Physico-Mechanical Properties of Coal Measures and Coal Seams for High Capacity Longwall

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Abstract

The Singareni Collieries Company Limited (SCCL) planned to introduce high capacity longwall in Adriyala Shaft Block as a part of it's ambitious program to achieve the set goals. For successful operation of this Longwall, forecasting of strata behavior as much close to reality as possible in pre-mining was recognized. In this connection, SCCL had tie-upwith CSIRO, Australia to work jointly, with a lead research provider in several areas. As part of these studies, to meet the requirement of generating needy data to conduct Numerical Modeling, extensive program was organized to take up different Physico Mechanical Properties (PMP) tests. In light of this, different tests suggested were taken up in SCCL, CIMFR and NIRM laboratories. The data thus generated were analyzed statistically to make use of the same for Numerical Modeling by CSIRO, Australia. The data generated during the course of organizing different tests, are synthesized and discussed in this paper.

General

Adriyala Shaft block forms an integral part of the Ramagundam coal belt which constitutes the southeastern part of the coal belt (Fig. 1). Generally, coal measures trend is N10°W –S10°E with ENE dips. The gradient varies from 1 in 6 to 1 in 7.5. The total area of the Adriyala Shaft Block is 4.60sq.km (Fig. 2). Initially, 57 boreholes (BHs) were drilled having an aggregate length of with 30,302m. Subsequently after interacting with CSIRO, Australia, 19 BH'sboreholes (+ 57 previous BH'sholes =76 BH'sboreholes) are additionally drilled with a total of totaling 10,226m drilling. With this, total meterage drilled in Adriyala Shaft Block comes to 40,528m, thereby the Density of Boreholes is coming to 16.40 BHs/sq.km. The first High capacity Longwall is proposed to be introduced initially in I seam.

Geology and Structure of Adriyala Shaft Block

The area, blanketed by a thin cover of soil, ranging in thickness from 0.61m to 4.35m is devoid of exposures and as such the stratigraphic sequence built up is solely based on the sub-surface data collected from the boreholes. The Talchir Formation is the oldest unit of the Lower Gondwana sequence proved in the BH No. GGK-17. The coal bearing Barakar Formation overlies the Talchir Formation with a gradational contact, like in other blocks of Ramagundam coal belt. Seven regionally correllatable coal seams viz., IA,I,II,IIIB,IIIA,III & IV, which can be correlated regionally, are developed in this block in descending order. The Barren Measures succeed the Barakar Formations, conformably with the gradational contact around 10 to 15 m above No. IA seam. Generally the coal measures trend in N 10°W –S 10°E with east-north easterly dips. The gradient varies from 1 in 6 to 1 in 7.5.

Physico Mechanical Properties (PMP) Tests

Physico Mechanical Properties (PMP) data is generated for a total of 14 Boreholes in the Adriyala Shaft Block (Fig. 2). Out of these 14 BHs, five BHs, viz. BH Nos. 593A, 617, 704, 715, 1119 were tested in Singareni

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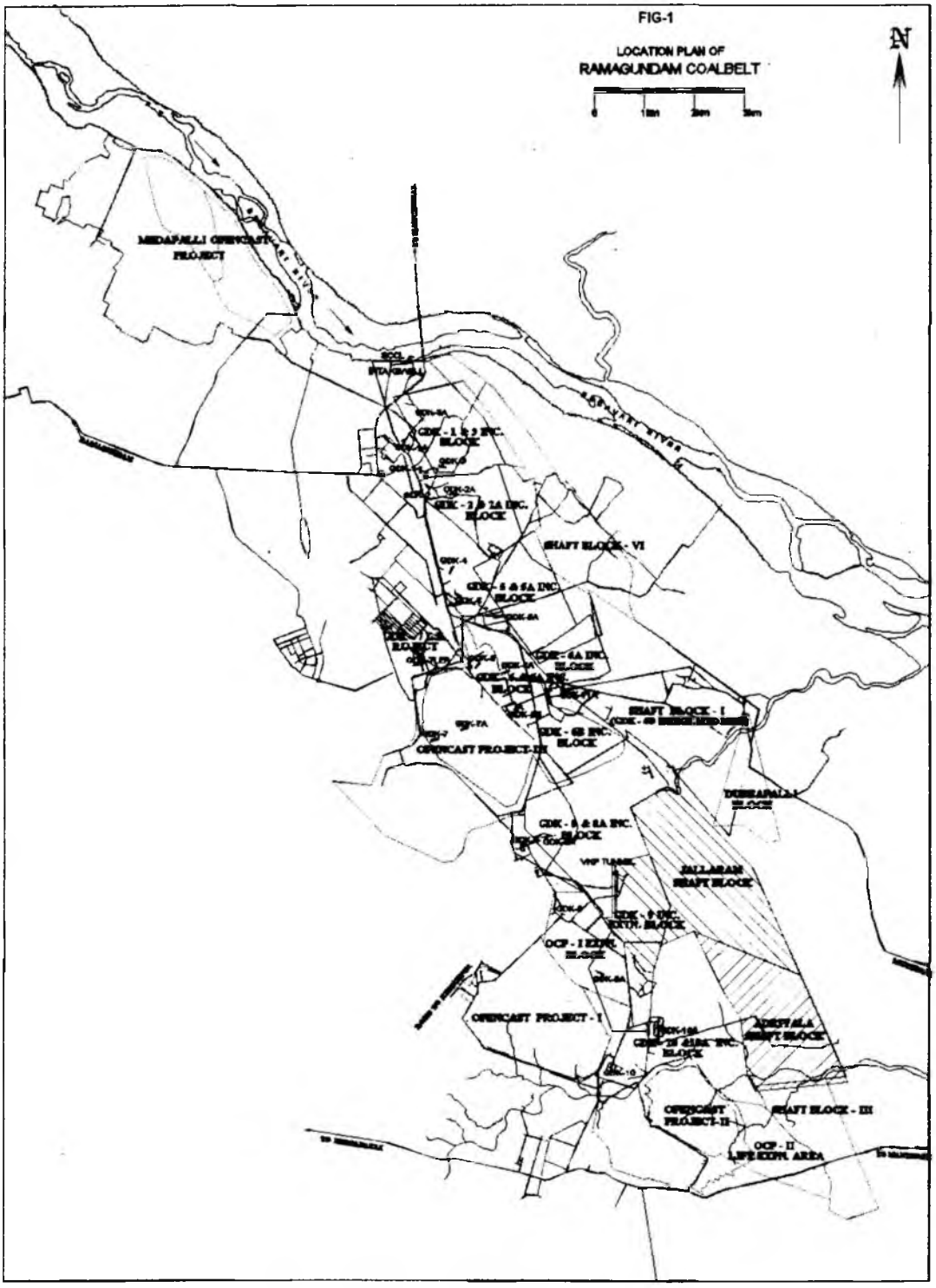
FIG-1
LOCATION PLAN OF
RAMAGUNDAM COALBELT
N
MEDAPALLI OPENCAST PROJECT
SHAFT BLOCK - VI
OPENCAST PROJECT-III
SHAFT BLOCK - I
OPENCAST PROJECT - I
SHAFT BLOCK - III
OCP - II

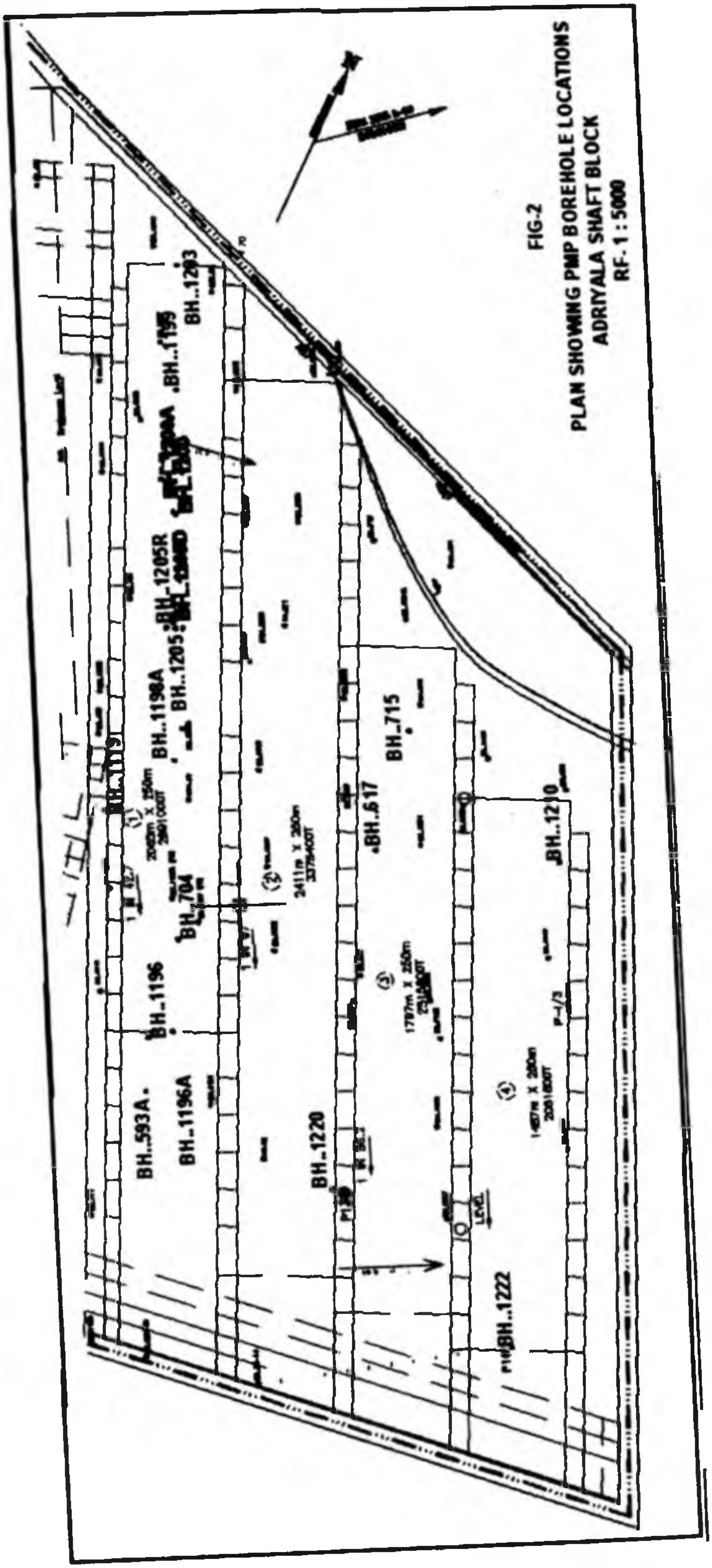

FIG-2
PLAN SHOWING PMP BOREHOLE LOCATIONS
ADRIYALA SHAFT BLOCK
RF. 1 : 5000

Collieries Company Limited (SCCL) laboratory at the time of preparation of Geological Report. In these five BHs, data on density, UCS and tensile strength were derived by testing the samples and the remaining data, viz. Youngs Modulus , Impact Strength, Shear Strength and Protodyaknov Strength were derived empirically. However, I & III seams of BH No. 1119 were tested by CIMFR, Dhanbad.

Subsequently, CSIRO, Australia suggested to carry out an adequate number of laboratory tests on borehole cores, viz.BH Nos. 1196, 1196A, 1198A, 1199, 1200, 1200A, 1203, 1205, 1205D, 1205R, 1210, 1220 and 1222 covering the entire lithology to quantify the rock mass strength and deformation parameters. The parameters determined in the laboratory are density, porosity, seismic wave velocity, Young's Modulus, Poisson's Ratio, shear strength, and tensile strength.

PMP Tests on Roof and Floor Strata of Coal Seams

Selection of cores for testing PMP was carried out on the basis of lithological grouping as well as respective distances from the proposed longwall panels. Initially for BH No.1196/ 1196A, CSIRO suggested the methodology to select the samples for PMP tests. Accordingly, samples were identified for the remaining BHs and referred the samples to CIMFR, Dhanbad. In SCCL laboratory, only Density, Uniaxial Compressive Strength (UCS) and Tensile Strength tests were be taken up on samples and the remaining tests, viz. Youngs Modulus, Impact Strength Index, Shear Strength are empirically derived. As, all the tests suggested by CSIRO, are not available at SCCL laboratory, some of the samples were also referred to CIMFR, Dhanbad. Thus the PMP data is generated both from CIMFR and SCCL Labs for BH Nos. 1196/1196A, 1198A, 1199, 1200 /1200A,1203, 1205/ 1205D/ 1205R and the data is generated for BH Nos. 1210,1220 &1222 only from SCCL Lab and the test details are presented in Table 1. The data thus generated for roof and floor strata of coal seams of all fourteen BHs is furnished in Table 2 and the PMP data generated for coal seams is furnished in Table 3. Geotechnical logs are prepared, depicting the lab data. As suggested by CSIRO, photographs were taken for the samples both before and after testing the samples by labs (Fig. 3a, b).

Fig. 3a: Samples before testing for UCS

Fig. 3b: Samples after testing for UCS

Table-1: PMP data generated from CIMFR and SCCL Labs, as per CSIRO guidance

Sl. No.	Tests	No. of tests carried out by	
		CIMFR	SCCL
1	Density	275	1641
2	Compressive strength	444	1641
3	Tensile strength	08	1641
4	Triaxial	90	
5	Young's modulus	212	
6	Poisson Ratio	212	
7	P wave	212	
8	S wave	212	
9	Porosity	212	
10	Direct Shear	58	
11	Cerchar Hardness	12	

Samples were identified from 10m to 15m of floor strata, Seam portion and 30m of roof strata of each workable seam to refer to CIMFR, Dhanbad and remaining samples to SCCL lab. In SCCL Lab results, only Density, Uniaxial Compressive Strength (UCS) and Tensile Strength data is considered.

Besides all the above tests, generated BQ size core apart from NQ size core on few samples to make comparison of the test results of both NQ and BQ core samples of Adriyala Block accordingly to take decision to generate BQ size core for any future LW blocks for the convenience of drilling operation. Further to make a comparison of UCS values generated both from Cylindrical and cubes for limited samples, an attempt was also made by conducting tests on BQ core samples and 1 inch cubes. The test results are in order where UCS values decrease with the size of sample (Table 4).

The main purpose of the extensive testing program proposed for the initial holes was to properly calibrate the geophysical logging equipment and it's techniques. The PMP test data, visual lithological data, and geophysical logging together would allow to arrive at an empirical relation so as to generate the required PMP data in an open hole and by Sonic logging. After extensive testing, it may need to drill only 6 - 7 cored holes in total to cover the remaining three longwall panels of Adriyala block, i.e. about 2 to 3 holes per panel at appropriate locations. Any other holes required in that area may be drilled as open holes with geophysical logging.

Rock mass surrounding the longwall panels can be divided into the following three groups:

- Floor rock - First 10 to 15m below the mining seam
- Mining seam including the coal roof
- Main roof up to 30m above the mining seam

It is suggested that for each mining seam the cores be selected for laboratory testing. The tests for number of cores may either increase or reduce on the basis of geological variation, presence of massive strata, presence of breakages, loss of cores etc.

Table 2: Summarized statement of PMP testing data of Roof and floor strata of coal seams. (BH Nos.: 593A, 617, 704,715, 1119, 1196/1196A, 1198A, 1199, 1200/1200A, 1203, 1205/ 1205D/ 1205R,1210, 1220 and 1222).

STRATA→ PARAMETERS ↓	Roof of I Seam	Parting between I & II Seams	Parting between II & III Seams	Parting between III & IV Seams	Floor of IV Seam
Density (gm/cc)	1.48-2.67	0.54-2.59	1.38-2.67	1.36-2.47	1.35-2.47
Porosity (%)	0.69-21.38	1.55-23.45	1.23-1.84	2.20-10.7	6.79- 11.23
Primary wave Velocity Dry (m/sec)	1120.80-5174.45	1755.56-3907.29	1241.90-2958.60	1106.14-3197.76	1932.90-3366.24
Secondary wave Velocity Dry(m/day)	688.37-2285.59	1087.95-2266.06	579.87-2112.88	328.35-1756.55	1063.34-2853.23
Tensile strength (kg/cm^2)	2.57-409.30	2.96-208.10	5.01-432.90	5.79-536.00	6.61-330.60
Compressive strength dry (kg/cm^2)	19.90-739.30	56.10-793.20	43.40-963.40	80.50-536.00	73.00-330.60
Young's Modulus $x10^5$ (kg/cm^2)	0.08-1.96	0.17-1.15	0.08-1.41	0.14-0.85	0.23-0.87
Shear strength (kg/cm^2)	6.77-88.03	11.47-125.16	10.75-124.88	17.41-61.85	16.97-88.24
Impact Strength Index	45.62-55.86	46.64-54.38	46.40-55.66	47.19-52.70	46.92-50.13
Protodyaknov Index	0.07-2.62	0.15-2.21	0.10-2.56	0.27-1.74	0.21-1.04
Poison Ratio (Loading)	0.02-0.45	0.01-0.44	0.01-0.45	0.04-0.38	0.01-0.38
Poison Ratio (Unloading)	0.02-12.93	0.02-5.25	0.03-11.46	0.17-7.81	0.10-12.40

Table 3: Comparision of Uniaxial Compressive strength of NQ, BQ and 1 inch cube samples

Borehole No.	Depth (m)	Rock Type	Uniaxial Compressive Strength	
			BQ samples	One inch cube
			Avg. (MPa)	Avg. (MPa)
BH # 1200A/ 1200	502.00-504.63	Mcg Grey sst.	10.91	
	409.00-410.01	CVCG Grey sst.	19.58	6.21
BH # 1203	354.00-357.00	Vcg Grey sst.	6.29	
	336.00-339.00	CG greenish grey sst.	7.72	4.68
BH # 1199	415.74-416.85	Cvcg sst.	9.44	11.87
	399.50-399.97	Mcg sst.	23.53	
BH # 1198A	497.00-498.82	Mcg Grey sst.	10.44	
	443.69-445.84	CVCG Grey sst.	11.18	8.03
BH # 1196A/ 1196	511.23-513.00	Mcg sst.	7.50	7.99
	412.00-415.00	CVCG sst.	3.45	

Tests on Coal Seams

Apart from testing the roof and floor strata of coal seams, various tests, viz. PMP, HGI, Cerchar Hardness, In-situ Strength and Post failure deformation tests were conducted on coal samples and the details are discussed hereunder.

PMP tests: PMP tests were taken up on coal samples. All these tests were conducted in CIMFR laboratory. The data thus generated for coal seams are summarized and furnished in Table 4.

Other tests: Besides PMP tests, other special tests were also taken on coal samples, viz. HGI, Cerchar Hardness, In-situ Strength and Post failure deformation test. HGI test was conducted on coal core samples of different seams, in SCCL lab and the data is furnished in the Table 5. As per the data, HGI ranges for Seam IA (B) from 45 to 51, I Seam from 46 to 49, II seam having HGI of 56 and for III seam it varies from 43 to 53 and HGI for IV seam is 48.

Table 4: Summarised statement of PMP testing data of coal seams

COAL SEAM→ PARAMETERS ↓		I Seam	II Seam	III Seam	IV Seam
Density (gm/cc)		1.36-1.53	1.46-1.72	1.30-1.66	1.32-1.56
Porosity (m/sec)		1.94-4.94	1.62-7.35	1.68-3.46	1.47-9.10
Primary wave Velocity Dry (m/sec)		693.27-929.96		276.58-1276.58	490.65-3129.40
Secondary wave Velocity Dry(m/day)		310.20-345.96		191.76-454.41	204.08-460.82
Tensile strength (kg/cm^2)		11.5-27.5		14.09-43.00	6.0
Compressive strength (kg/cm^2)		78-455	173.9-296.8	78-397	71.90-376.3
Young's Modulus x10^5 (kg/cm^2)-(Loading)		0.17-2.05	0.17	0.13-2.19	0.077-0.27
Young's Modulus x10^5 (kg/cm^2)-(Unloading)		0.39	0.26	0.16-0.791	0.125-0.415
Poison Ratio (Loading)		0.14-0.22	0.06	0.06-0.37	0.08-0.24
Poison Ratio (Unloading)		0.08-0.12	0.02	0.09-0.33	0.06-0.33
TRIAXIAL STRESS	At 5 MPa	59.01		67.04	
	At 10 MPa	79.58		81.20	
	At 15MPa	90.26		86.58	
	At 20 MPa	-		102.62	
	Cohesion	6.65		8.98	
	Angle of Internal Friction (Degrees)	40.11		35.38	
Double Shear Strength(MPa)				1.63-4.71	

Table 5: Hardgrove Grindability Index (HGI) of Coal Seams

BH.NO	Depth		Strata	Coal Seam	HGI
	From (m)	To (m)			
1203	389.31	390.86	Coal	II	56
	454.34	455.47	Coal	III	44
	456.82	458.70	Coal	III	48
1205	369.93.	371.01	Coal	IA(B)	45
1210	513.18	514.75	Coal	IA(B)	51
	640.74	642.26	Shaly Coal	III	43
	643.44	645.80	Coal	III	48
	647.33	650.33	Coal	III	53
	655.18	657.80	Shaly Coal	IV	48
1220	470.50	471.86	Coal	IA3	50
	498.53	499.42	Coal	I	49
1222	565.21	565.85	Coal	I	46

Table 6: Cerchar Hardness data for BH.NO- 1199, Adriyala Shaft Block

Depth		Strata	Cerchar Hardness	Remarks
From (m)	To (m)			
375.43	377.13	Coal	23.8	I SEAM
404.77	405.00	Coal	11.0	Penetration varied with time with intermittent stoppages due to the presence of hard layers (Pyritic/quartzitic) II SEAM
474.23	475.00	Coal	5.2	III SEAM
480.00	480.50	Coal	5.1	III SEAM
486.45	487.00	Coal	7.9	IV SEAM

Similarly, Cerchar Hardness tests were conducted on different coal seams in CIMFR laboratory and the data is furnished in Table 6. The test is generally used for defining the strength and cuttabihty characteristics of coal or rock samples. It is based on a steel needle with defined geometry and quality that is scratched over 10 mm of a rough rock sample under a static load of 70 N. As per the classification of Cerchar Hardness, I Seam is difficult to cut and the remaining II,III and IV seams are easy to cut.

To determine the post failure behavior of coal, tests were conducted on few selective samples by stiff testing machine with time control, load control and deformation control. Few coal samples were collected from underground workings and tested under deformation control with a rate of 0.005 mm/ sec, and load control of 20 kgf/sec under Stiff Testing Machine to assess the Post failure behavour.

The strata overlying the mining seam at Adriyala are relatively thick and hence support load is controlled by both the strata and coal seam stiffness. In case, the abutment load exceeds the coal seam strength, face spall may develop inducing roof detachment or increased main roof convergence. Thus it is essential that reliable coal seam properties are determined.

NIRM has conducted a series of in situ coal strength tests on 30cm x 30cm x 30cm

blocks. The in situ strength test report (NIRM, 2008) provides some indication of strength reduction with coal sample size. These tests showed a minimum strength of 3.5MPa and a maximum of 10.5MPa. The stiffness values for I Seam were measured between 30,000kg/cm to 40,000kg/cm which seems to be very low. The minimum in situ strength of coal for III Seam was 4.74MPa (when corner failed) and the maximum measured was 19.27MPa. The measured average strength was 13.2MPa. Coal specimens from III Seam were found to be stiffer than I Seam, with stiffness value ranging between 50,000kg/cm and 70,000kg/cm. Since these stiffness values appear to be low and to further confirm, NIRM repeated the tests. As per the revised data, the minimum value of in-situ strength of coal was 2.6 MPa, and the maximum value was 11.5 MPa. The stiffness of the coal in seam III, varies from 26,096 to 1,21,781 kg/cm. The coal samples tested in the barrier pillar showed significantly higher in situ strength compared to the samples tested in other pillars, indicating the effect of abutment pressure. Therefore, the average in-situ coal strength as measured in the barrier pillars is 10.9MPa.

Typical strength values measured by NIRM (2008) can be summarised as 10.5MPa and 10.9MPa for I Seam and III Seam respectively. However, the in situ strength values seem to be affected by the presence of 1) clay bands in the roof or floor in the vicinity of the test specimen, 2) existing fractures in the test specimen etc.

Analysis of Test Data

Shivakumar et al. (2008) analysed the laboratory data of both SCCL and CIMFR and performed statistical analyses. An extensive study of scale effect on coal strength was undertaken by (Medhurst, 1996). The expression derived in that study has been used by Shivakumar et al. (2008) to study the PMP data generated from Adriyala block. Laboratory tests on NX size core of I Seam conducted by CIMFR, revealed compressive strength ranging from 21.09MPa to 22.95MPa (SCCL, 2006). These strength ranges correspond to values obtained for mid-bright coal of around 26.98MPa as reported in Medhurst, 1996. The UCS values reduce significantly with the decrease in size.

Based on the statistical analysis carried out by CSIRO, it was reported that the average UCS values are 12.8MPa and 15.1MPa for SS40 and SS80 respectively. Further, CSIRO opined that the individual test results seen to vary widely; the difference between the minimum and the maximum values is around 38MPa. Table 8 indicates that the average UCS of SS80 can be expected to deviate up to 20%. Also it was added that the expected

Table 7: Combined UCS test results (MPa) from all the boreholes tested by both SCCL and CIMFR

Strata	SCCL	CIMFR	Average
BMB	9.66	13.10	10.09
CL100	17.65	29.29	25.41
SS100	12.53		12.53
IAT	22.52		22.52
IB90	22.65	37.86	26.45
IA	26.38		26.38
SS80	8.91	15.14	12.09
I	25.20	39.50	29.28
SS70	16.44	15.72	16.11
II		16.53	16.53
SS60	15.96	18.70	17.04
IIIB	9.61		9.61
SS50	14.54	13.80	14.47
IIIA	18.14	22.46	20.30
SS40	11.07	12.28	11.52
III	12.15	25.62	22.93
SS30	16.09	18.18	16.85
IV	14.21	20.70	19.41
SS20	13.26	22.89	15.04

Table 8: UCS of immediate sandstone units I Seam and III Seam

	UCS (MPa)					
Sandstone units	Average	Std Dev	Min	Max	90% confidence	95% confidence
SS40	12.8	7.0	5.9	35.9	±2.3	±2.7
SS80	15.1	11.0	2.6	33.4±	±2.45	±2.9

average UCS of SS80 lies in between 15.1±2.45MPa.

Summary and Conclusions

Based on all PMP tests conducted in Adriyala Shaft Block, the following conclusions are drawn.

1. The PMP data is extensively used to assess the stability of overlying strata of working section of coal seams which helps in designing the desired support pattern.
2. Organisation of conducting different Physico-Mechanical Properties tests to suit the requirement of carrying out Numerical Modeling is very essential.
3. Comparison of test results of both NQ and BQ core sample, and Cylindrical and 1 inch cubes revealed that UCS values decrease with the size of sample.
4. The average UCS values are 12.8MPa and 15.1MPa for SS40 (parting strata between IIIA and III) and SS80 (parting starta between IA and I seam) respectively.
5. The expected average UCS of SS80 lies in between 15.1±2.45MPa. The average UCS values of I and III seams are 29.28 MPa and 22.93 MPa respectively.
6. To ascertain the hardness and cuttability of coal, the data generated from HGI, Cerchar Hardness, coal strength, etc. are required. In light of this, the tests conducted on coal seams can be used for the design of coal cutting tools, viz. Road header picks, Shearer picks, Continuous miner picks, etc.
7. The range of HGI for I & III coal seams are 46-49 and 44-56 respectively.
8. As per the classification of Cerchar Hardness, I Seam is difficult to cut and the remaining II, III and IV seams are easy to cut.
9. The minimum strength of in situ coal was 2.6MPa and the maximum 11.5MPa. The stiffness of coal in seam III, varies from 26,096 to 1,21,781 kg/cm.

It is the first time that such voluminous data has been generated for planning high capacity Longwall Project in SCCL. Realizing the importance and increase in the level of confidence with the experience of data generation for Adriyala Longwall Project, SCCL decided to modernize it's Rock Mechanics Laboratory by procuring Servo controlled Hydraulic Rock testing machine.

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