Soil and Rock Mechanics Investigations for the Assessment of Strata Behaviour of an Opencast Coal Mine

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Abstract: The Singareni Collieries Company Limited (SCCL) planned for deepening the Opencast projects from the present depth of 250m to 400m. For successful operation and forecasting of strata behaviour in pre-mining was recognized. In this direction, SCCL had tie-up with CSIRO, Australia to work jointly, with a lead research provider. As part of these studies, to meet the requirement of generating needy data to conduct Numerical Modelling, 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 and NIRM laboratories. The data thus generated were analyzed statistically to make use of the same for Numerical Modelling by CSIRO, Australia. The data generated during the course of organizing different tests, are synthesized and discussed in this paper. The paper deals with the methodology evolved in generation of desired soil and Rock Mechanics data to assess the stability of pit slopes, internal dump and OB dumps.

Keywords: Physico-mechanical properties, pit slope stability, internal dump stability, SPT tests, PLT tests.

1. INTRODUCTION

The Singareni Collieries Co. Ltd. (SCCL) entered into a collaborative research project with CSIRO, Australia, for the data review and detailed site characterization studies at the Open Cast field sites. It includes a number of advanced geotechnical investigations and slope stability analyses and design studies for both overburden dumps and deep opencast coal mines. The studies helps to develop a fundamental understanding of the mechanisms of slope failure in overburden dumps and deep opencast mines in the prevailing geological conditions in order to optimise opencast mining layouts and designs in coal mining conditions. These studies to develop skills and technology required for supporting large opencast mines in Indian conditions for optimal design of overburden dumps and deep opencast mines up to 400m in depth in the Godavari Valley Coalfield.

2. GEOLOGY AND STRUCTURE OF RG OC-II BLOCK

The RG OC-II Mine block is located within the Ramagundam Coal Belt along the western margin of the Godavari Basin (Figuer **1**). Up to seven regionally co relatable coal seams contained within the Lower Permian Upper Barakar Formation are the target of coal exploration and mining. Near the major boundary fault F1, located on the western side of the RG OC-II block, coal bearing Barakar Fm directly come in contact with metamorphic basement rocks of Achaean group, where missing a natural sequence of Pakhal Fm and Sullavai Fm (Figure **2**). Four minable seams named from top to bottom I, II, III and IV and three thin seams, IA, IIIB and IIIA are regionally consistent over many kilometres. Within the block, to large extent, III and IV seams are merged and formed into a combined seam. Trend of coal seams/ coal measures varies from NW-SE to NNE-SSW with varying gradient of 1 in 4.40 to 7.30. On the southern side, major fault F1 forms the limit of the block. It is presumed that throw of the fault could be +300m?, as natural sequence of Formations are missing along with part of Archaen Fm (?). Apart the major fault, the block is intersected by several faults with varying throw amount.

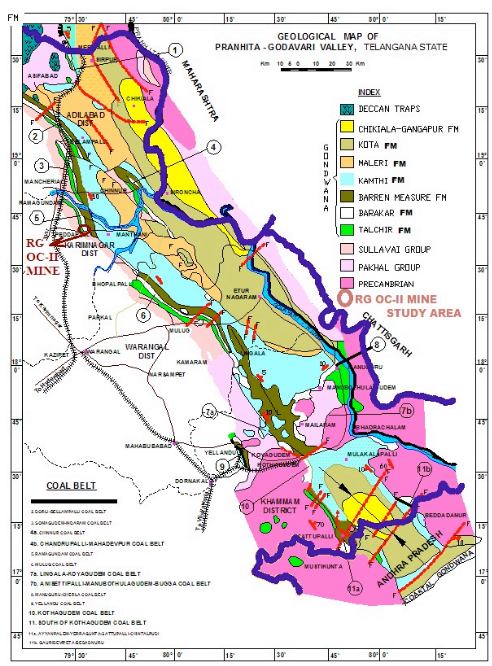

Figure 1: Geological map of Pranhita-Godavari valley Coalfield.

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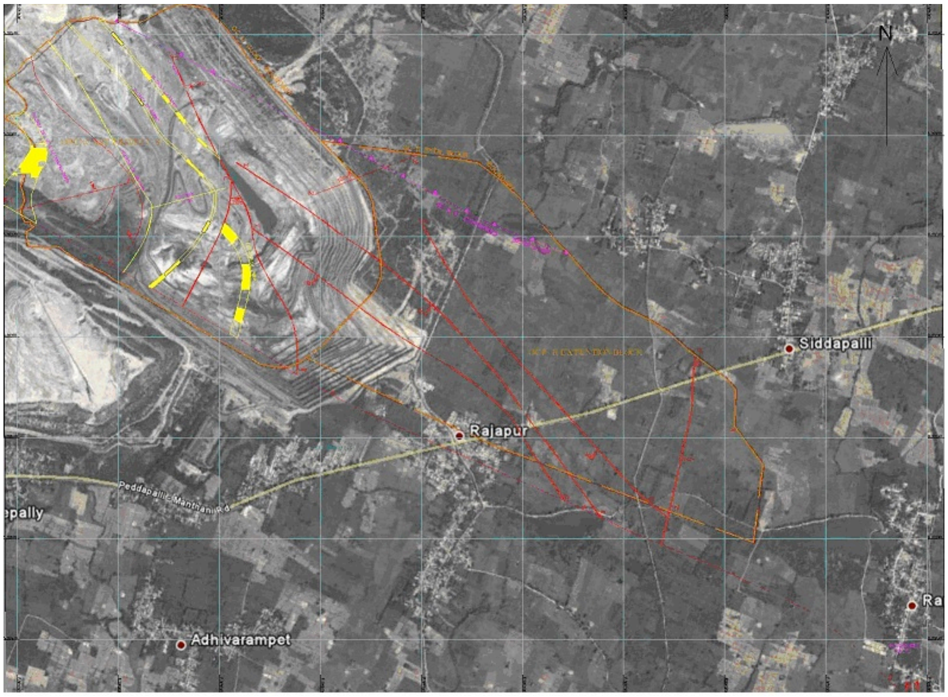

Figure 2: Google image showing the Quarry position of RG OC-II mine and is indexed in Figure **1**.

3. METHOD OF MINING

The project was sanctioned based on the project feasibility report envisaging the Inpit-Crusher-Conveyor Technology. The concept of In-pit Crusher Conveyor Technology is adopted for the first time in India and is the unique feature of this project. Dumpers transport the material from the Shovel to the Crushers, where Overburden/ Coal is crushed to - 300mm/- 200mm size respectively making it amenable for belt conveying. Overburden after crushing is carried out from Crushers by steel cord belt conveyors and then dumped out side through the Tripper car and Spreader combination. Spreaders are crawler mounted equipment and can dump the OB over a width of 100mtrs, to a depth of 30 meters and to a height of 22.5 meters from the crawler level. Tripper car provides for shifting the transfer point of Overburden from the belt to Spreader, all along the conveyor.

4. EARLIER INVESTIGATIONS

In RG OC-II mine block, Physico-Mechanical Properties data has been generated in different stages i.e. from Exploration to Mine Development stage. Total 13 BH's core samples have been subjected to various tests viz. Density, Compressive strength, Tensile strength etc. Some of these BH's samples were tested in Singareni Collieries Co. Ltd. (SCCL) Rock Mechanics laboratory. In the SCCL Rock Mechanics laboratory, few direct tests are conducted viz. Density, Compressive Strength, Tensile Strength, Slake Durability etc. Remaining tests results are derived with empirical relation. In the Exploration stage and in the initial stage of mine development, boreholes were identified to generate Physico-mechanical Properties. Summary of Physico-Mechanical Properties of these boreholes are furnished in Table **1**. Some Soil Mechanics tests were conducted by Regional Engineering College, Warangal [1] (Table **2**) as desired by the mine planners.

Basavachary M, Babu Rao YS and Sharma DN [2], conducted detailed studies in the adjacent RG OC-I mine to find out the Geological reasons for the failure of slopes. It was reported that major boundary fault contributed for the failure of slopes, since it's down throw is towards quarry and it accelerated the bench sliding. Further, the incrops of II, IIIB and IIIA coal seams at shallow depth comprising clay bed, coupled with ground water also contributed for the failure of slopes.

5. PRESENT INVESTIGATIONS

The objective of the present investigations by Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia is to review and assess available data with respect to both overburden dumps and opencast mines. On the basis of the assessment, recommendations were made on the requirements for collection of further data sets through

Table 1: Summary of Physico Mechanical Properties of RG OC-II (BH. No's. 463, 473, 480, 660, 663, 815, 816, 817, 818, 819, 1204, 1218, GBH-07-08)

Parameter	Units	Roof of IA		Parting between IA and I		Parting between I and II	
		Min	Max	Min	Max	Min	Max
Density	gm/cc	1.74	2.6	1.98	2.6	1.98	2.75
Tensile strength	kg/cm^2	1.92	52.82	2.00	68.90	1.37	162.03
Compressive Strength	kg/cm^2	18	431	33	574	47	611
Young's Modulus	x10^5 kg/cm^2	0.13	0.91	0.10	1.19	0.19	1.26
Shear Strength	kg/cm^2	5.21	79.21	7.87	61.75	9.21	135.59
Impact Strength	Index No.	45.62	53.31	45.62	55.86	46.46	56.52
Protodyaknov Strength	Index No.	0.02	1.92	0.64	2.62	0.13	2.80

Parameter	Units	Parting between I and III		Parting between IIIA and III		Floor of III and IV	
		Min	Max	Min	Max	Min	Max
Density	gm/c.c	1.78	2.71	2.00	2.73	2.2	2.45
Tensile strength	Kg/cm^2	5.67	128.33	4.75	147.19	7.29	55.51
Compressive Strength	kg/cm^2	49	1057	57	1307	85	469
Young's Modulus	x10^5 kg/cm^2	0.19	2.10	0.07	1.47	0.18	0.61
Shear Strength	kg/ cm^2	13.73	144.97	11.92	172.83	19.4	85.8
Impact Strength	Index No.	46.49	54.18	46.64	58.49	47.14	53.99
Protodyaknov Strength	Index No.	0.12	2.16	0.15	3.35	0.33	0.90

Table 2: Soil Mechanics and Rock Mechanics Test Results Generated by NIT, Warangal

Particle size analysis			Atterberg limits			Density. g/cc	Porosity %	Undrained Shear parameters		Unconfined Compressive strength. Kg/Sq.cm	Shear strength Kg/Sq.cm	Remarks
Sand % (0.075mm-4.75mm)	Silt% (0.002mm-0.075mm)	Clay% (0.002 mm)	Liquid limit %	Plastic limit %	Plasticity Index%			Cohesion Kg/Sq.cm	Angle of Internal friction(°)			
			45.00	24.80	20.20	2.16	24.80	0.06	36.70			Part of II Seam
	77.00	23.00	51.93	35.17	16.76	1.76	43.30	0.03	26.20			Floor of II and Roof of IIIB Seam
						2.23-2.50	10.60-19.10			76-92		
						2.27	15.00			73-130	17.30	Parting Between IIIB and IIIA
	85.00	15.00	35.89	21.20	14.69	1.95	34.80	0.117	28.40			Clay Roof of IIIA seam
								0.11	21.30			IIIA Incrop
						2.42	12.30			72-458	14.90-17.00	Roof of III and IV Comb. Seam
						1.41-1.45				228-688	22.20-22.40	Part of III and IV Comb.Seam

additional geological mapping, drilling boreholes, testing of borehole core samples for different Rock Mechanics tests, hydrogeological investigations etc to assist with the work involved in the subsequent stages of the mine operation.

5.1. Studies Conducted by CSIRO, Australia

Under the Sight Characterisation study, CSIRO recommended to take up additional boreholes to carryout various Soil Mechanics and Rock Mechanics tests for the "Stability of Internal dump", "Stability of Adriyala dump(under formation) and "Stability of Pit slope". Accordingly additional boreholes are drilled and generated the needy data. The details of methodology followed in identifying the borehole core samples for various tests being carried out by different laboratories viz. SCCL, National Institute of Rock Mechanics (NIRM) etc are discussed. An extensive and commendable geotechnical testing program has been initiated by SCCL and provided the data to the CSIRO for Modelling and suggestions and recommendations.

5.2. Discontinuity Mapping

A detailed geological mapping was carried out, recording the data on Joint sets and Faults to assess the stability of slopes and working benches formed both in Sedimentary and Metamorphic formations in the RG OC-II. A comprehensive and detailed geotechnical mapping was carried out to assess the stability of slopes by Sharma DN, Vinaykumar R and Rajendar G [3] and the findings were concluded as follows:

- **Joints:** In the Metamorphic benches, only two most prominent sets of Joints are found wherein J1 trends in N35°E and J2 trends in N5°E. Whereas in Sedimentary benches, three sets of Joints viz. J1 in N75°W, J2 in N65°E and J3 in N35°W (Figure **3**).

- **Faults:** In the study area, including Major Fault F1 (between Metamorphic and Sedimentary benches), faults within the Metamorphic benches as well as within Sedimentary benches are mapped and their impact on stability of benches viz. wide cracks, failure etc. are reported. It is inferred that the variation in the Joint trend is influenced in the vicinity of faults (Figure **3**).

Failure of benches are found to be result of unfavorable orientation of discontinuities viz. Joints, faults etc.

5.2.1. Pit Slope Stability

To assess the stability of Pit slope, four Bore holes viz. 1278, 1279, 1292 and 1296 were drilled as proposed at about approximately 400m away from each other. In which three are Core Boreholes (1278, 1279 and 1292) and one is non-core borehole (1296). Three borehole samples were tested at National Institute of Rock Mechanics (NIRM) for different tests viz.- Unconfined Compressive Strength (at natural moisture content), Triaxial strength properties and

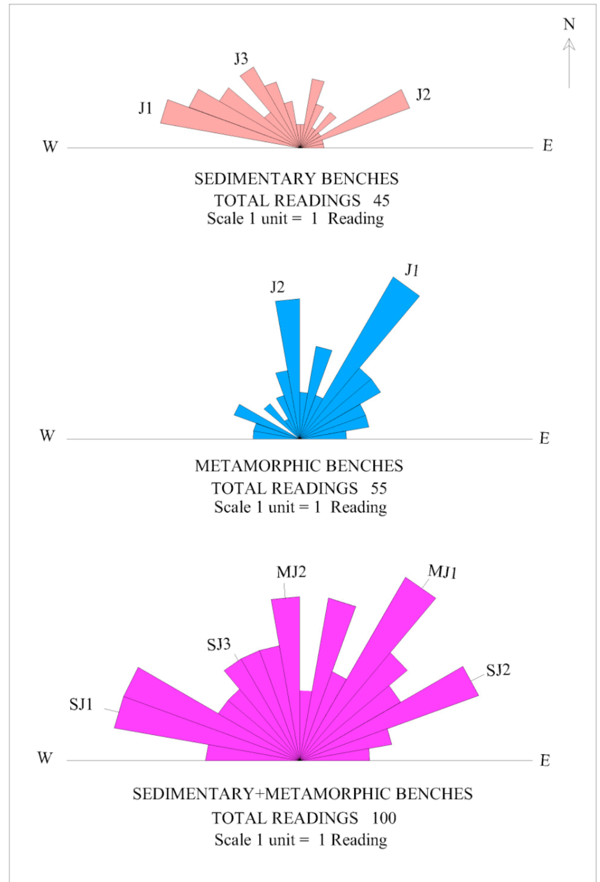

Figure 3: Rose diagrams of Joint pattern of Metamorphic and Sedimentary benches.
(MJ1 = Metamorphic J1, MJ2 = Metamorphic J2, SJ1 = Sedimentary J1, SJ2 = Sedimentary J2, SJ3 = Sedimentary J3).

Discontinuity Shear strength [4]. The data thus generated is furnished in Table **3.** These tests were conducted for the bottom 200m column of the borehole only (upto 20m below bottom most IV Seam) as suggested by CSIRO. Besides these tests, on

Table 3: Summary of Various Tests Conducted by NIRM (BH. No's. 1278, 1279 and 1292)

S. No.	Mechanical Property	Min	Max
1	Uniaxial Comp. strength, Mpa	2.10	53.20
2	Triaxial Compression Test		
a	Cohesion, c (MPa)	2.38	39.55
b	Friction angle (Deg.)	25.18	42.48
3	Direct Shear test of parting		
a	Normal stress (MPa)	1.35	7.60
b	Shear strength (MPa)	1.71	8.61
4	Young's Modulus (GPa)	1.29	12.63
a	Poissons Ratio	0.24	0.50

Table 4: Summary of Various Tests Conducted by SCCL (BH. No's. 1278, 1279 and 1292)

		Roof of IA		Parting between IA and I		Parting between I and II		Parting between II and IIIA	
		Min	Max	Min	Max	Min	Max	Min	Max
Density	(gm/c.c)	1.61	2.56	1.71	2.67	1.35	2.83	1.27	2.66
Tensile strength	kg/cm^2	3.32	21.73	2.14	27.85	2.55	35.59	2.88	30.27
Compressive strength	kg/cm^2	21	244	14	329	15	681	20	567
Young's Modulus	x10^5 kg/cm^2	0.14	0.56	0.12	0.72	0.13	9.00	0.13	1.17
Shear Strength	kg/cm^2	6.47	52.66	5.25	61.90	6.45	94.37	8.33	63.91
Impact Strength	Index No.	45.99	49.97	45.87	51.49	45.89	57.77	45.98	55.47
Protodyaknov Strength	Index No.	0.03	1.00	0.02	1.42	0.03	3.15	0.03	2.58
Slake Durability	Index No.	38	75	31	82		-	58	90

		Parting between IIIA and III		Parting between III and IV		Floor of IV Seam	
		Min	Max	Min	Max	Min	Max
Density	(gm/c.c)	1.99	2.51	1.39	2.35	2.06	2.49
Tensile strength	kg/cm^2	3.68	44.30	3.26		6.28	23.83
Compressive Strength	kg/cm^2	44	410	28	317	76	360
Young's Modulus	x10^{5}kg/cm^2	0.18	0.88	0.15	0.70	0.24	0.78
Shear Strength	kg/cm^2	11.22	97.66	15.03		20.76	54.80
Impact Strength	Index No.	46.40	52.94	46.12	51.28	46.98	52.04
Protodyaknov Strength	Index No.	0.10	1.81	0.24	1.36	0.23	1.57
Slake Durability	Index No.	84	87	-	-	83	95

remaining samples, routine tests viz. Density, Tensile strength, Unconfined Compressive Strength (UCS), Slake durability (Id1) were conducted in SCCL laboratory (Table **4**). Test results clearly indicates that the methodology of sampling was meticulously planned to suit the requirement of input for FLAC 3D modelling for drawing meaningful conclusions and is progress. Through modelling, it is intended to assess the stability of Pitslopes stability.

5.2.2. Internal Dump Stability

To generate the needy data, 4 bore holes were drilled along the toe of the Internal dump at an interval of 150m, up to a depth of 20m (below IV seam that is quarry floor) to assess the foundation characteristics. A systematic methodology is followed to generate the data viz. Uniaxial compressive strength (UCS) of the material obtained at 5 locations in each borehole (4m apart). Tests are conducted only on natural moisture conditions (i.e., without oven dry). Three samples are tested from each location (i.e., 5 x 3 = 15 UCS tests). If coal or other weak layers are found, Shear strength is determined for the portion of the coal/weak layer nearest to the coal/stone interface. Shear strength tests are conducted on contact planes of different lithological units. Care is taken to ensure that sample moisture is not lost during storage and transportation. All the above tests were conducted at NIRM [5] are tabulated in Table **5** and remaining samples were tested in SCCL laboratory (Table **6**). The overall range of properties

Table 5: Summary of Tests Conducted by NIRM (BH. No's. CSIRO- ID-1 to 5)

S. No.	Test/Lithology	Range (MPa)
1	Uniaxial comp strength	
	Sandstone- very coarse grained to very fine grained	62.29 to 29.47
2	Direct shear Test	
a	Sandstone (from shaly to sandy sandstone)	
	i. Normal stress	2.49 to 6.62
	ii. Shear stress	2.13 to 9.77
b	Coal	
	i. Normal stress	2.49 to 6.62
	ii. Sheer stress	2.78 to 6.13

Table 6: Summary of Various Tests Conducted by SCCL (BH. No's. CSIRO- ID-1 to 5)

Parameter	Units	Min	Max
Density	(gm/c.c)	2.03	2.47
Tensile strength	Kg/cm^2	2.96	24.83
Compressive Strength	kg/cm^2	37	395
Young's Modulus	$x10^5$ kg/cm^2	0.17	0.85
Shear Strength	kg/cm^2	10.89	68.03
Impact Strength	Index No.	46.26	52.67
Protodyaknov strength	Index No.	0.08	1.74

considering all the samples of the five boreholes are summarized in the following tables. Test results clearly indicate that the methodology of sampling was meticulously planned to suit the requirement of input for FLAC 3D modelling for drawing meaningful conclusions and is progress. Through modelling, it is intended to assess the Internal stability of the Pit.

5.2.3. Adriyala Dump under Formation

Since the dump is under formation on fresh land, it is essential to study Lithology/Profile and soil characteristics of the floor of the dump. The general procedure is to drill boreholes in the form of a grid at 250 x 250 or 500 x 500 m. It is suggested that Profiles/Lithologs of the boreholes be constructed along Strike and Dip-rise sections, at intervals of 250m upto a depth of 25m. SCCL drilled total 9 boreholes out of which 3 are cored boreholes (CSIRO ED-1 to 3) and 6 are non cored boreholes. All these boreholes were logged by Geophysical methods. From the cored boreholes, collected samples and got the required tests from NIRM [6]. The data thus generated is provided in Table **7**. Remaining samples are tested in the SCCL laboratory (Table **8**). Isometric Panel diagram (Fence diagram) is prepared to depict the subsurface lithology in strike and Dip directions (Figure **4**). Taking into consideration of the Figure **4**, the locations of Standard Penetration Test (SPT) and Plate Load Test (PLT) are identified. These tests are to be conducted on dump material to understand the dump material characteristic specifically for the stacker dump.

Table 7: Summary of Various Tests Conducted by NIRM (BH. No's. CSIRO_ED 1 to 3)

S. No.	Test/Lithology	Range
1	Uniaxial Comp. Strength (MPa)	
	Sandstone- very coarse grained to very fine grained	3.24-19.72
2	Direct Shear Test (MPa)	
	Normal Stress	0.59-1.37
	Shear Stress	0.81-2.09
3	Young's Modulus (GPa)	
	1^{st} Cycle of loading	0.51-9.2
	1^{st} Cycle of unloading	2.91-15.89
	2^{nd} Cycle of loading	2.6-11.95

5.2.4. SPT and PLT Tests

To ascertain the foundation characteristics in increasing dump height to 120 m above ground level, In-situ Plate Loading Tests (PLT) have to be conducted

Table 8: Summary of Various Tests Conducted by SCCL (BH. No's. CSIRO_ED 1 to 3)

Parameter	Units	Min	Max
Density	(gm/c.c)	1.79	2.19
Tensile strength	Kg/cm^2	3.45	7.84
Compressive Strength	kg/cm^2	12	127
Young's Modulus	$x10^5$ kg/cm^2	0.12	0.34
Shear Strength	kg/cm^2	9.71	20.29
Impact Strength	Index No.	45.83	47.89
Protodyaknov strength	Index No.	0.01	0.45

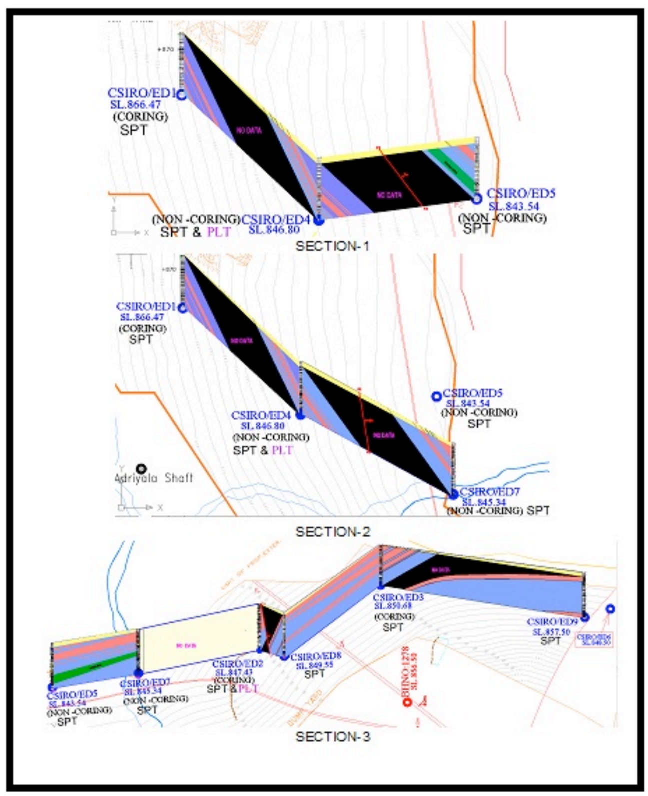

Figure 4: Isometric Panel Diagram (Fence diagram) depicting the Profile of Adriyala Dump Under formation upto about 25m from surface.

on dump material. Care has been taken to collect the samples from both Black cotton soil and weathered mantle. Central Soil and Material Research Station (CSMRS), New Delhi is approached in this connection and proposed to conduct PLT tests with the capacity of plate load testing equipment on OB dump as well on the fresh surface soil with 200 tons and having plate size of 1m X 1m. After taking up these tests, the data will be considered to ascertain the maximum height of dump is permissible in the given situation.

Also it is proposed to conduct shear testing on interface of sandstone and clay in the internal dump area with the help of CSMRS having Soil testing facilities.

6. RESULTS AND DISCUSSIONS

The RG OC-II Opencast Project is a most prestigious one in India being first time introduced this Technology. In the initial stage itself, lot of data pertaining to Soil Mechanics and Rock Mechanics was generated. During the development, additional Rock Mechanics data was added to understand the slope stability issues. Subsequently depth of working is proposed to extend upto a maximum of 400m and to increase the height of dump from 90 to 120m. Accordingly to study the Openpit Slope stability, Internal Dump stability and Adriyala Dump under formation, a detailed studies are taken up as a part of the Project between SCCL and CSIRO, Australia. Majority of the Rock Mechanics tests are completed and few Soil Mechanics related tests are to be taken up. Expert suggestions of CSIRO helped in generating the needy and extensive Rock Mechanics test data to use it as input, by the CSIRO, Australia for Modeling to predict the stability related issues. However, the work is in progress to generate the remaining data of Soil Mechanics and subsequently final advise from CSIRO is expected in connection with Slope stability at greater depths of 400m, Internal Dup stability and Adriyala Dump under formation.

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