	**1992**	**0**	**5556**	**3764**

Source: *(Central Ground Water Board Report, Ministry of Water Resources, Government of India, 2016)*

CONCLUSION

This review has attempted to give an insight on augmentation of minewater from coalmines of Jharia Coalfield for potable purposes to mitigate the problem of water scarcity. This paper elucidates the importance of integrated water resource management in the backdrop of water crisis scenario plaguing the inhabitants of Jharia Coalfield by the utilization of minewater discharged from the coalmines of Jharia Coalfield for domestic and industrial use. This review provides water management strategy for Jharia Coalfield to match the water demand with availability. It is found that the volume of unutilized minewater seepage is a reservoir large enough to meet the present requirement. Therefore, there is a need to adopt strict water management practices in the Jharia Coalfield belt. This paper attempts to shed light on the minewater treatment techniques currently in use in Jharia Coalfield with an emphasis on the minewater treatment facility of BCCL at Pootkee-Balihari Area which was started as a pilot project for the purpose of augmenting minewater for drinking purposes. The review provides information on the schemes that are implemented for the utilization of minewater discharges. An assessment of mine utilization after implementation of the aforementioned schemes is carried out in clusters 8, 9 and 10 of Jharia Coalfield under BCCL. The assessment revealed greater utilization of minewater (~ 69% of total minewater discharge). However, there is potential to further optimize the utilization of minewater. Further research is required to fill the knowledge gaps in optimising the utilization of minewater for potable purposes. The schemes for minewater utilization need to be implemented in other parts of Jharia Coalfield as well. There is scope for improvement in minewater treatment techniques, resulting in improved water quality for consumption.

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Strata Monitoring Instruments used in Underground Coal Mines: A Review

Lokhande R D[1], Kothakonda Maharshi [2], Ryakala Vinay[3], Sudam Srujan[4], Bhupendra Zilpe[5]

ABSTRACT

Extraction of coal from underground is not easy. It generally encounters problems like failure or collapse of roof rock, bumps, overriding of pillars and number of ground control problems. Due to these it causes damage to man and machine as well as loss of production. To control the problems related to roof strata, it is necessary to study the behavior of roof strata. The measurement of stresses or strain acting over it is also important and this is possible with field instrumentation. There are different types of instruments available to measure different parameters in the mine. This paper reviews full details of field instrumentation to understand the behavior strata.

Keywords: *Coal mining, strata control, bed separation.*

INTRODUCTION

Consider the stratigraphic cross section of a coal mine. In its virgin state, before any opening is made, the rock mass is in equilibrium everywhere in the cross section. Once an opening such as an entry is made in the coal seam, the coal seam and rock mass in the vicinity of the opening are no longer in equilibrium. The rock mass in the roof has lost support from below, the floor rock no longer has an applied load from above, and the coal seam is no longer constrained along the sides (ribs) of the opening. If no artificial supports are erected, the time interval between exposure of the roof, floor, and ribs and their collapse will depend on rock properties and local conditions.

Ground control is the science that studies the behavior of rock mass in transition from one state of equilibrium to another. It provides a basis for the design of support systems to prevent or control the collapse or failure of the roof, floor and ribs both safely and economically.

In designing the best suitable support system for ground control, the basic principle of rock mechanics is frequently used. Each candidate system is structurally analyzed in terms of stress (force) and strain (displacement) distribution, which allows the stability of the system to be determined by using appropriate fracture criteria.

Since ground control deals with the stability of mine structures by analyzing the imposed stress (or load) configuration and the induced strain (or deformation) in each structural element, knowledge of the distribution of the stress or strain within each element is of at most importance. The exact magnitude of stress or strain can be obtained by analytical modeling or by measurement with field instruments.

Different parameters are monitored to understand the behavior of the strata under stressed conditions, namely, load on supports, stress, convergence and bed separation. These parameters are measured separately and then co-related to understand the strata conditions. Manual and automatic monitoring of the strata is possible. Instruments may give an error in readings due to some fault in construction or manual error, so one should be careful. Due to moisture conditions in the strata, instruments may start malfunctioning after a few years. Here, we discuss about the various instruments used in mining measuring various parameters and their working principles.

This paper reviews a full range of field instrumentation that is required for monitoring ground conditions, to understand the behavior of potentially unstable rock mass and to predict rock mass failure.

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Various modes of instrument operation exist, namely:

Mechanical:

- Often provide the simplest, cheapest and most reliable methods of detection, transmission and readout.
- Mechanical movement detectors use a steel rod or tape, fixed to the rock at one end, and in contact with a dial gauge or electrical system at the other.
- The main disadvantage of mechanical systems is that they do not lend themselves to remote reading or to continuous recording.

Hydraulic:

- Diaphragm transducers that are used for measuring water pressures, support loads and so forth.
- The quantity measured is a fluid pressure which acts on one side of a flexible diaphragm made of a metal, rubber or plastic.

Electrical:

- The most common instrument mode used in mines, although mechanical systems still find widespread use in displacement monitoring.
- Electrical systems operate on one of three principles, electric resistance strain gauge, vibrating wire and self-inductance. [2]

MEASUREMENT OF LOAD

The purpose of a load cell is to record reliably the load on underground roof supports. Very often the component to be instrumented will be in a hostile environment and consequently the designer of the instrumentation scheme must be fully conversant with the interactions between the various parts of the underground system, the environment and its changes with time, and with excavation progress.

Vibrating wire load cell

The load cell has been designed for the measurement of loads in the rock bolts. It has a transducer working on vibrating-wire principle. As shown in Fig.-1(a), Fig.-1(b) and Fig.-1(c), it incorporates either three, four, five or six vibrating wires mounted parallel to the cells axis of symmetry and equally spaced, housed in a metal cylinder. Each vibrating wire assembly consists of a tensioned wire clamped at both ends. A coil/magnet is located at the mid-section of the wire. If an electrical pulse is supplied to the coil/magnet the wire will be plucked and oscillate at its natural resonant frequency. A change in applied axial load will be inversely proportional to the frequency of the wire because of change in length of the wire. If any change in the applied axial load is present, then the length of the vibrating wire changes so change in frequency is observed. The coil/magnet acts as a pickup as the oscillations of the wire through the magnetic field induces an alternating current in the coil which can be detected and shown in a readout unit, converted into load using calibration charts.

Efficacy and adequacy of the support system can be inferred on the basis of these load cells. Several research engineers are responsible for the application of the vibrating-wire principle for the load measurement. The papers of (Cooling and Ward, 1953), (Ward, 1955), (Skempton and Ward, 1951), (NGI, 1962), (Ward and Cheney, 1960), (Di Biagio and Kjaernsli, 1961), (Sutherland and Findlay, 1961), and (Cooling, 1962) present details of some of the earlier uses and applications of these load gauges. [3]

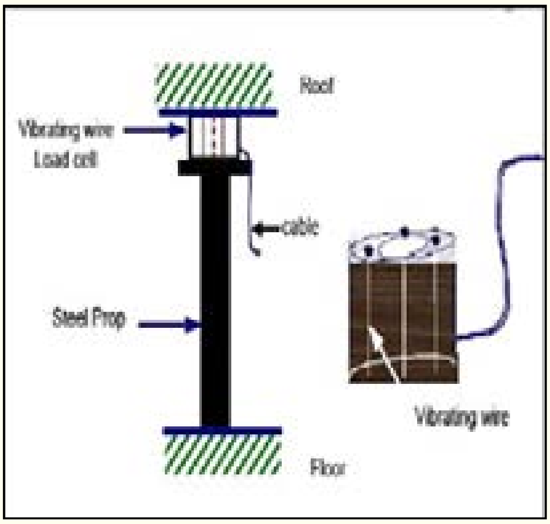

Fig-1(a): Vibrating wire load cell

Mechanical Disc Load Cell

In order to measure tensile loads in anchor, Interfels GmbH has produced an elastic element comprising a cup spring. The element, fixed between an abutment plate and a top yoke plate deflects when loaded, Fig.-2. A dial gauge or an electrical displacement transducer measures the compression of the elastic spring and the load is found by comparison of the displacement

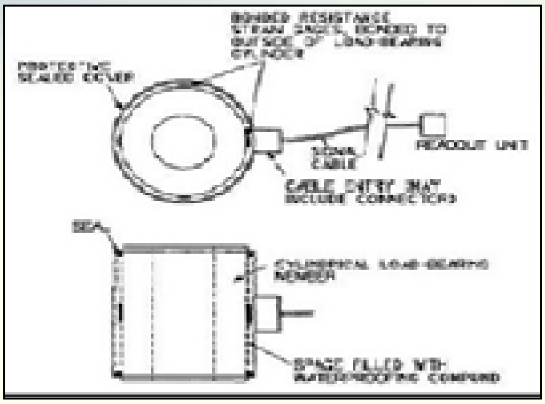

Fig-1(b): Schematic of Electrical Resistance Load Cell (Dunnicliff,1988,1993)

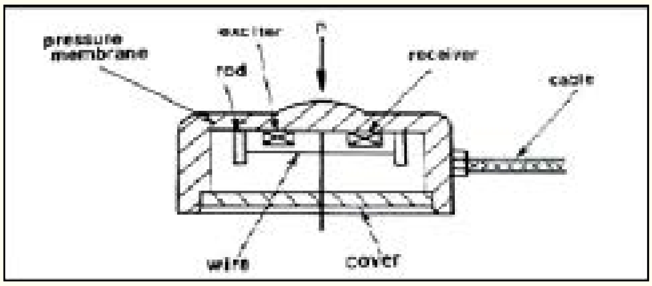

Fig-1(c): Vibrating wire load cell (Song et el., 1982)

recorded with a calibration curve. The reading of a cup spring deflection is achieved by a dial gauge with a special feeler-end, reading to an accuracy of 0.01 mm. A special calibration device ensures that the same initial zero value is used for each measurement, Fig.-4. The measuring accuracy is about ± 0.5%. Because of the hysteresis of the cup springs, the applied load-disc compression relation is non-linear and such a curve is shown in Fig.-3. This hysteresis loop requires care in using the gauge to be sure that the correct part of calibration curve is being used (Thomas H. Hanna, 1985).

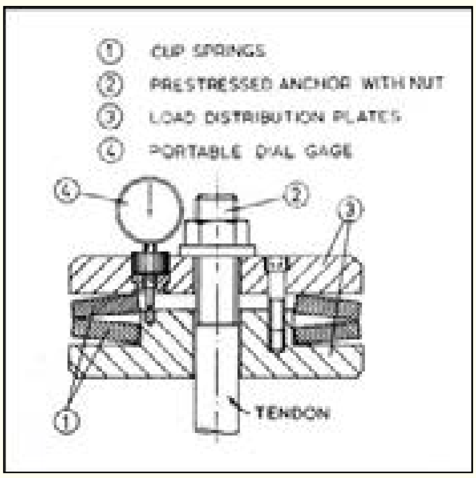

Fig-2 : Mechanical Disc

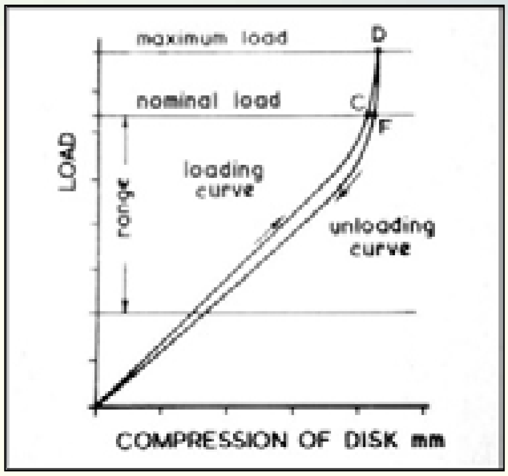

Fig-3 : Caliberation Curve

Strain gauged load cell

The operating principle of these cells relies on the basic property of a metal that its electrical resistance varies directly in response to deformation caused by applied mechanical load. Details of strain gauges and their use are reviewed by (Hendry, 1964) and (Scott, 1972). It consists of a Stainless Steel cylindrical housing with up to 16 resistance strain gauges in a Wheatstone bridge configuration. When the cell is subjected to load, the strain gauges change their resistance, the resulting output signal is directly proportional to the applied load. The cell is connected to a sheathed cable which is itself connected either directly to a readout unit, or via a switched terminal unit. They can also be wired directly to data loggers for remote monitoring. In the Load cell, arrangement for compensation of both temperature effects and off-center loading are provided. Complete details of these cells including waterproofing, calibrating, installation on site and recording are given by (Whitaker, 1963). They are available in different sizes, in both annular and solid style.

Application: Monitoring load on supports.

Hydraulic pressure load cell

Hydraulic Load Cell consists of a sensitive pressure pad formed by joining two stiff steel discs at their periphery. The cell body is filled with de-aired hydraulic fluid. When load is applied to the load cell, the pressure of the hydraulic fluid changes. The change in pressure correspond directly to the load applied. By recording the change in pressure pad, load can be determined. To take readings a portable unit is connected to the pressure sensitive hydraulic transducer fitted in the load cell.

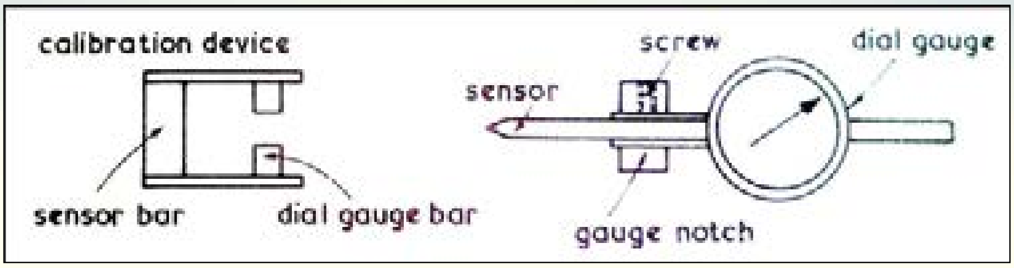

Fig-4: Caliberation device & dial gauge

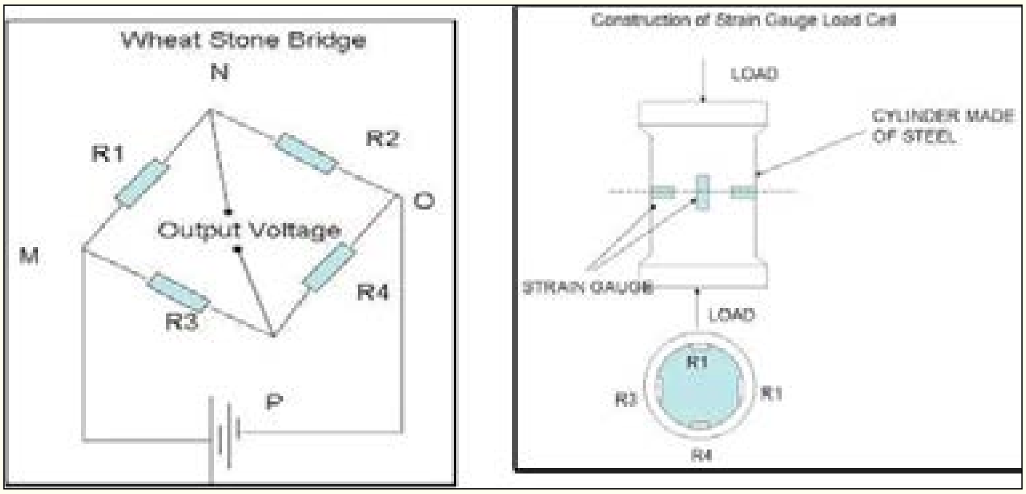

Fig-5: Strain Gauged Load Cell & Wheatstone Bridge

Pressure is supplied to one side of a flexible diaphragm in the transducer Fig.-6. A special hydraulic load cell has been developed by the Losinger Company for the long-term monitoring of ground anchors (Dietrich, 1977).

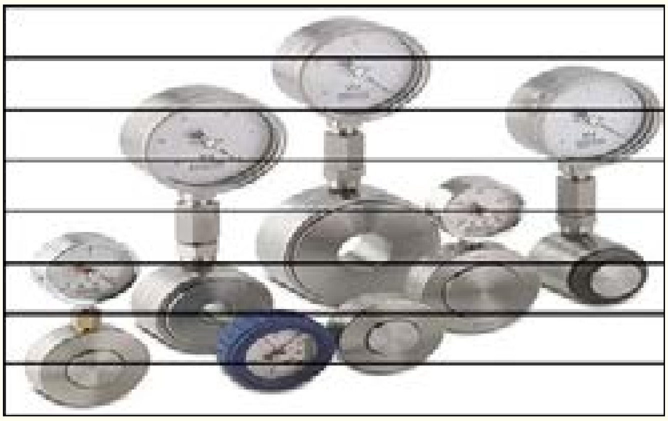

Fig-6: Hydraulic Cell

Rock bolt load cell (vibrating type)

Roof Bolt Load Cells are simple rugged instrument Fig.- 7. They are easy to read and are useful for routine bolt operation. It is an economical Tool with proper accuracy. It consists of load cell which has a sensor working on vibrating-wire principle. Firstly, the roof bolt is installed. Now-a-days, there are different types of bolting machines available, which are used for the installation of roof bolt. Bolting machines (Lang *et. al.*1979) equipped with both single boom and dual-boom are available. The load cells should be installed to the roof bolts using specially prepared steel seating arrangement. It is essential that the load bearing surfaces above and below the Load cells are smooth and flat, parallel and sufficiently strong to avoid significant distortion under load. The roof bolt load cells should be installed at the junctions to study the change in load over the roof bolt.

Strain gauged roof bolt

Strain gauged rock bolts can be used to measure the distribution of bolt loads for design purposes. (Sawyer and Karabin, 1975) describe the development of instrumentation to enable load distribution to be obtained. Bolt loads can be monitored along each bolt by the use of multiple strain gauges. Multiple pairs of strain gauges are embedded at regular spacing along each bolt enabling the axial loads and bending moments to be measured along its full length. Strain gauged rock bolts provide a valuable tool for monitoring support system performance against design specification. Instrument layout is given in

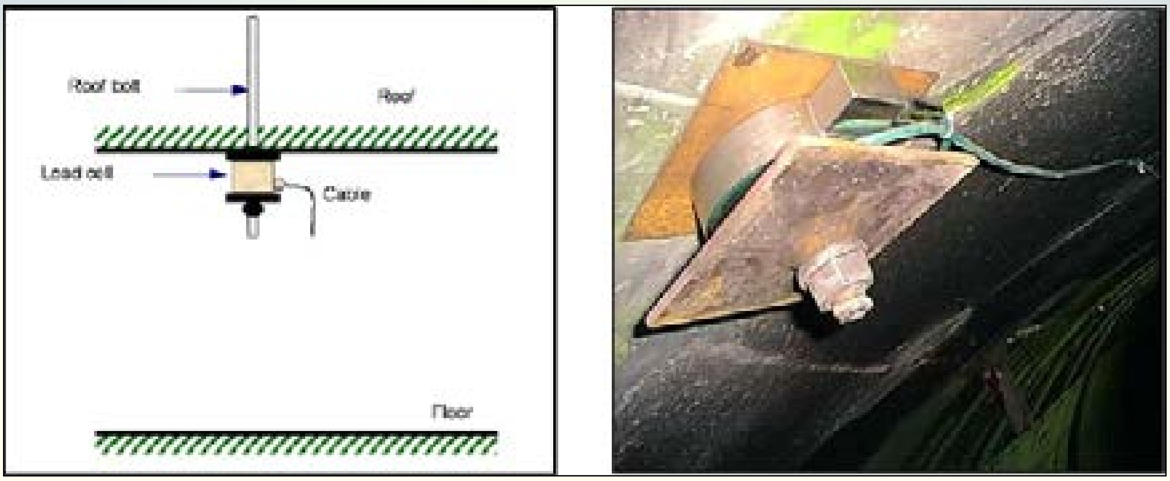

Fig-7: Rock bolt load cell

Fig.-8. Rock bolt strain gauge can be fixed in roof, sides, surface slopes, embankments, etc. Wireless local reading or remote hard-wire reading up to two kilometers away are available. Normally, for the 22 mm diameter bolts, the bolt loads should not exceed 25 t (250 kN), which is the yield strength of the bolt steel (A.S. Bloor, 1989).

Fig.-8: Strain Gauged roof bolt

MEASUREMENT OF STRESS

The stress state in the ground is of special interest to geotechnical engineers particularly when they are dealing with movements in the ground which may modify the in-situ stress states. Except on principal planes, the stress system is complex and for convenience of measurement the stress vector at a point, on a boundary or in a ground mass may be resolved into the normal and shear average components. Stress cells are used to monitor the stress coming on the pillars.

Vibrating wire stress cell

Principle: This instrument is used for measuring unidirectional stress changes in the pillar. It consists of a wire tensioned across the steel cylinder of 38 mm diameter. The cylinder deforms due to stress changes in the rock causing tension in the wire to change. (Hawkes, 1974).

A bore hole 38 mm diameter is required for installing the stress meters at the mid height of the pillar either horizontally or slightly inclined according to the dip of the seam. The stress meter is installed in to the borehole with the help of installation tools at a depth of 4-8 m.

Generally, these stress cells are used in the pillars to measure the vertical stress. But stress cells measuring stress in more than one direction are also available.

Biaxial stress meter

This instrument is used to measure the compressive stress changes in rock. It consists of 3 or 6 vibrating wire sensors angled at 60^0 allows the principal stress changes to be measured to the plane perpendicular to the stress meter axis. It consist of a high strength steel cylinder which is installed into 60 mm size borehole. The steel cylinder will deform when there are stress changes in host material. Vibrating wire sensors will measure the deformation in the cylinder as shown in Fig-10.

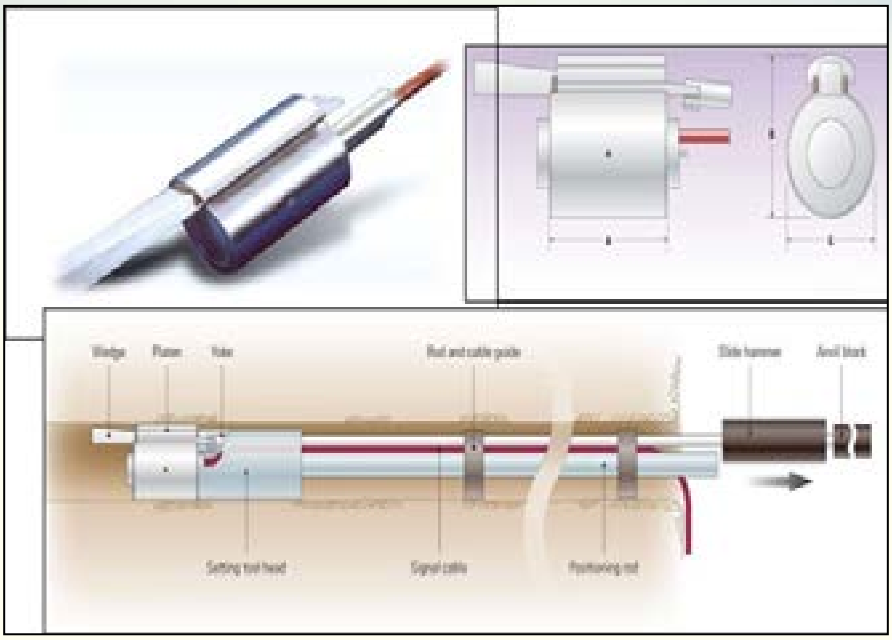

Fig-9: Vibrating wire Stress Cell (Anon, 2013a)

Fig-10: Biaxial stress meter

Triaxial stress meter

The stress cell consists of a soft inflatable membrane with about eighteen electrical resistance strain gauges mounted flush on its outer surface. The gauges will be glued to the surface of the borehole for any direct measurement of strain changes occur in rock Fig.-11.

Fig-11: Triaxial stress meter

CONTINUOUS PRESSURE CHART RECORDER

A pressure recorder consisting of bourdon tubes in phosphor bronze rolled in concentric circles for pressure sensing supports and a mechanically wound clock that rotates the recording chart once in 24 hours are used to monitor the resistance or pressures of the powered Fig -12 (Anon 2019 e).

Principle: The hydraulic pressure will deflect a lever arm that is fixed at a tail end of the tube when the hydraulic lines of the support are connected to the bottom tube. The amount of deflection is measured by transmitting to the recording pin as pressure and rotating chart is use to record the readings. The writing device in the recording pin should maintain clean line plotting and should not pose any smearing potential.

Many of today's chart recorders can also record information in a digital format for download to a computer.

- The resistance or pressures of the powered support are monitored by a pressure recorder consisting of bourdon tubes in phosphor bronze rolled in concentric circles for pressure sensing and a mechanically wound clock that rotates the recording chart once in 24 hours.
- When the hydraulic lines of the support are connected to the bourdon tube, the hydraulic pressure will deflect a lever arm that is fixed at the tail end of the tube.
- The amount of deflection is transmitted to the recording pin as pressure and recorded in the rotating chart.
- It is essential that the writing device in the recording pin maintain clean line plotting and pose no smearing potential. [24]

POTENTIOMETRIC (SERVO) INSTRUMENTS

Analog chart recorders use a galvanometer movement to directly drive the pen which have limited sensitivity. The direct drive of the marking pen is replaced with a servomechanism where energy to move the pen is supplied by an amplifier in a potentiometric type of recorder Fig.-13. The motor-operated pen is arranged to move the sliding contact of a potentiometer to feed back the pen position to an error amplifier. The amplifier drives the motor in such a direct as to reduce the error between desired and actual pen position to zero. With a suitable signal processing amplifier, such instruments can record a wide range of process signals (Z.C. Song, T.L. Deng, Y.S. Liu and M.K. Zhen, 1982).

DIGITAL CHART RECORDERS

A modern chart recorder is an embedded computer system with an analog to digital converter, a microcontroller, and a hard-copy printing device; such instruments allow great flexibility in signal processing, variable chart speed on process upsets, and can also communicate their measurements to remote points.

Fig-12: Continuous Pressure Chart Recorder

Fig-13: Potentiometric instrument

Fig-14: Digital recorder

Mr. McElroy's design was an instant loading paper roll 'table-top' unit using an Integrated Chopper Circuit for signal conversion. The unit had plug in circuit boards, plug in single or multi-range modules and plug in single or multi-speed modules. The recorder's sensitivity was 1 microvolt to 100 volts fullscale, which at the time was an industry first. Mr. McElroy also aided in the design and build of the Gas Chromatograph used for analyzing dirt and rock samples from the 1969 moon landing.

CRACK METER

The instrument consists of an extendable shaft connected to a spring, which is further connected to a vibrating wire sensing element. As the shaft moves, the spring is proportionally stretched, further proportionally stretching the vibrating wire sensing element. The vibrating wire is very sensitive to strain changes, and emits different frequencies at different strains upon excitation.

Operation

The installation of the Crackmeter consists of drilling two holes at desired locations and grouting the two anchors in place. The Crackmeter cable should be installed away from electrical noise, and additional lightning protection may be installed if deemed necessary. The movement of the joint or crack may then be easily monitored by connecting the cable to an RST Readout. Furthermore, the Crackmeter also has a built in thermistor, and thus the temperature may also be measure.

It is recommended, depending upon site conditions, to consider installing a guard to protect the instrument from debris. [42]

MEASUREMENT OF CONVERGENCE

Telescopic Convergence indicator

The TCI consists a graduated rod fitted in a piper as shown in Fig.-16. The instrument has a least count of 0.5 to 1 mm and telescopic movement for a length of 2 to 4 m. The reference points are the metal rods grouted in the floor and roof. The anchors are placed in floor and roof vertically in a straight line. Convergence rod measures the distance between the anchors, which gives the convergence (NIRM Report, 2008).

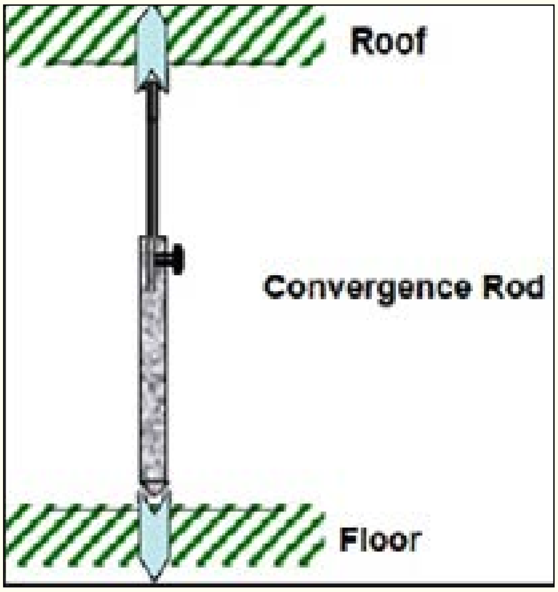

Fig-16: Telescopic Convergence Indicator

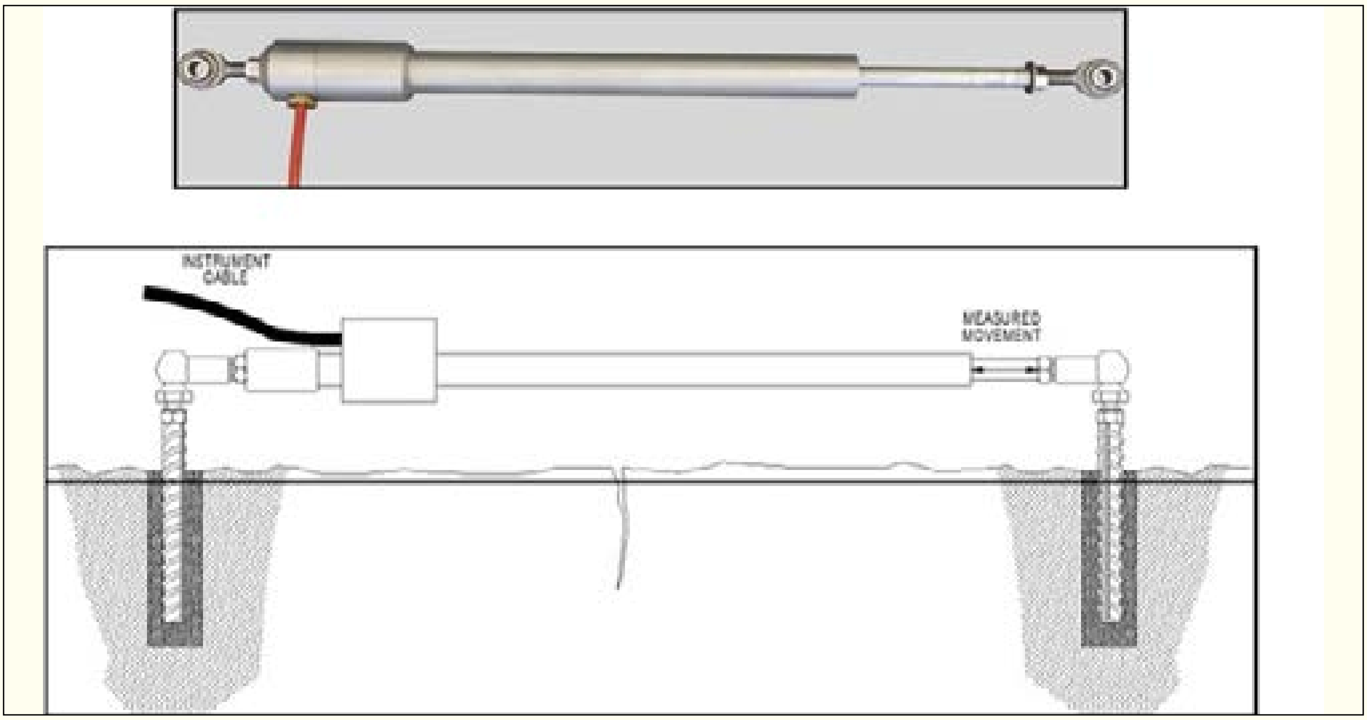

Fig-15: Principle and operation of Crackmeter

Remote convergence indicator

The RCI has telescopic tubes whose ends are fixed in immediate roof and floor. It consists of a potentiometer which is connected to the top sliding telescopic tube, and a slider is fixed to the bottom tube. The slider moves on the resistance coil, due to the movement of roof which results in change in resistance of the coil and is directly proportional to the convergence or divergence. A Battery operated read out unit measures the change in resistance Fig.- 17. The RCIs were installed at the junctions in the middle of the panel (NIRM Report, 2010).

Application: For remote monitoring of roof to floor convergence

TAPE EXTENSOMETER

Tape Extensometer is a device used to measure the distance between two anchors grouted in shallow holes in the ground or on the structures as shown in the Fig-18. It consists of stainless steel tape with equally spaced precision punch holes. The free end of the tape is attached to spring load connector which locates on the top of the reference anchor. The fixed end of the tape houses the steel tape and as a location identical to that at free end. There is also tape tensioning system with digital read out display unit as shown in Fig-19.

Application:

- Its function is similar to the telescopic convergence rod in measuring the convergence.
- The surface profile movement of roadways can also be measured with this instrument.

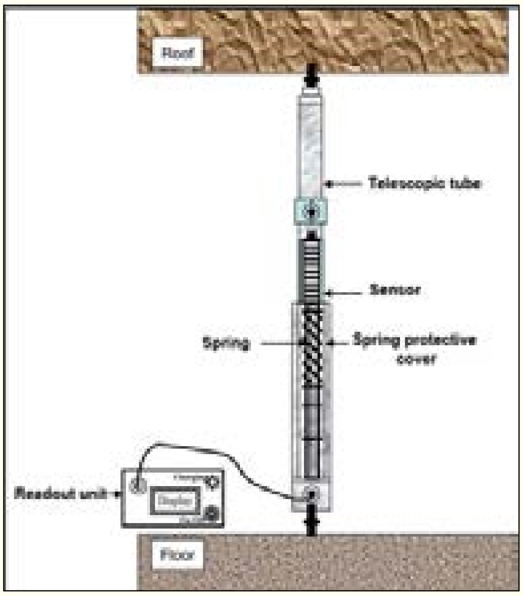

Fig-17: Remote Convergence Indicator

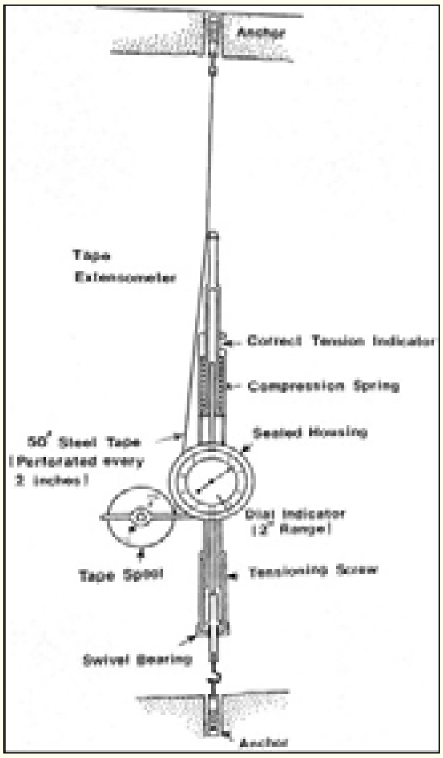

Fig-19: Tape Extensometer (Syd S. Peng, 1986)

Fig-18: Tape Extensometer

BED SEPARATION

Bed separation is one of the important parameters that is considered during strata monitoring with the help of some instrument.

Tell tale Extensometer

This system is designed to measure bed separation and delamination Fig.-20. The anchor is fixed inside the borehole at different horizon as shown in Fig.-21. After inserting the anchor free end of the wire is passed through the reference tube and crimped to the indicator. The scale on each indicator is visually read against the bottom reference tube and to record the delamination with 1 mm accuracy Fig.-22. Movement between the anchors is determined by subtracting the movement of the lower anchor from the movement of the upper anchor (Yu, T.R., 1983). The details of the instrument is given in (NIRM Report, 2004).

Wire extensometer designs have been given by (Whittaker and Woodrow, 1977) and (Pekkari and Stillborg, 1982). Tell tale also comes with rotary indicator and auto warning system as shown in Fig-23.

Application: Monitoring bed separation in roof strata

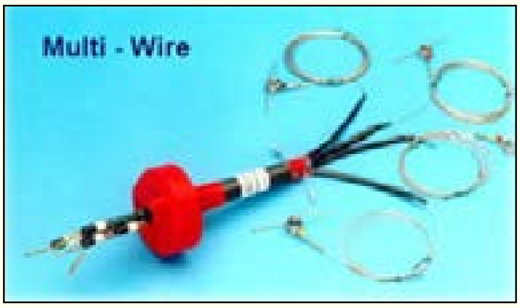

Fig-20: Multi-wire tell tale extensometer

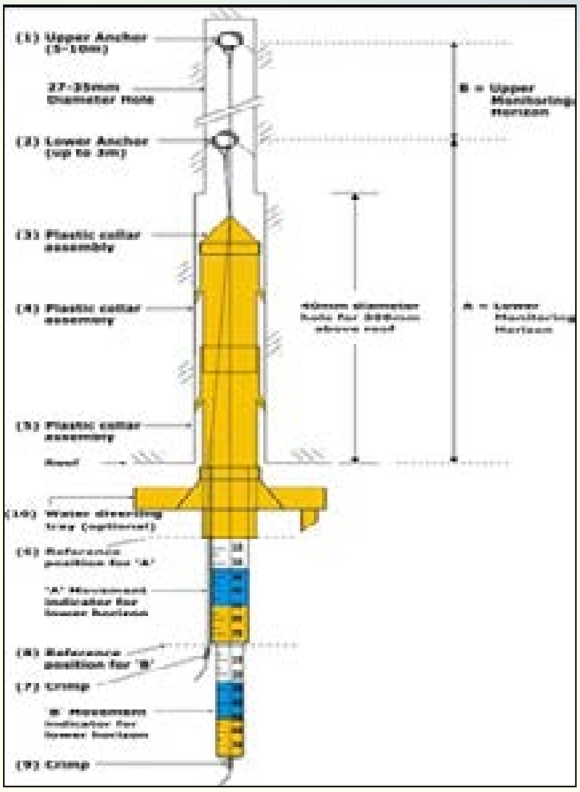

Fig- 21 : Two Anchor wire extensometer

Fig- 22: Auto warning tell tale extensometer (Anon, 2013c)

Multiple rod extensometer

Some anchors are put at different depth of a bore-hole in borehole extensometer and monitoring of the variation in the distances between the anchors with reference to a point on the exposed rock surface is done from time to time (C.M.R.S, 1989). Borehole extensometers are classified depending on working principle as follows:

Rod type Extensometer

- Mechanical Anchor Extensometers (Fig.-26)
- Grouted type Multi point Extensometers(Fig.-27)
- Hydraulic anchor extensometers (Fig.-24)

(Amstad and Koppel, 1977) and (Stillborg *et al.*, 1982) are the ones who designed Rod extensometers. Small diameter rods of steel or fiberglass are used to connect the anchors of a borehole extensometer which are grouted in the ground, at various distances

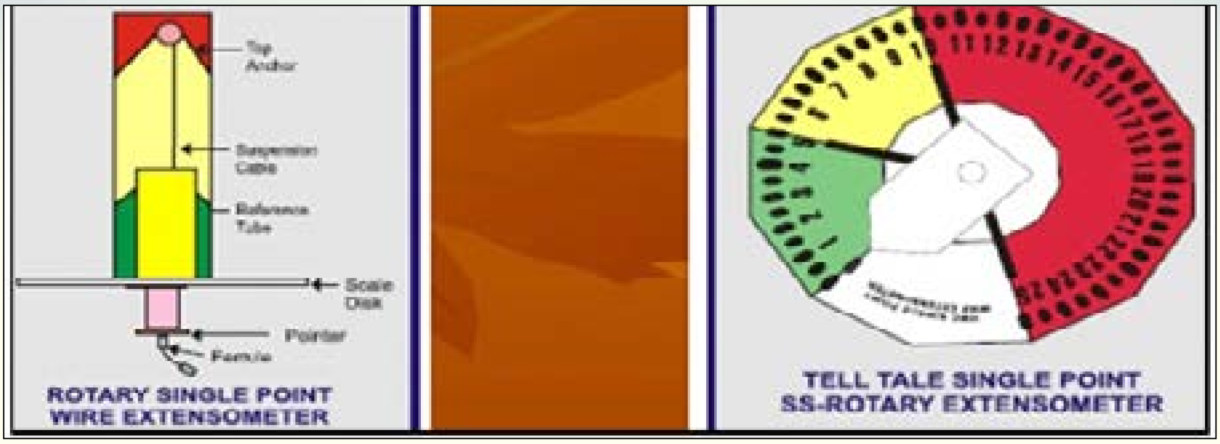

Fig- 23 : Rotary Tell tale extensometer

and surface mounted reference heads. (Bordes and Debreuille, 1983) One can tell how much each anchor - and its increment of soil or rock - is moving in response to excavation by detecting movement of the tops of the rod at the surface and so take steps to mitigate developing problems.

Sensitivity of these instruments varies between 0.002 and 0.1mm depending on the readout system in use. These extensometers may also be placed in down or up boreholes and displacements across cracks or joints can be measured by mounting on the ground surface. The anchors may be either grouted or hydraulic. The hydraulic borehole anchors can be installed in boreholes irrespective of its orientation. They are especially useful in boreholes which are fractured or oriented in upward direction and in which grouting is difficult.

Application: For monitoring bed separation in roof and floor.

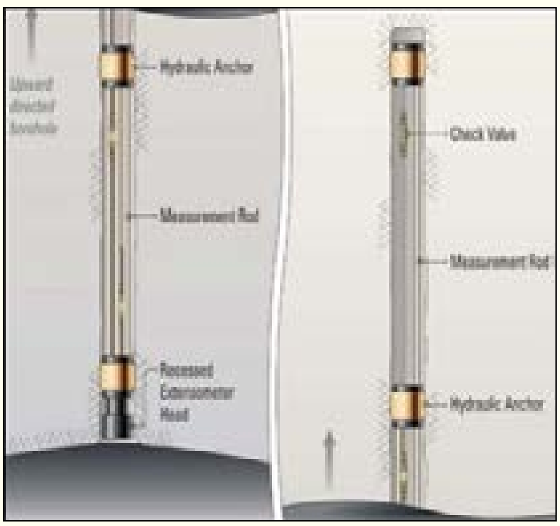

Fig.-24: Hydraulic anchor rod extensometer

Fig.-25: Multi rod extensometer

Magnetic Ring Multipoint Borehole Extensometer (MRMPBX)

Magnetic ring multipoint borehole extensometer or MRMPBX consists of ring magnetic anchors as shown in Fig. 28 positioned on a central access tube which are fixed in the ground allocations where displacement is to be monitored (Gupta and Farmer, 1981).

A probe incorporating a Read switch is made to travel within the access tube to sense the position of magnets outside the access tube. The Read switch closes on entering a magnetic field and activates a buzzer or an indicator light in the signal receiving instrument. The cable of the probe is marked at suitable intervals for measuring the location of each magnet from the end of the access tube Fig.-29.

MRMPBX is used to measure vertical movement of the strata and horizontal movement in the pillar. It is used to measure the bed separation, roof to floor convergence and pillar dilation. It is the only instrument that measure both the lateral and vertical movement.

Vibrating wire extensometer

The Geonor extensometer operating on the vibrating-wire principle is shown in Fig-30. The moveable head of the extensometer by a spring is attached to one end of the wire. Change in tension in the spring is caused by the displacement of extensometer, with which frequency of vibration is altered of the tensioned wire. Change in spacing between the extensometer and the anchor plate

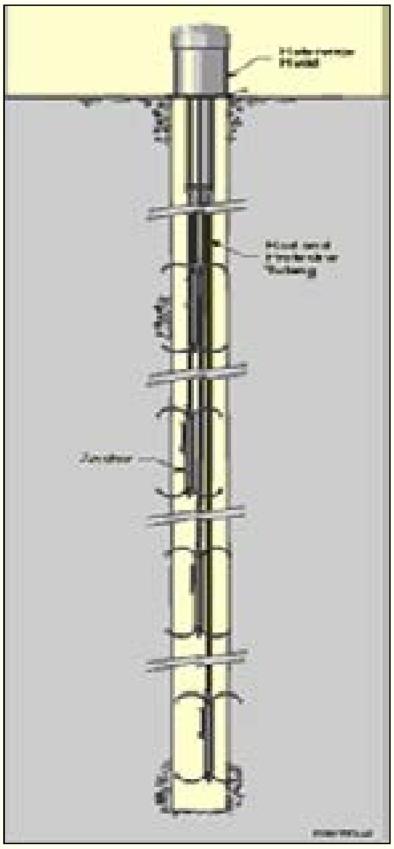

Fig.-26: Mechanical Anchor rod extensometer

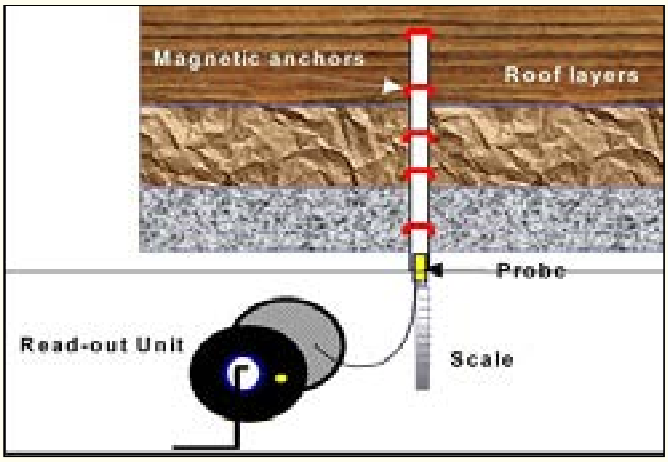

Fig.-28 : Magnetic Extensometer

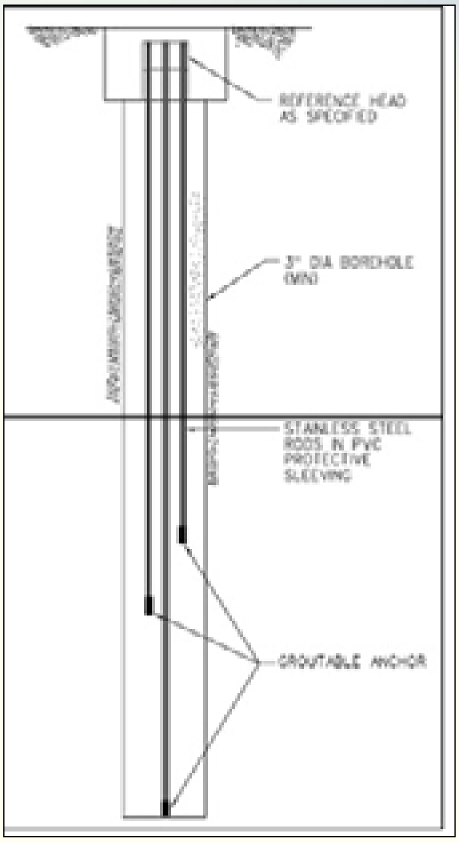

Fig.-27: Grouted type extensometer (Anon, 2013b)

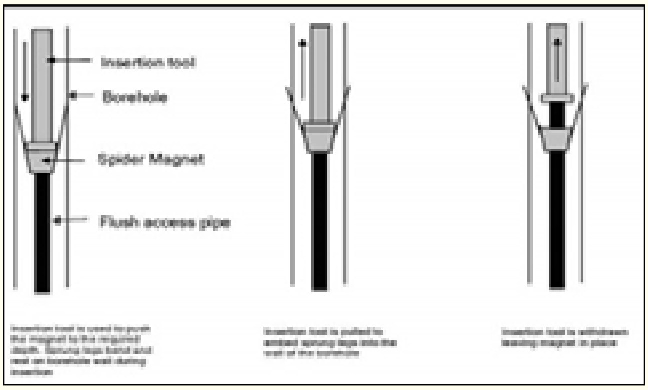

Fig.-29: Anchor installation

is measured by change in frequency of vibrating wire. (Thomas H. Hanna, 1985).

Sonic Probe Extensometer

Magnetostrictive properties of the probe material plays a key role, on which the princple of sonic probe relies. Current has been driven up the lenght of the wand by an electric pulse in the head of the probe. An ultrasonic signal that travels back to the head in the wave guide is induced by interaction with the field produced by toroid magnet Fig.-31. This audial signal is converted into an electrical signal and the time between pulses resolves the differences in position of the speed of sound in the wave guide is known (Anon, 2019e).

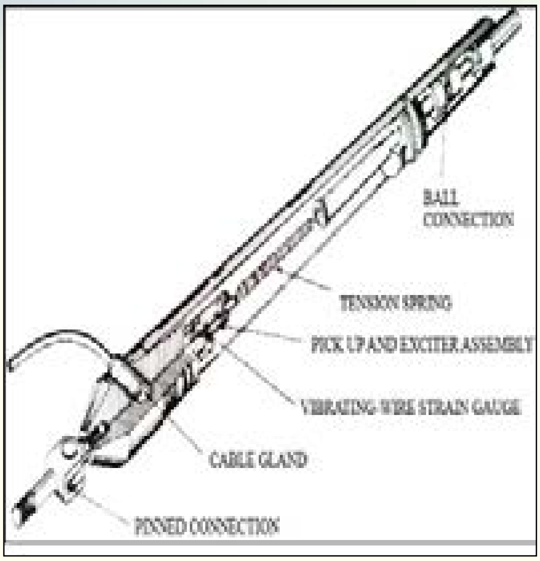

Fig -30: Geonor P-265 vibrating-wire extensometer

Piezometers

Piezometer (Fig.-33) converts water pressure to frequency signal via a diaphragm and a tensioned steel wire. Tension of the steel wire changes with the change in pressure on the diaphragm. The wire vibrates at its natural frequency when excited by a magnetic field that is transmitted to the readout unit. The readout unit processes the signal and displays a reading. The readout unit is calibrated by the established relationship between pressure applied on the diaphragm and the frequency of the signal returned to the readout device, used to convert Hertz readings to voltage. Piezometer is put into a borehole, sometimes after tying to a grout pipe, and the entire borehole is backfilled with a non-shrinking and low permeability grout. [44]

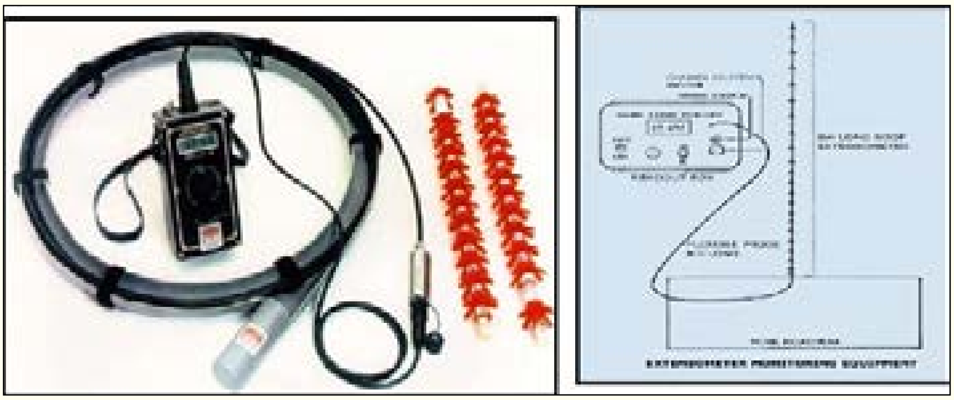
Fig.-31: Sonic Probe Extensometer

Pillar strain meter

Electrical strain meters ("Pillar Strain Meters") are used to measure the deformation of the pillar, Fig.-32. In this instrument, there is a steel/brass telescopic rod inside a larger diameter steel/brass tube anchor fixed in the pillar, and the other end is fixed in the anchor at 1 m below it. A potentiometer (a resistance coil, rheostat) or Vibrating wire sensor attached to the bottom telescopic pipe. (Anon, 2019e).

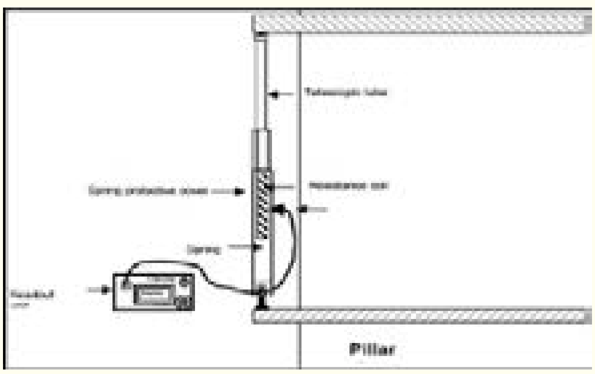

Fig.-32:Pillar Strain Meter


Fig.-33: Electrical Piezometer

TIME DOMAIN REFLECTORY (TDR)

TDR technique was originally developed to locate breaks in power transmission cables. It is based on the principal of electrical pulse technique. In this technique, for monitoring the movement of rock masses, coaxial cables are installed in drill holes or along the mine entries such that when there is a movement in rock mass, the cables will damage. This damage will be locate the movement of rock mass by the virtue of the pulse reflection created by the breaks in cable. [45]

Principle Operation and Installation

The installation kit consists of a TDR cable tester and the cable to be tested. Defects such as crimps, short circuit or breaks are detected when these defects reflect the ultra-fast rise time voltage pulses sent down the cable from the tester. The reflected voltage will appear as a step-up or step-down transition on the cable tester display by superimposing the reflected voltage on the advancing initial step as shown in Fig.- 34. Inductive faults result in a step-up transition while capacitive faults result in step-down transition. The location and nature of a cable fault is determined by inspection of the TDR signal that is recorded. Reference mark is recorded each time the cable is tested. The location of cable breaks or any other cable defects resulting from movement of rock mass can be determined with respect to those reference marks. [45]

Applications:

- Location of deformation in rock masses induced by mining.
- Monitoring the propagation of overburden fractures above a longwall coal panel.
- To monitor rock mass deformation in the vicinity of a strip mine highwall.
- Rock mass deformation, bed separation, and large block movement generated by strains and failure along coaxial cables installed in drill holes and TDR reflections generated by strain and failure were monitored. [45]

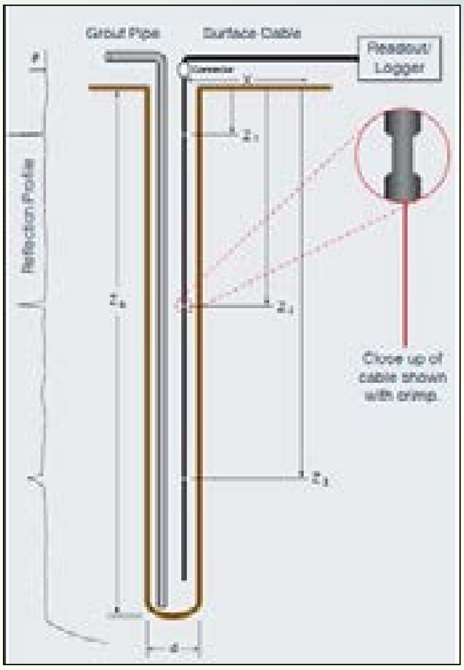

Fig.-34: A typical installation of TDR

Fig.-35: Portable Time Domain Reflector cable into borehole to be filled with grout

CONCLUSION

In underground coal mining problems like failure or collapse of roof rock, bumps, overriding of pillars etc. are very frequent. Therefore various parameters like displacement of roof, bed separation, stress, load on support etc. have to be monitored regularly that are responsible for the above problems. From the studies conducted on different types of instruments that are being used in underground coal mining it may be observed that every instrument has its own importance in strata control investigation to understand the behavior of potentially unstable rock mass and to predict rock mass failure.

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