Rock Mech. Rock Engng. (2005) 38 (5), 399–410
DOI 10.1007/s00603-005-0051-x

Rock Mechanics and Rock Engineering
Printed in Austria

Extraction of Coal Under a Surface Water Body – a Strata Control Investigation

By

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Received August 30, 2004; accepted January 24, 2005
Published online March 31, 2005

Summary

The extraction of coal seams under built-up structures and especially under water bodies has been a challenge to the miners due to the potential risk of disturbance to the surface. A number of safety and ground control problems are associated with the mining operations under water bodies. These can be dealt with through proper planning for the optimization of coal recovery and systematic strata control investigations. At Godavari khani (GDK) no. 3 incline of the Singareni Collieries Company Limited (SCCL), two panels namely SS-10/1A and SS-10/1B in no. 1 seam, were identified for extraction under the surface water body called Janagaon tank. A feasibility study was carried out by the authors for working these panels, and hydraulic sand stowing method was recommended. Further, strata behaviour monitoring was carried out using remote type geotechnical instruments during the extraction of pillars in one of the panels. The extraction of the pillars in the experimental panel progressed smoothly without any strata control problems. The mine management could extract coal reserves in the panel with more than 60% recovery, which were otherwise unworkable. This paper presents the feasibility of extraction of pillars under the Janagaon tank, and strata behaviour observations made during the actual extraction.

Keywords: Coal extraction, bord and pillar mining, surface water body, tensile strain, numerical modelling, safety factor, strata movement.

1. Introduction

Mining of coal has been carried out successfully under reservoirs of water, aquifers, rivers and also under the sea in various parts of the world. There are numerous problems associated with structural stability, safety and that of mining operations arising while working under water bodies (Singh and Jakeman, 1999). They have been adequately dealt with through proper planning and optimization of coal recovery, followed by systematic strata control investigations. When mining underground there is always the potential risk of water inrush from its source at the surface through induced cracks. Under such conditions, adequate thickness of parting, and integrity of the protective barriers are the major requirements. The method of extraction should address these issues while attempting for maximum coal recovery.

The authors conducted the studies at GDK-3 incline, SCCL, where two seams, namely, no. 1 and 2 seams were extensively developed by bord and pillar method. It was proposed to depillar panels no. SS-10/1A and SS-10/1B in no. 1 seam under the surface water body called Janagaon tank. Feasibility studies were carried out for working these panels, and a suitable method of extraction in conjunction with hydraulic sand stowing was recommended. Further, strata behaviour investigations were carried out during extraction of pillars in panel no. SS-10/1B. Details of these studies are presented in this paper.

2. Experiences of Working Under Water Bodies

Coal mining below the ocean floor and under water impoundments has been successfully carried out by caving methods in many parts of the world. In Canada, extraction of coal was carried out in Cape Breton Island in the state of Nova Scotia under the ocean floor since 1720 (Singh and Jakeman, 1999). England also has some share of the national coal output from undersea workings, of which about 70% was derived from the longwall method of mining and 30% from the room and pillar mining (Whittaker, 1979). One of the major design requirements in these cases is the control of surface subsidence strain to less than 10 mm/m at the seabed or at the bottom of the aquifer, thus reducing the possibility of development of fissures resulting from this strain. However, the limit of cover between the seabed and the site of extraction as well as the height of extraction determines the selection of mining method. The depth of mining under the sea floor in North East of England varied from 125 m to 410 m and no record of inrush of sea water into the workings were reported.

In China, several coal mines with a total coal reserves of about 25 billion tons are in the vicinity of water bodies (Zhang and Shen, 2004). China has developed specific methods of coal mining and experimental techniques under aquifers and surface water. Some empirical formulas for predicting the maximum height of the fractured and caving zones were developed from the field tests results of several longwall mining faces:

$$H\ (\text{in m}) = \left(\frac{100\,M}{aM + b} + c\right) \tag{1}$$

where:

H = maximum height of failure zone
M = extracted seam thickness, m
a, b = coefficients depending upon the lithology
c = mean square deviation.

In India, extraction of coal underneath and in the vicinity of water bodies was successfully carried out at Sudamdih, Moonidih, Surakachar and Ningah collieries (CMRS, 1984). The experience in the field led to defining the safe limits of subsidence movements for different situations. Subsidence-free underground mining at shallow cover with higher percentage of coal recovery is very difficult. Development of rock mechanics and strata control norms has proved to be useful in optimizing the coal recovery with relatively safer underground structures (Singh et al., 2004). Studies were also conducted to assess the feasibility of partial extraction below the surface structures in two coal mines in India in conjunction with partial hydraulic sand stowing under a Science & Technology project (Gupta, 1996).

3. Geomining Details of the Experimental Panel

At GDK-3 incline, seams no. 1 and 2 were developed by Bord and Pillar (B&P) method extending to the entire property of the mine. Due to the surface structures including Janagaon Village, highest flood level of river Godavari, Janagaon tank with seasonal nallah, hydraulic back filling of river sand is predominant in this mine since 1992. Panels no. SS-5/2A and SS-5/2B in no. 2 seam lying below the experimental panels in no.1 seam were already depillared in the past in conjunction with hydraulic sand stowing during the period 1998–2002. It was reported by the mine management that due to extraction of these panels in no. 2 seam, no perceptible changes in the reduced levels at the floor level were indicated in the proposed panels of no. 1 seam (NIRM, 2002). The average parting thickness between no. 1 and 2 seam is 18 m.

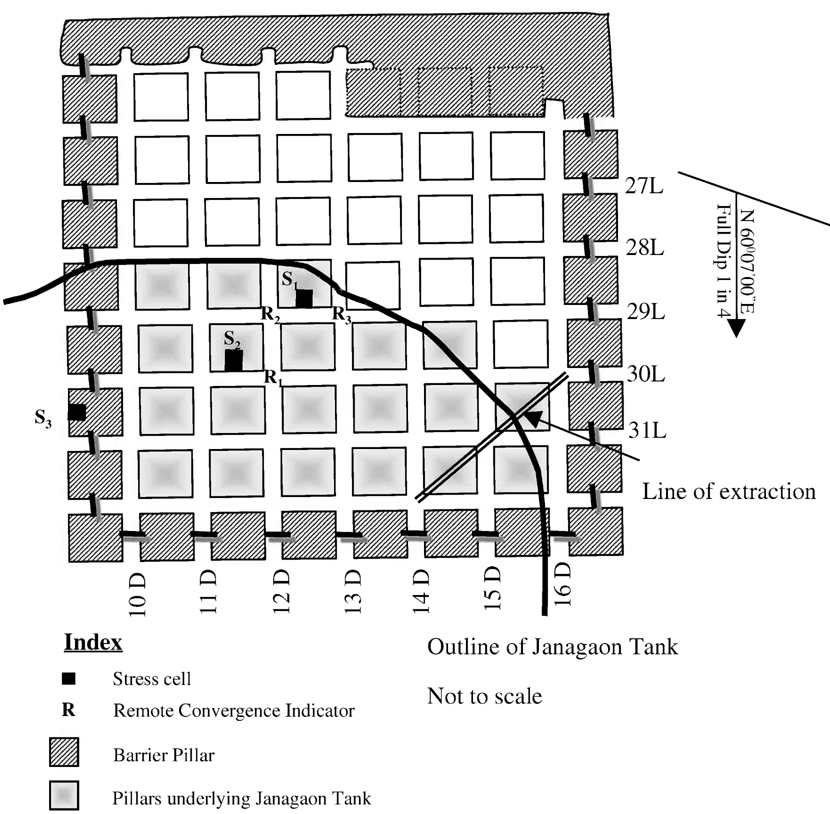

Fig. 1. Plan showing instrumentation in panel no. SS-10/1B

Seam no. 1 is 6 m in thickness, dipping at a gradient of 1 in 4. The development was done along the sandstone roof to a height of 2.4 m. The roof of the seam consists of 15 m thick grey sandstone inter-bedded with a 0.06 m thick medium grained sandstone which contains pyretic matter. The grey sandstone bed is overlain by weak bands of carbonaceous clay and shale. No overlying seams are present above these panels.

The SS-10/1B panel consisted of total 42 pillars from 25L to 32L and from 10D to 16D. The average size of the pillars was 30 m $\times$ 30 m (centre to centre). Figure 1 illustrates the part plan of the panel. The depth of cover was ranging from 130 to 197 m. The width of the original galleries was 4 m.

4. Feasibility of Extraction of Pillars in the Panel

In order to conduct a meaningful assessment of working under water bodies, it is imperative to look into the following vital aspects:

1. Details of local geology in the area.
2. Prediction of surface subsidence and estimation of strain values.
3. Designing a method of extraction (caving or stowing).

With back filling/stowing practice world wide there are many practical problems in achieving 100% compaction. In view of this, at GDK-3 incline, it was proposed to adapt an infallible system of partial extraction with adequate remnants in conjunction with hydraulic sand stowing.

The key factor in the success of any partial extraction system is the long-term stability of the remnants left as protective structures in underground. The stability of the developed pillar arrays in the experimental panel was evaluated with a view to arrive at the most feasible extraction method maximizing the coal recovery and minimizing the cause of instability of workings and disturbance to the surface. However, as stowing is a predominant system in this mine, only the variants involving stowing were considered. For long-term stability, the safety factor considered was within the range of 0.6 to 1.0 for the remnant stooks confined with sand stowing (Gupta, 1996 and Sheorey, 1993). The following variants of pillar extraction through reduction of pillars in arrays by splitting or thinning were evaluated:

1. One level split of 4.8 m and one dip split of 4.8 m width.
2. One level split of 4.8 m and two slices of 5 m width.
3. One level split of 4.8 m and three slices of 4 m width.

Stability of the remnant stook for all the variants were estimated through empirical, and two dimensional numerical model studies.

4.1 Estimation of Safety Factor Using Empirical Methods

The Safety factor is calculated as the ratio of the pillar strength and the average pillar stress. As the safety factor for the remnant stook is calculated without considering the influence of stowing, the load on the pillars/stooks would increase with increase in the depth of cover. Therefore, the stability of the pillars/stooks at a maximum depth of 197 m was studied. The stook of similar size at a lower depth cover would have more stability. The strength of the remnant stooks was calculated using the pillar strength equation given below (Sheorey, 1993):

$$S \text{ (in MPa)} = 0.27\sigma_c h^{-0.36} + \left(\frac{H}{250} + 1\right)\left(\frac{w}{h} - 1\right), \tag{2}$$

where:

S = strength of coal pillar, MPa
σ_c = uniaxial compressive strength of 0.025 m cubes of coal, MPa
= 24.12 MPa (test result supplied by the mine management)
h = height of extraction = 2.4 m
H = depth of cover = 197 m
w = width of the remnant, m.

The distribution of load on the remnant stook of uniform size is calculated using Tributary Area Method. The average stress on the pillar is given by the following equation (Sheorey, 1993):

$$\sigma \text{ (in MPa)} = \left(\frac{Ap - As}{As}\right)\gamma H \tag{3}$$

where:

Ap = total area of influence
= $\{(w_1 + a + w_2) \times (w_3 + b + w_4)\}$, m^2
a = length of the remnant, m
b = width of the remnant, m
w_1, w_3 = half of the width of the main gallery, m
w_2 = half of the width of slice, m
w_4 = half of the width of split, m
As = area of the remnant = $a \times b$, m^2
γ = unit rock pressure = 0.025 MPa/m
H = depth of cover, m.

The safety factor of the remnant pillar estimated using the above equations and also the percentage of coal recovery for different variants is given in Table 1.

From the above calculations using the available empirical equations, the safety factor was found to be 1.04 for the variant with a level split and two slices method

Table 1. Comparison between different variants

Variants	Length of remnant (m)	Width of remnant (m)	Stress over pillar (MPa)	Strength of the pillar (MPa)	Factor of safety	Coal extraction (%)
1	10.6	10.6	4.94	10.86	2.20	37
2	10.6	5.3	7.92	8.23	1.04	61
3	10.6	4.0	9.71	7.29	0.75	69

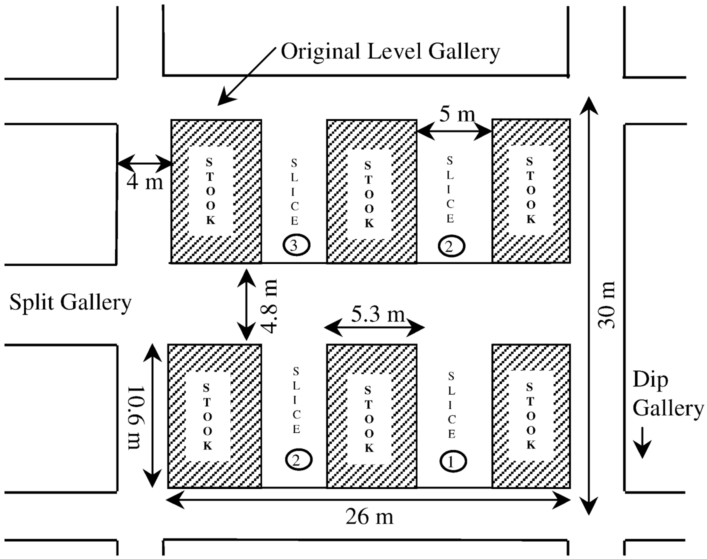

Fig. 2. Suggested method of extraction of pillars in the panel

(Fig. 2) in conjunction with hydraulic sand stowing with specific reference to conservation (>60% recovery).

4.2 Stress Distribution Using Numerical Modeling

For better understanding of stress distribution around the remnant stooks for the above mentioned variant, numerical modeling studies were carried out using two-dimensional Universal Distinct Element Code (UDEC) version 3.00. The following rock mass properties provided by the mine management were used in the numerical model to simulate the ground conditions of the experimental site: Young's Modulus $E_{coal} = 2$ GPa, $E_{rock} = 5$ GPa, Poisson's ratio $\nu = 0.3$. The boundary conditions assigned for fulfilling the assumed symmetry includes depth of cover = 130 m, the void left after stowing = 20% of the extraction thickness, the width of panel = 150 m, the pillar width = 30 m, the width of slice = 5 m, and the width of remnant = 5.3 m. In the model, five pillars along the strike direction were formed.

Various stages of extraction of pillars with slicing were considered to understand the stress distribution around the workings. The distribution of major and minor principal stress on the stooks showed that the maximum vertical stress in the remnant/stook was of the order of 7 MPa (Fig. 3), which was in accordance with empirical approach. The safety factor of the remnant was calculated using the Mohr-Coulomb failure criterion. From this exercise it was concluded that the proposed method of a level split with two slices is stable with sand stowing.

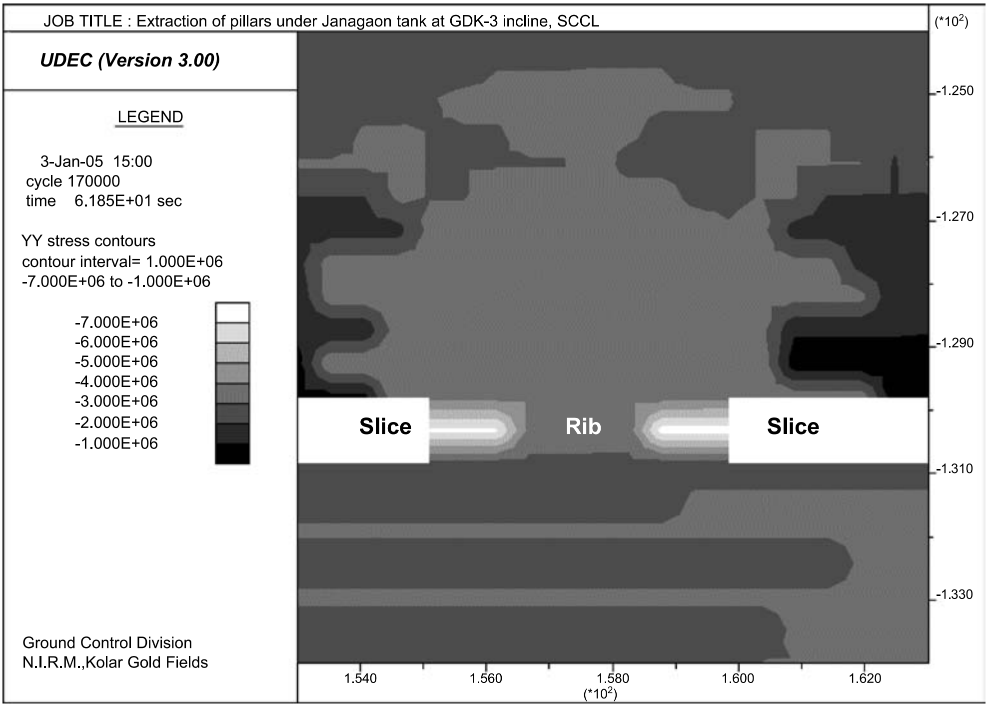

Fig. 3. Distribution of vertical stresses around the workings

4.3 Estimation of Surface Strain

The experience in the field led to provisionally defining the safe limits of subsidence movements for different situations. For the Indian geomining conditions, the maximum permissible tensile strain in the bed of water bodies due to underlying extraction is 3 mm/m (Sheorey, 1993). The maximum possible subsidence in a given area due to critical or super-critical width of excavations is given by the following relation (Indian Standards, 2002):

$$S_{\max} = M e_f g_f R_f D_f d' t, \tag{4}$$

where:

M = extracted seam thickness, m
e_f = extraction factor = $(ER)^{\mathrm{k}}$
ER = extraction ratio = $\dfrac{\text{extracted volume}}{\text{total volume of coal}}$
k = constant = 1 for soft coal seam (UCS < 15 MPa)
= 2 for hard coal seam (UCS > 15 MPa)
g_f = goaf treatment factor = 0.95 in case of caving
0.07 to 0.1 for sand-stowing
D_f = factor for effect of depth of working
= 0.87 for depths up to 250 m

= 0.96 for depth range from 250 to 400 m
= 1.0 for depths >400 m
d' = factor for the effect of dip of the seam = $\cos\alpha$
α = angle of the apparent dip, degree
t = time factor (taken to be unity for finished subsidence)
R_f = rock factor for the combined effect of composition and condition of overburden rock masses = 0 for no subsidence
= 1 for maximum subsidence

The ratio G/E_v representing the strength of the rock mass are given in Indian Standards, (IS 15180: 2002). For estimation of maximum slope and strains due to subsidence, the following equations are used (CMRS, 1984):

$$G = k_1 S/H \tag{5}$$

$$E_{(-)} = k_2 G \tag{6}$$

$$E_{(+)} = k_3 G \tag{7}$$

where:

G = maximum slope, mm/m
$E_{(-)}$ = maximum compressive strain, mm/m
$E_{(+)}$ = maximum tensile strain, mm/m
S = maximum subsidence, mm
H = average depth, m.

The values of all the constants k_1, k_2 and k_3 are derived from the nomograms developed based on experience (CMRS, 1984):

$$k_1 = 4, \qquad k_2 = 0.3 \text{ and } 0.15, \quad \text{and} \quad k_3 = 0.2 \text{ and } 0.15$$

Using the above relations, the strain values were calculated for the conditions in SS-10/1B panel at GDK-3 incline. These strain calculations indicated that even after considering partial stowing, the maximum tensile strain value at the surface would be about 0.82 mm/m.

Based on the empirical and numerical model studies, it was recommended that the most suitable method of extraction with specific reference to conservation (>60% recovery) and stability of the workings is the level split and two slices method in conjunction with hydraulic sand stowing. The way of extraction of pillars was such that not more than two splits remained unstowed in the entire panel (DGMS, 2003). The factor of safety of the remnant stook/rib with this method of extraction without considering sand stowing was 1.04. This was greater than the accepted range for long term stability (0.6 to 1.0) with remnant stooks in association with sand stowing (Sheorey, 1993 and Gupta, 1996). The panel was extracted with the recommended method along with the strata behaviour monitoring.

5. Strata Behaviour Observations

In view of insufficient data on the efficacy of stowing system and its influence, the roof deformation and the abutment load during extraction of pillars in the panel were

Table 2. List of instruments installed in panel no. SS-10/1B

Sl. no.	Instrument	Location	Parameter monitored
1.	Remote convergence indicators	1. 30LN/12R Junction 2. 29LN/12R Junction 3. 29LN/13R Junction	Roof to floor convergence inside the goaf
2.	Vibrating-wire stress cells	1. 29LN/12R 2. 30LN/11R 3. 31LN/9R	Change in stress over pillar/stook

monitored using remotely operated geotechnical instruments. The location of the instruments installed in the experimental panel is illustrated in Fig. 1. The list of the instruments installed in the panel is given in Table 2.

A summary of the strata behaviour observations made during extraction of pillars is given in the following.

5.1 Roof to Floor Convergence

At 30LN/12R junction location, the maximum cumulative roof to floor convergence of 22 mm was recorded initially for a period of two weeks before the goaf line crossed it. Further roof movements took place, and the cumulative convergence recorded at this location was 33 mm till the goaf was fully stowed with sand. The strata movements stabilized after complete stowing. The maximum cumulative roof to floor convergence recorded at this station was 56.2 mm for a total period of 74 days with an average rate of movement of 0.74 mm per day during the monitoring period (Fig. 4).

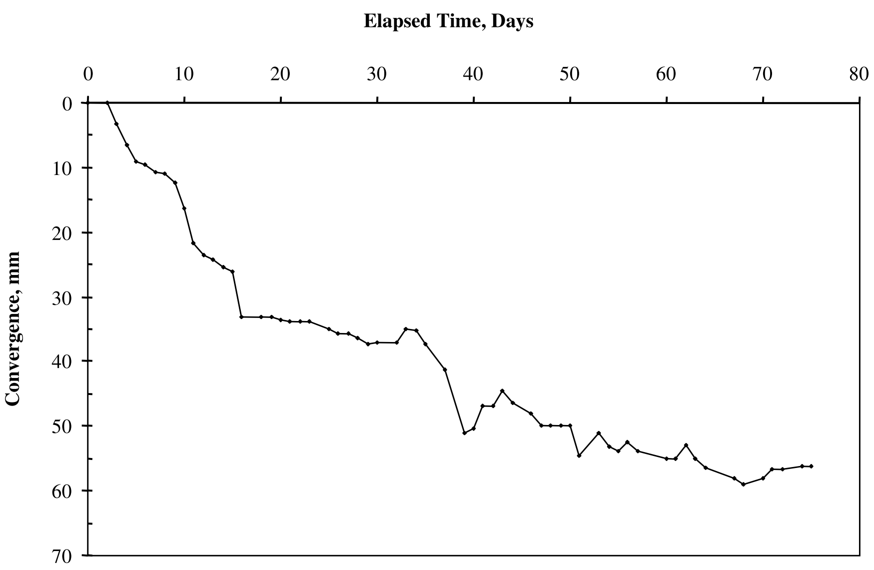

Fig. 4. Convergence observation at 30LN/12R junction in the panel

At 29LN/12R junction, a maximum cumulative convergence of 23.9 mm was recorded during the monitoring period of 70 days, and the overall rate of movement was 0.34 mm per day. There was no further increase in convergence after this period. Similarly, at 29LN/13R junction, a maximum convergence of 20 mm was recorded for a period of 37 days and the rate of convergence was 0.5 mm per day during this period. There was no further increase in movement afterwards. As reported by Gupta (1996), the maximum cumulative roof to floor convergence measured in the galleries was 12 mm. Also more convergence was recorded in fully stowed portion due to higher percentage of extraction when compared to partially stowed ($2/3^{rd}$ of the extraction height) face.

5.2 Stress Over the Pillars

At 29LN/12R, the stress cell recorded some relaxation over the pillar initially for about 20 days. Thereafter, as the goaf line reached the station, a rising trend in stress was recorded. A maximum change in stress of 0.17 MPa was recorded for a period of nearly 60 days (Fig. 5). The rate of change of stress over the pillar was almost negligible indicating that the stooks were free from abutment load. The trend observed was as expected in a stowing panel. Complete stowing was done in the nearby goaf and subsequently, destressing was recorded, which continued afterwards till the end of the monitoring period.

At 30LN/11R, there was only 0.15 MPa increase in stress over the pillars with the advance of the line of extraction over a period of nearly 150 days (Fig. 6). The stresses around the workings were stabilized after complete stowing. The average rate of change of stress at this location was only 0.001 MPa per day. In the barrier pillar at

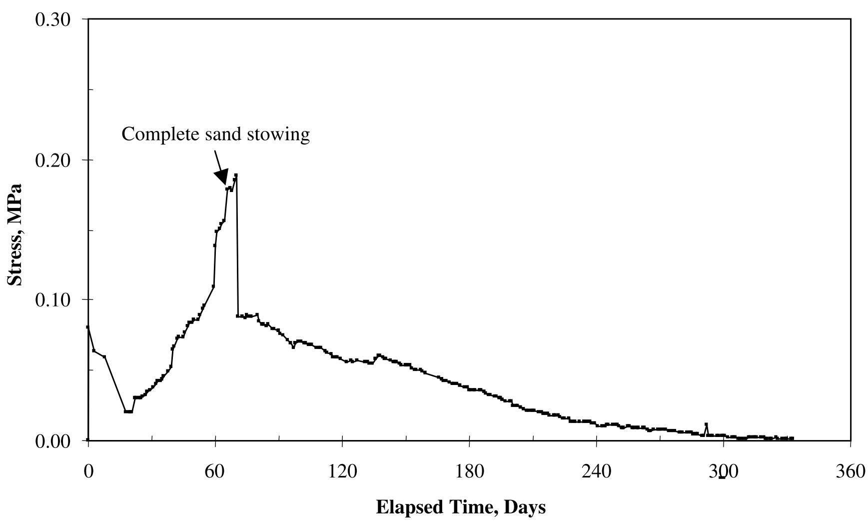

Fig. 5. Observation of stress over the pillar at 29LN/12R

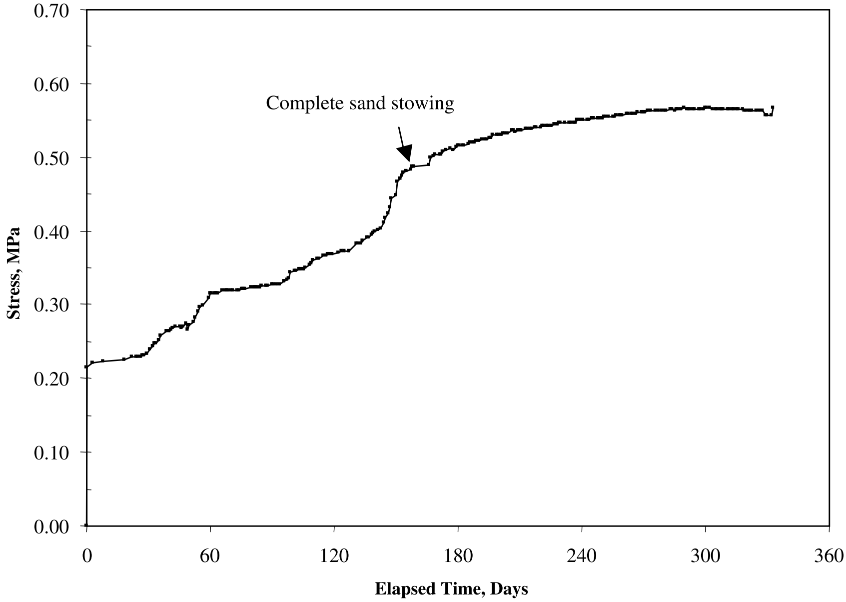

Fig. 6. Observation of stress over the pillar at 30LN/11R

31LN/9R, there was no significant variation of stress. Gupta (1996) reported increase in pillar stress of 0.35 MPa in the partially stowed panel as compared to 0.26 MPa in case of fully stowed panel.

6. Conclusions

Based on these studies the mine management could extract coal reserves in the panel with more than 60% recovery and maintaining the stability of the workings, which were otherwise unworkable under the surface water body. The maximum cumulative roof to floor convergence recorded in the panel was 56.2 mm, where, most of the movements recorded were after support withdrawal from the goaved out area and prior to complete stowing. The roof to floor movements stabilized after complete stowing.

The abutment loads in the experimental panel were insignificant and the maximum change in stress over the pillar recorded near the line of extraction was 0.17 MPa. The surface strain calculations indicated that even after considering partial stowing, the maximum tensile strain value at the surface was 0.82 mm/m, which was far lower than the permissible limit of 3 mm/m.

The approach followed in this study may be helpful in working coal seams under similar geomining conditions. Further, more such trials with detailed instrumentation and three-dimensional numerical modeling may be done in future to establish norms for working under such difficult conditions.

Acknowledgements

The authors of this paper gratefully acknowledge the help and encouragement extended by the management of SCCL during the study, particularly the mine management of GDK-3 incline. Dr. S. Jayanthu, and Mr. S. Benady, Scientists of NIRM were associated with a part of these studies. The principal author wish to thank Dr. G. R. Adhikari, Scientist and Head, Excavation and Blasting Division, NIRM for his guidance during preparation of this paper.

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