Assessment of cavability and categorization of coal measure roof rocks by parting plane approach

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Abstract*—From the observations of caving of the overlying roof rock in longwall panels it can be inferred that the caving is dominated by the weak parting layers, laminated nature and massiveness of the roof rock formation. This caving process is controlled by the presence and geo-technical properties of strong beds and weak parting beds in the roof rock layers. Based on the study conducted at different coalfields over longwall panels a 'Parting Plane Approach' has been developed for identifying the parting planes in the roof along with strong and weak rock beds. The strata caving behaviour over longwall workings is manifested by local and main falls. They are governed by the thickness, rock mass strength and the induced stresses in the Caving Layer 1 or the Immediate Roof and the Caving Layer 2 or the Main Roof respectively. A software has been developed in MATLAB platform to identify the rock beds as belonging to the Caving Layer 1 and the Caving Layer 2 or the Immediate Roof and the Main Roof. A parameter, Equivalent Main Fall Span (aeq), has been introduced for classifying the overlying roof rock. In this paper the various methods for determination of aeq, viz. an Empirical method, a Mathematical approach, and a Numerical modelling based approach have been discussed along with case studies.

***Keywords*— longwall mining; cavability; rock categorization; equivalent main fall span**

I. Introduction

Analysis of the cavability of longwall roof rocks has been attempted worldwide by many researchers over the years. Some notable methods of classification of roof rocks have been introduced by Davydynans [16], Proyavkin [4], Kuznetsov and Voronin [15], Korovkin [17], Hongzhu [19], Pawlowicz[9], Bilinski [1], Kidybinski [3], Peng and Chiang [14], Singh and Singh [15] and Sarkar [11] among others. A critical review of the different approaches of cavability assessment reveals that the classification of overlying roof is based mainly on lithology of strata, bedding thickness of strata, roof convergence at the goaf edge, bed separation resistance, rock strength and stand up time of the unsupported strata. Classifications based on these factors are able to provide a pre-investigation tool for assessment of caving behaviour. In this paper a methodology has been described for categorization of roof rocks overlying a coal seam proposed to be extracted by longwall method with caving.

The following sections discuss the algorithm for identification of caving layers, categorization of coal measure and a case study.

II. Development of Algorithm for Identification of Caving Layers

Rock characteristics of Indian coalfields vary a lot within the caving zone itself. Studies conducted by CIMFR, in about 50 locationsofmultiple coalfields, have revealed that Indian coal measure rocks are mostly comprised of sandstone and shale of varying strengths. The presence of clay band and intrusions are infrequent, though not rare. The result of a random survey of various coalfields for content of coal measure rocks, within ten times of height of extraction, in the caving zone has been shown in Table I.

TABLE I: Sandstone Content in Caving Zone within Ten Times of Height of Extraction

Coalfields	**Sandstone content**
Raniganj (ECL)	27 – 100 % with an av. of 70%
Jharia (BCCL)	08 – 81 % with an av. of 44%
Sonhat (SECL)	54 – 100 % with an av. of 87%
Godavari (SCCL)	More than 90 %

For the study of the behaviour of rock formations, bed thickness and lamination (indicated by RQD) are the two parameters which indicate massiveness. Sandstone with an average RQD of 40 percent or less laminates and caves easily. RQD is generally found to be ranging from 38 to 95 percent in case of Eastern Coalfields Limited (ECL) and Bharat Coking Coal Limited (BCCL), 70 percent or more in case of Singareni Collieries Company Limited (SCCL),whereas in South Eastern Coalfields Limited (SECL) rock formations belong to two distinct groups, one having RQD above 75 percent, and the otherbelow 20 percent. The two broad divisions of laminated and massive rock formations may again be divided based on their compressive strength. Weighted average uniaxial compressive strength of 200 kg/cm2 or less may be considered as low, 200-500 kg/cm2 may be considered as moderate, whereas above 500 kg/cm2 would be considered as high (Sarkar, 1995).Massive rock formations though rare in Jharia coalfield are quite common in the eastern part of Raniganj coalfield, and are frequently encountered in SECL and SCCL. Therefore, to understand the caving behaviour of overlying strata of a coal seam, the primary requirement is to determine different caving layers based on the various physico-mechanical properties of the rock types.

A. Parting Plane (PP)Approach

Based on the study on the characteristics of overlying roof rocks, a methodology has been developed for identification of caving layers overlying the coal seam.

In the present study the strata above the longwall panels have been divided as:

(a) Immediate roof: This is the fractured caving layer 1, which readily caves behind the supports forming the goaf.

*(b) Main roof:*This is the caving layer 2 and is identified as the fractured strata above the immediate roof that subside onto the caved material in the goaf. During the fracturing process, the main roof can induce either continuous vertical load or periodic falls onto the immediate roof. The classification of the main roof indicates the type of loading that the main roof contributes to the longwall support.

*(c) Upper main roof:*This layer is the caving layer 3 which does not play any major role on support load if its thickness is small compared to the main roof. If its thickness is comparable to the thickness of the immediate and main roof, the periodic breakage of this roof results in major periodic weightings.

(d) Overlying roof: Above the upper main roof, the rock strata deforms without causing any major cracks cutting through the strata thickness and behaves as a continuous rock media getting subsided in due course of time as the face progresses.

The steps to determine different caving layers include the following steps:

Step 1: Identification of the Parting Planes

A logical parameter, Pb, for identification of parting planes, is determined for a rock bed. Pb is TRUE if the bed is laminated consisting of shale/ coal / carbonaceous shale / clay or having low RQD less than 33% or with Caving Index (Is) less than half of the Caving Index of the strongest bed (Ismax) within ten times the height of extraction. Otherwise, the Pb value for the bed is FALSE. If the logical parameter Pb is TRUE for the ith bed, it indicates that there may exist a parting plane above the ith bed.

Step 2: Formation of Rock Beds

A large number of functions have been developed in MATLAB for automatic processing of borehole data, physico-mechanical properties tested in the laboratory and identifying the rockbeds in a given borehole. From the borehole data, the length of the individual core pieces, the corresponding rock type and properties such as compressive strength, tensile strength, density and Young's modulus for each core piece are obtained.

The weak zones in the bore holes are identified within core logs based on the condition of discontinuities and average spacing of the discontinuities as observed from different bore holes for a particular rock type. A rock type is considered to be weak if it is laminated and the RQD is low. Furthermore, a zone is considered weak if the recovery isless than 75% ofthe maximum recovery percentage obtained in the bore hole. There may also be weak zones within a massive sandstone bed of large thickness, particularly in zones where a few broken core pieces of length less than 10 cm are observed, thus having a thin spacing between weak discontinuities of shale bands within a thick sandstone bed. The parting planes are also identified by the variation of the caving index of the bed with increasing thickness.

Taking all these four factors i.e. weak rock type, recovery percentage,presence of weak bandswithin massive strata and the caving index, for defining the weak zones, the final beds are identified within the borehole log.The weighted average compressive strength, tensile strength, young's modulus, RQD, caving index & Bieniawski RMR are calculated for the identified beds.

Step 3: Identification of Caving Layers

A parameter, rci, defined by Eq.1, is used to identify the main roof and immediate roof for the ith rock bed.

$$r_{ci}=d_i/\ t_e \qquad (1)$$

where, di is the distance of the top of the ith bed from roof of the extracted coal seam and te is the thickness of extraction. The parting plane between the immediate roof and the main roof exists over the nearest bed, lying below the strongest bed, for which Pb value is TRUE. The parting plane between the main roof and the overlying rock beds exists below the bed, lying above the strongest bed, for which the Pb value is TRUE and the parameter rci is greater than 5, that is, the thickness of immediate roof and main roof is more than five times the height of extraction.

Another logical parameter Mr is calculated for each bed based on the above logical statements. Mri is TRUE if the ith bed belongs to the main roof and Mri is FALSE for the beds of the immediate roof lying below and above the main roof.

III. Categorization of the Coal Measure Rocks Based on their Caving Behaviour

When a longwall face advances, the span of the unsupported roof in the goaf also increases.After a certain span, the immediate roof caves in,this is known as local fall. The immediate roof continues to cave in periodically with progressive advance of the face. When the face advances beyond a certain limit depending upon the characteristics of the roof, the main roof overlying the immediate roof fails. The failure and subsequent caving of the main roof is known as the main fall. This is accompanied by a substantial convergence of the roof in the face. The front abutment stress at the face reaches the maximum value just before the occurrence of the main fall.

The main fall span decreases as the face width increases up to a critical face width beyond which it remains same. The main fall span corresponding to this critical face width is defined as the Equivalent Main Fall Span (aeq). As the facewidth increases beyond the critical face width, the main fall occurs at the equivalent main fall span only. Therefore, it is important to know the equivalent main fall span of a longwall face from which the main fall span for any panel dimension can be predicted. The equivalent main fall span can be determined by the following methods:

A. Determination of Equivalent Main Fall Span from observed Main Fall

For any longwall panel, the main roof may be assumed as a rectangular plate of dimension a x b. The maximum bending moment and stress developed in the main roof at main fall may be calculated from β, a factor depending on the rectangularity (b/a) of the plate (Table II; Timoshenko, 1947), with a and b representing smaller and larger dimensions respectively between the face width, lf, and observed main fall span, Sm.

TABLE II: VALUE OF B FOR DIFFERENT VALUES OF B/A

b/a	1	1.25	1.50	1.75	2.0	∞
β	0.0513	0.0665	0.0757	0.0806	0.0829	0.0833

When b/a is greater than 2, β tends to a constant value β' = 0.0833. When b/a is less than 2 for a longwall main roof, the equivalent main fall span, aeq can be calculated for an infinitely long face by Eq. 2(i.e. when b/a>2, $\beta \rightarrow \beta' = 0.0833$), where 'a' is the smaller dimension between the face width, lf, and observed main fall span, Sm for the main roof over the longwall panel. The multiplier α can be obtained from the values of β given in Table 2 and β'=0.0833. The critical face width is twice the equivalent main fall span. The main fall span remains unaffected for face width more than the critical face width.

$$a_{eq} = \left(\beta / \beta'\right)^{1/2} a = \alpha\ a \quad (2)$$

The main fall span of a new longwall face with given face width can be estimated from equivalent main fall span determined by statistical regression of known main fall spans of a number of previously worked out longwall panels.

B. Theoretical Determination of Equivalent Main Fall Span from Rock Properties

Based on plate theory Obert and Duvall [9]have estimated the maximum stress (Eq. 3) for a horizontal gravity loaded rock layer clamped at both ends.

$$\sigma_{max} = \frac{\gamma a^2}{2t} \quad (3)$$

Since the rock is weaker in tension, the equivalent main fall span as may be calculated based on the tensile strength σ_t, thickness of the main roof t and density γ as given by Eq. 4. The main fall span Sm, is calculated using Eq. 5 where

$$\alpha = \left(\beta / \beta'\right)^{1/2} \quad (4)$$

$$a_{eq} = \sqrt{\frac{2\sigma_t t}{\gamma}} \quad (5)$$

$$S_m = \frac{a_{eq}}{\alpha} \quad (6)$$

C. Numerical Estimation of Equivalent Main Fall Span from Rock Properties

Numerical modeling method using the commercially availableFLAC3D finite difference codes is applied for predicting the progressive caving behaviour of strata in a given geo-mining and strata condition. Equivalent main fall span can also be determined by this method.

D. Empirical Estimation of Main Fall Span from Caving Index Numbers

Based on the maximum value of Caving Index Is for a rock bed within the caving zone Sarkar [11] correlated the span of main fall Sm with the maximum value of Is empirically as

$$S_m = 0.72\ I_s^{0.51} \quad (7)$$

E. Categorization of roof rock

Observations on main fall and periodic fallhas been undertaken at 18 different mines belonging to a wide range of roof rock cavability from Easily Cavable (Jhanjra) and Moderately Cavable (Balrampur) to Cavable with Difficulty (Khottadih) and Cavable with Substantial Difficulty (Churcha) in various coalfields of India. Based on such observations and calculations of aeq, it is proposed that the overlying roof rocks should be classified as follows:

TABLE III: CATEGORIZATION OF OVERLYING ROOF ROCK BASED ON EQUIVALENT MAIN FALL SPAN

Category of Roof	Caving Nature	Equivalent Main Fall Span
I	Easily Cavable	<35 m
II	Moderately Cavable	35 m-55 m
III	Cavable with Difficulty	55 m-75 m
IV	Cavable with Substantially Difficulty	75 m-100 m
V	Cavable with Extreme Difficulty	>100 m

IV. CASE STUDY OF PANEL 3A OF GDK 10A INCLINE MINE, SCCL

The proposed approach is applied to predict main fall span for Panel 3A of GDK10A Incline mine. A number of panels have been worked out in No. 1 seam at GDK 10A Incline Mine, SCCL by longwall retreating with caving method. Table IVsummarizes the experience of strata behaviour of some of the previously worked out panels in GDK 10A Incline mine. Panel 3A was planned to be worked out at a depth of 325m with the 4 x 800T IFS Chock Shield powered supports for a face length of 165 m with an extraction height of 3.3m.

A. Identification of caving layers for Panel 3A

To identify the stratigraphic formation of the overlying rocks, the lithology and the physico-mechanical properties of a representative borehole were considered. The physico-mechanical properties of different rock beds overlying the coal seam are given in Appendix I and II. The caving layers over this longwall panel were identified by the Parting Plane Approach and are given in Table V(a) and V(b).

TABLE IV: STRATA BEHAVIOR EXPERIENCES IN WORKED OUT PANELS OF GDK 10A INCLINE MINE

Panel No.	Dimension (length x width) (m x m)	Average depth of coal seam (m)	Face retreat for local fall (m)	Face retreat for main fall (m)
2	990 x 150	209	37.1	76.8
3	1024 x 150	244	30.6	66.1
11	900 x 110	254	34.8	72.0
7	955 x 118	272	-	69.5
12	720 x 93.5	282	37.2	73.2
8	990 x 125	295	44.7	68.7

B. Statistical Determination of Equivalent Main Fall Span, a_{eq} and Main Fall Span for Panel 3A

The strata behaviour expected at Panel 3A has also been estimated statistically based on the main fall span experienced in previously worked out panels in the same seam and the mine. The equivalent main fall span is calculated by using Eq. 2 for different panels from the observed main fall span which were worked under similar condition as prevailing in the proposed panel 3A and is given in Table VI.

The equivalent main fall span varies from 66m to 78m for the mining depth range varying between 209 m to 295 m from surface. The corresponding values of critical face span are 132 m & 156 m respectively. The plot of equivalent main fall span versus mining depth as shown in Fig. 1 shows that the equivalent main fall span decreases with increase in the depth of mining. The best fit equation correlating the equivalent main fall span with mining depth is given as Eq. 7. The expected value of equivalent main fall span for Panel 3A for a cover depth of 325 m is extrapolated as 62 m using the best fit equation (Eq. 7) and the corresponding value of critical face span is 124 m. The expected main fall span for Panel 3A having a face width of 165 m i.e. above critical width will be 62 m.

TABLE VI: EQUIVALENT MAIN FALL SPAN FOR DIFFERENT LONGWALL PANELS OF GDK 10A

o	Depth (m)	Main fall span (m) observed	Face width (m)	a	b/a	β	a_{eq}
2	209	78	150	78	1.923	0.082566	78
3	243.5	66.1	150	66.1	2.269	0.0833	66
11	254	72	110	72	1.527	0.076482	69
7	272	69.5	118	69.5	1.697	0.080417	68
12	281.5	73.2	93.5	73.2	1.277	0.067064	66
8	295	68	125	68	1.838	0.082166	68

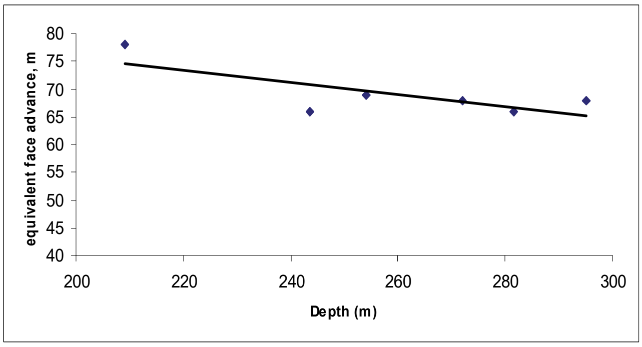

Fig. 1: Depth vs. equivalent span of main fall for GDK10A, SCCL

C. Theoretical Determination of Equivalent Main Fall Span, a_{eq} and Main Fall Span forPanel 3A

As given in Table 5b, the thickness of main roof is 13.86 m. The equivalent main fall span for the main roof is calculated by Eq. 4 as 64.6 m and the main fall span calculated by Eq. 5 is 64.6 m.

D. Numerical Estimation of Equivalent Main Fall Span, a_{eq} and Main Fall Span forPanel 3A

The equivalent main fall span estimated numerically for Panel 3A was found to be 64 m.

E. Empirical Estimation of Main Fall Span from Caving Index Number

Table 5b shows that the caving index of the strongest bed is 7949. The main fall span calculated by Eq. 6 is 70.22 m.

F. Main Fall from Field observation of Panel 3A

The extraction of the Panel 3A started on 30th January 2007. Attempts have been made to collect relevant information and data from the field, so as to understand the span of local fall, main fall and average periodic fall interval. There were 108 powered supports in the face and pressure gauges were fitted to each leg circuit. The records of the pressure in these leg circuits were monitored in the general shift. Though this pressure does not represent the actual load on the support during weighting, this information along with the number of leg circuits at yield pressure (bleeding leg circuits) in the middle zone between C22 and C87 of the face provides the information regarding the weighting and its intensity.

$$a_{eq} = -0.1098\, H + 97.63 \quad (7)$$

After a face advance of 11 m, local fall was observed behind the support. At a face position of 41.7 m on 20th February 2007, a major local fall was observed which was accompanied by rise in pressure in leg circuits and the averagepressure in the mid zone between powered supports no. C22 to C87 was recorded as 288 bar with average load of 576 tonne. Again on 24th February at face position of 56.1 m, a major local fall occurred with an average pressure of 268 bar andaverage load of 534 tonnes in the mid zone.The average load on face started increasing from 549 tonnes on 26th February at a face position of 62.7 m and continued till 28th February when the load reached to 681 tonnes at a face point of

TABLE V(A). PHYSICO-MECHANICAL PROPERTIES OF DIFFERENT ROCK TYPES ABOVE SEAM 1 AS PER B.H.NO.1124 OF GDK 10A MINE, SCCL

Bed No	Avg Rock Type	Depth from surface, m		Ht. above coal seam,m		Bed thickness, m	RQD, %	Avg. Core Length, cm	Density, gm/cc	CS, ksc	TS, ksc	YM, ksc	CI	RMR
		from	to	from	to									
1	Fine to Medium Grained Sandstone	367.72	371.10	-6.95	-3.57	3.38	93	21.73	NA	337	36	NA	4991	67
2	Shaly Sandstone	367.50	367.72	-3.57	-3.35	0.22	0	NA	2230	296	30	NA	NA	47
3	Coal	364.15	367.50	-3.35	0.00	3.35	56	9.59	NA	NA	NA	NA	NA	44
4	Shaly Coal	361.18	364.15	0.00	2.97	2.97	57	9.83	NA	NA	NA	NA	NA	43
5	Medium to Coarse Grained Sandstone	357.62	361.18	2.97	6.53	3.55	94	22.28	2066	265	28	NA	4142	63
6	Coarse Grained Sandstone	353.94	357.62	6.53	10.21	3.68	65	12.67	2033	151	13	NA	946	40
7	Medium Grained Sandstone	340.08	353.94	10.21	24.07	13.86	87	19.72	2059	298	31	NA	7949	62
8	Shale	339.19	340.08	24.07	24.96	0.89	59	10.54	NA	NA	NA	NA	NA	46
9	Fine to Medium Grained Sandstone	337.50	339.19	24.96	26.65	1.69	92	21.37	2060	372	39	NA	3818	67

TABLE V(B): CAVING LAYERS ABOVE SEAM 1 AS PER B.H_NO.1124 OF GDK 10A INCLINE MINE, SCCL

Bed No	Bed No		Depth from surface, m		Ht. above coal seam,m		Bed thickness, m	RQD, %	Avg. Core Length, cm	Density, gm/cc	CS, ksc	TS, ksc	YM, ksc	CI	RMR
	from	to	from	to	from	to									
No.1 Seam	Coal		364.15	367.50	-3.35	0.00	3.35	56	9.59	NA	NA	NA	NA	NA	44
Immediate roof	4	361.18	357.62	0.00	10.21	10.21	73	15.19	2049	207	20	NA	2515	55	
Main roof	7	340.08	353.94	10.21	24.07	13.86	87	19.72	2059	298	31	NA	7949	62	
Upper main roof	8	339.19	339.19	24.07	26.65	2.58	80	17.65	2060	372	39	NA	3818	60	
Overlying roof	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

67.1m. In this period, around 20-25 legs circuits in the middle zone were observed to reach the yield load during each cycle. The fall continued for a few days and was observed all along the face width. This fall was recorded as the main fall which took place between 62.7m and 67.1 m. Thereafter, periodic weightings were observed at intervals of 11m to 17m.

G. Validation of the proposed approach

The main fall span for Panel 3A has been determinedempirically from Caving Index Number, statistically from main fall span of previously worked out panels and also predicted from aeq calculated theoretically using rock properties. The results given in Table VIIhave been found to be matching fairly accurately. This indicates that the equivalent main fall span concept can be considered as a standard method for predicting main fall span of a longwall face as well as categorization of roof rocks.

V. CONCLUSIONS

A mathematical-cum-logical methodology has been developed for identifying the parting planes during caving of rock layers in longwall panels in deeper horizon, from borehole lithologs and strength properties. This Parting Plane (PP) approach may be used for identifying caving layers. In the PP approach, the logical parameter, Pb, is considered for identifying weak beds which will act as parting plane. This parameter is TRUE for weak bed and FALSE for competent bed.

TABLE VII: COMPARISON OF MAIN FALL SPAN DETERMINED BY DIFFERENT METHODS

Sl. No.	Method for Determining Main Fall Span	Main Fall Span
1	Statistical estimation of main fall span from aeq	62m
2	Theoretical estimation of main fall span from aeq	64.6-74.5m
3	Estimation of main fall span from Caving Index Number	70.22m
4	Numerical Estimation of main fall span	60-64m
5	Observed main fall span	62.7-67.1m

The equivalent main fall span corresponding to the critical face length of a longwall panel has been found to be standard parameter for categorization of overlying roof rocks. Different methods have been used for determining this parameter, viz. statistical, theoretical and numerical methods and the results from different methods have been found to be reasonably matching.

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ANNEXURE I : DETAILED LITHOLOGY OF OVERLYING ROOF ROCKS AS PER B.H.NO.1124 (SEAM1) OF GDK 10A MINE, SCCL

Sl No.	Rock type	Length of core pieces, cm	Extrapolated length, cm
1	fmgsst	35.00	38.25
2	fmgsst	13.00	14.21
3	fmgsst	53.00	57.92
4	fmgsst	54.00	59.02
5	coal	7.00	7.65
6	sh	6.00	6.56
7	sh_sst	10.00	10.93
8	sh_sst	5.00	5.46
9	sh_sst	10.00	10.00
10	sh_sst	8.00	8.00
11	sh_sst	8.00	8.00
12	sh_sst	32.00	32.00
13	fmgsst	55.00	55.00
14	fmgsst	10.00	10.00
15	fmgsst	22.00	22.00
16	fmgsst	41.00	41.00
17	fmgsst	8.00	8.00
18	fmgsst	6.00	6.00
19	fmgsst	9.00	9.00
20	fmgsst	10.00	10.00
21	fmgsst	45.00	45.00
22	fmgsst	24.00	24.00
23	fmgsst	12.00	12.00
24	mcgsst	20.00	20.69
25	mcgsst	33.00	34.14
26	mcgsst	10.00	10.34
27	mcgsst	14.00	14.48
28	mcgsst	9.00	9.31
29	mcgsst	6.00	6.21
30	mcgsst	9.00	9.31
31	mcgsst	5.00	5.17
32	mcgsst	6.00	6.21
33	mcgsst	15.00	15.52
34	cvcgsst	24.00	24.83
35	cvcgsst	23.00	23.79
36	cvcgsst	12.00	12.41
37	mcgsst	104.00	107.59
38	mcgsst	2.00	2.03
39	mcgsst	8.00	8.11
40	mcgsst	10.00	10.14
41	mcgsst	14.00	14.19
42	mcgsst	16.00	16.22
43	mcgsst	23.00	23.31
44	mcgsst	15.00	15.20
45	mcgsst	17.00	17.23
46	mcgsst	16.00	16.22
47	mcgsst	27.00	27.36
48	mcgsst	15.00	15.20
49	mcgsst	13.00	13.18
50	mcgsst	10.00	10.14
51	mcgsst	10.00	10.14
52	mcgsst	15.00	15.20
53	mcgsst	47.00	47.64
54	mcgsst	10.00	10.14
55	mcgsst	5.00	5.07
56	mcgsst	13.00	13.18

57	mcgsst	10.00	10.14
58	fmgsst	37.00	42.05
59	fmgsst	13.00	14.77
60	fmgsst	23.00	26.14
61	fmgsst	9.00	10.23
62	fmgsst	5.00	5.68
63	fmgsst	9.00	10.23
64	fmgsst	5.00	5.68
65	fmgsst	15.00	17.05
66	fmgsst	38.00	43.18
67	fmgsst	10.00	11.36
68	fmgsst	13.00	14.77
69	fmgsst	36.00	40.91
70	fmgsst	23.00	26.14
71	fmgsst	23.00	26.14
72	fmgsst	5.00	5.68
73	mgsst	10.00	10.56
74	mgsst	6.00	6.34
75	mgsst	46.00	48.59
76	mgsst	11.00	11.62
77	mgsst	39.00	41.20
78	mgsst	7.00	7.39
79	mgsst	19.00	20.07
80	mgsst	40.00	42.25
81	cvcgsst	11.00	11.62
82	cvcgsst	13.00	13.73
83	cvcgsst	24.00	25.35
84	cvcgsst	5.00	5.28
85	cvcgsst	7.00	7.39
86	cvcgsst	8.00	8.45
87	cvcgsst	12.00	12.68
88	cvcgsst	15.00	15.85
89	cvcgsst	11.00	11.62
90	cvcgsst	16.00	16.96
91	cvcgsst	9.00	9.54
92	cvcgsst	8.00	8.48
93	cvcgsst	10.00	10.60
94	cvcgsst	6.00	6.36
95	cvcgsst	7.00	7.42
96	cvcgsst	11.00	11.66
97	cvcgsst	9.00	9.54
98	cvcgsst	9.00	9.54
99	fmgsst	34.00	36.04
100	fmgsst	5.00	5.30
101	cgsst	13.00	13.78
102	cgsst	6.00	6.36
103	cgsst	8.00	8.48
104	cgsst	21.00	22.26
105	cgsst	10.00	10.60
106	cgsst	18.00	19.08
107	cgsst	26.00	27.56
108	cgsst	15.00	15.90
109	cgsst	16.00	16.96
110	cgsst	12.00	12.72
111	cgsst	6.00	6.36
112	cgsst	8.00	8.48
113	cgsst	5.30	5.38
114	cgsst	7.00	7.11
115	mcgsst	37.00	37.59
116	mcgsst	22.00	22.35
117	mcgsst	10.00	10.16
118	mcgsst	17.00	17.27
119	mcgsst	18.00	18.29
120	mcgsst	37.00	37.59
121	mcgsst	17.00	17.27
122	mcgsst	45.00	45.72
123	mcgsst	37.00	37.59
124	mcgsst	15.00	15.24

125	mcgsst	13.00	13.21
126	mcgsst	5.00	5.08
127	mcgsst	10.00	10.16
128	mgsst	18.00	19.71
129	mgsst	27.00	29.56
130	mgsst	12.00	13.14
131	mgsst	5.00	5.47
132	coal	8.00	8.76
133	coal	6.00	6.57
134	coal	3.00	3.28
135	carb_sh	10.00	10.95
136	coal	18.00	19.71
137	coal	6.00	6.57
138	coal	7.00	7.66
139	coal	6.00	6.57
140	coal	20.00	21.90
141	coal	7.00	7.66
142	coal	20.00	21.90
143	coal	16.00	17.52
144	coal	8.00	8.76
145	coal	6.00	6.57
146	coal	8.00	8.76
147	coal	10.00	10.95
148	coal	9.00	9.85
149	coal	16.00	17.52
150	coal	28.00	30.66
151	coal	9.00	9.00
152	coal	6.00	6.00
153	sh	20.00	20.00
154	shcoal	4.00	4.00
155	shcoal	7.00	7.00
156	shcoal	10.00	10.00
157	shcoal	9.00	9.00
158	shcoal	14.00	14.00
159	shcoal	6.00	6.00
160	shcoal	9.00	9.00
161	shcoal	60.00	60.00
162	shcoal	12.00	12.00
163	shcoal	9.00	9.00
164	shcoal	12.00	12.00
165	shcoal	6.00	6.00
166	shcoal	6.00	6.00
167	shcoal	8.00	8.00
168	shcoal	8.00	8.00
169	shcoal	5.00	5.00
170	shcoal	8.00	8.00
171	shcoal	18.00	18.00
172	shcoal	5.00	5.00
173	shcoal	9.00	9.00
174	shcoal	8.00	8.00
175	shcoal	9.00	9.00
176	shcoal	6.00	6.00
177	shcoal	5.00	5.00
178	shcoal	5.00	5.00
179	shcoal	7.00	7.00
180	shcoal	9.00	9.00
181	shcoal	8.00	8.00
182	shcoal	7.00	7.00
183	shcoal	13.00	13.00
184	shcoal	5.00	5.00
185	shcoal	12.00	12.00
186	shcoal	16.00	16.00
187	shcoal	30.00	30.00
188	sh_sst	7.00	7.00
189	sh_sst	5.00	5.00
190	sh_sst	5.00	5.00
191	sh_sst	5.00	5.00
192	vfgsst	15.00	15.00

193	vfgsst	8.00	8.00
194	vfgsst	8.00	8.00
195	vfgsst	10.00	10.00
196	fgsst	23.00	23.00
197	fgsst	39.00	39.00
198	fgsst	14.00	14.00
199	fgsst	12.00	12.00
200	fgsst	10.00	10.00
201	fgsst	39.00	39.00
202	fgsst	10.00	10.32
203	fgsst	4.00	4.13
204	fgsst	30.00	30.97
205	mcgsst	22.00	22.71
206	mcgsst	41.00	42.32
207	mcgsst	18.00	18.58
208	mcgsst	30.00	30.97
Borehole end, Depth of coal seam from surface 364.15,m			

ANNEXURE II: AVERAGE PHYSICO-MECHANICAL PROPERTIES OF DIFFERENT ROCK TYPES OF GDK10A MINE, SCCL

Lithology	**Comp. strength, Kg/cm^2**	**Tensile strength, Kg/cm^2**	**Density, gm/cc**
cvcgsst	119.15	8.90	2030
cgsst	126.30	10.30	2030
mcgsst	243.90	27.00	2073
mgsst	361.50	33.90	2035
fmgsst	372.00	38.80	2060
fgsst	382.60	43.80	2240
vfgsst	391.00	26.07	2240
sh_sst	296.00	29.60	2230
coal	154.60	12.90	1535
fmgsst	Fine to Medium Grained Sandstone	mcgsst	Medium to Coarse Grained Sandstone
sh	Shale	cvcgsst	Coarse to Very Coarse Grained Sandstone
cgsst	Coarse Grained Sandstone	mgsst	Medium Grained Sandstone
sh_sst	Shaly Sandstone	cgsst	Coarse Grained Sandstone
carb_sh	Carbonaceous Shale	vfgsst	Very Fine Grained Sandstone
shcoal	Shaly Coal	fgsst	Fine Grained Sandstone