Journal of Engineering Geology *Volume XLV, Nos. 1 & 2*
A bi-annual Journal of ISEG *June & December 2020*

Behaviour of cohesion and angle of friction on variant rockmass foundation for the design of underground dam in Chasnalla colliery, Jharkhand, India

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Received: November 2020/ Accepted: February 2021

Abstract

In the mining industry, dams are constructed as static supports for bearing strain and act as sealing elements. They seal off preventing any inrush of water from drains, aquifers etc. A key requirement in the evaluation of sliding stability of dam structure is by determining the shear strength parameters i.e. cohesion and internal angle of friction of the foundation joints and discontinuities. The shear strength parameters cannot be predicted on the basis of case histories or by any rockmass classification. Consequently, the feasibility in the measurement of *in-situ* shear parameters cannot be avoided due to variation of rock mass properties at different sites. The best way of evaluating shear strength parameters is by actual measurement of *in-situ* shear parameters on site. The shear strength of rock depends upon number of factors such as strength of rock, rock type, joint pattern, rate of loading, rate of shearing etc.

This paper describes the approach used for designing the underground dams on different rockmass (sandstone, coal and shale). Chasnalla underground Colliery is one among the three operational mines of Collieries division of M/s Steel Authority of India Ltd. which is in the Eastern part of the Jharia Coalfield. It is proposed to construct water dam at six locations to prevent inrush of water infiltrating from the opencast workings and also from river Damodar. This paper deals with the most comprehensive technique used to determine the shear strength parameters of rockmass by conducting *in-situ* investigations on rock and concrete interfaces.

Keywords: Cohesion; Friction angle; Underground dam; Probability; Rock mass rating;

1 Introduction:

In mines, underground dams are constructed mainly to prevent inundation of dip side workings by isolating the adjacent flooded areas. They also serve to flood a portion of a mine and to limit the amount of pumping and to keep water under control so that it may draw off as when required. In some instances a dam acts as barrier when approaching old workings. The factors which govern the design of dam is peak & residual shear strength parameters of rock discontinuities. This is significant in determining the friction angle and cohesion.

In order to determine the shear strength of joints/ discontinuities most of the criteria always propose the direct shear tests by concrete-rock interface. It is the best method to understand the shear behavior of bonded rough joints and to relate the shear strength parameters. Due to complexity of the shear behavior of bonded joints, it was decided to perform several experiments on different types of rockmass. For this purpose, thirty direct shear tests were performed on bonded samples at different levels of normal stress.

Chasnalla Colliery of Collieries Division, M/s Steel Authority of India Ltd is located in the Eastern part of the Jharia Coalfield, District Dhanbad, Jharkhand and covers an area of about 3.5 sq.km. It is situated at about 20km from Dhanbad Railway Station. The Chasnalla mine concession lies between latitudes 23º40’03”:23º38’33”N and longitude 86º26’52”:86º27’57”E. Chasnalla Colliery has been in operation prior to nationalization and operation is still continuing. It was first started in the year 1938 as underground mines (Chandra, D. 1992).

Chasnalla Colliery Mine has been developed through two vertical shafts i.e., up cast & down cast. Two longwall panels in 13th seam are being operated. De-pillaring is being done by Jankowice Long wall method of mining with hydraulic sand stowing. To prevent the inrush of water from old workings and from river Damodar, it is proposed to construct the water dams at six locations on different rockmass (sandstone, shale and coal). The direction of water thrust at the proposed water dam locations are from West to East and the proposed locations, rock type is given in the Table 1. The RMR for the rock masses at the proposed water dam locations ranges between 53 - 60 and falls under the Fair rock category.

Table 1
Details of the proposed locations for water dams

Sl. No.	Seam/Location	Horizon & RL (m)	Rock type (at floor)
1	12th seam – Gate road	H-1; at (-) 9.5 m	Shale
2	12th seam – West lateral	H-1; at (-) 28.0 m	Shale
3	13/14th seam – Foot wall	H-1; at (-) 30.0 m	Bituminous Coal
4	13/14th seam – Hang wall	H-1; at (-) 30.5 m	Bituminous Coal
5	14th seam – West lateral	H-2; at (-) 147.8 m	Bituminous Coal
6	13th seam – West lateral	H-2; at (-) 148.4 m	Bituminous Coal
7	Stone drift	H-2; at (-) 148.4 m	Sandstone

2 Geology around Project Area:

The Jharia coalfield forms a part of the east-west trending Gondwana basins of the Damodar valley in north-eastern part of India. Basement of the Jharia coalfield is composed of metamorphic rocks overlain by the Talchir Formation followed by Barakar Formation which is the main coal bearing formation and covering an area of about 210 km^2. Raniganj Formation is another coal bearing formation in the Jharia coalfield and situated above the Barakar formation.

2.1 Geology of the study area:

The study area consists of the sedimentary rocks mainly sandstone, shale and coal. General strike direction of the steeply dipping strata is East-West (N70°W-S70°E) and the dip varies from 35° to 42° due south (S20°W). The ore body exhibits well developed bedding or relict stratification (Figure 1) marked by alternate bands of sandstone, shale and coal. In general, at this location rock mass and rock material is fresh. The thickness of bedding planes varies from 5 cm to 30 cm.

Figure 1 Contact between steeply dipping shale and sandstone

Sandstone: Medium to coarse grained sandstone varies in color, i.e., greyish white, blackish and reddish brown with intercalations of carbonaceous shales were present at the tested location. Which is characterized by steeply dipping bedding planes (35°-45°) towards N180° to N200° with prominent vertical joints. Surface of bedding joints and vertical joints are smooth planar and spacing of these discontinuities varies between 7 cm to 35 cm. Rock mass is blocky in nature and due to presence of intercalations of friable shale and very thin layer of coal, it is easily ruptured along the contact between sandstone and shale or coal.

Shale: Fine grained carbonaceous shales which is characterized by steeply dipping bedding planes (35°- 45°) towards N180° to N200° with prominent vertical joints are present at tested location. Surface of bedding joints and vertical joints are smooth planar and spacing of these discontinuities varies between 2 cm and 30 cm. Rock mass is blocky in nature and due to presence of thin layer of coals which is friable, it is easily ruptured along the contact between shale and coal.

Coal: Dense coal of black color shows banded structure in which dull and bright bands are alternate. Due to presence to two sets of vertical joints and one set of sub-horizontal joints it is blocky in nature. Spacing of cleats varies between 5 cm and 15 cm. Due to presence of friable coal layer, i.e., bright glassy/silky bands of coal which are up to one centimeter thick it is ruptured easily along this.

2.2 Geotechnical assessment of the rock mass at test locations:

All the lithological and structural features were observed and mapped at the test locations. The rock mass classification parameters namely, Uniaxial compressive strength (UCS), rock quality designation (RQD), spacing of discontinuities, joints conditions, orientation of discontinuities and hydrogeological conditions, were estimated. Classification of rock mass using Rock Mass Rating (RMR) of Bieniawski (1989) has been done and presented in Table 2. RMR for the rock masses at test locations varies from 51 to 58 and falls under the Fair rock category. Average density of the coal, shales and sandstones are 1.42 t/m^3, 2.31 t/m^3 and 2.38 t/m^3 respectively. The engineering properties of rock mass vis-à-vis RMR (Bieniawski, 1989) given in Table 3 corroborates most of the values determined in the testing.

3 Determination of *In-situ* Shear Parameters

3.1 Site preparation

A. Preparation of test block

Rock-to-rock interface: An area of 1000 mm X 1000 mm is demarcated at the test location. The surface is prepared by clearing the loose rock to expose the fresh rock surface. One rock block is cut to a size of 700 X 700 X 350 mm at each site with chisel and hammers only. The irregular rock block was enclosed in the formwork and filled with concrete mortar/slurry to get a smooth surface. The test sample is then encapsulated with MS sheet of enough stiffness to prevent collapse or significant distortion during application of shear and normal loads. A channel approximately 20 mm deep by 80 mm wide is cut around the base of the block to allow freedom of shear and lateral displacements. The top portion of the block is also kept flat for installation of the normal loading system.

Concrete to Rock interface: An area of 1000 mm X 1000 mm is demarcated at the test location. The surface is prepared to expose fresh rock mass with chisel and hammers. A plain cement concrete block of size 700 x 700 x 350 mm with mix ratio 1:1.5:3 (Cement: Fine aggregate: Coarse aggregate) is prepared at each site over the exposed rock mass. A channel approximately 20 mm deep by 80 mm wide was cut around the base of the block to allow freedom of shear and lateral displacements. The top portion of the block was also kept flat for installation of the normal loading system.

B. Preparation of reaction block

Normal loading: Plain cement concrete pad of size 1000 X 1000 mm and thickness of 30 to 50 mm is prepared in the roof at each test site. The reaction pad is carefully positioned and aligned vis-à-vis the test block to carry the thrust from normal loading system.

Shear loading: Vertical plain cement concrete pad of size 700 X 700 mm and thickness of 100 to 150 mm was prepared in the upstream/side wall of the drift and carefully positioned and aligned vis-à-vis the test block to carry the thrust from shear loading system.

Table 2
Determined RMR values at test locations for coal, shale and sandstone

Lithology	**UCS***		**RQD**		**Spacing**		**Condition of discontinuity**										**Ground water**		**Orientation**		**RMR**
							Persistence		**Aperture**		**Roughness**		**Infilling**		**Weathering**						
	Value (MPa)	R	Value (%)	R	Value (cm)	R	Value (m)	R	Value (mm)	R	Type	R	Type	R	Grade	R	Quantity (L/min)	R	Value	R	Value
Coal	25	4	85	17	6-20	8	>20	0	T	6	S	1	N	6	I	6	Damp	10	Fav	-2	56
Shale	19	2	85	17	6-20	8	>20	0	T	6	S	1	N	6	I	6	Wet	7	Fav	-2	51
Shale	34	4	89	17	>20	10	>20	0	T	6	S	1	N	6	I	6	Damp	10	Fav	-2	58
Coarse grained Sandstone	24	2	85	17	6-20	8	>20	0	T	6	S	1	N	6	I	6	Wet	7	Fav	-2	51
Fine grained Sandstone	39	4	89	17	>20	10	>20	0	T	6	S	1	N	6	I	6	Damp	10	Fav	-2	58

Note: R-Rating; S-smooth; T-Tight; N-none; Fav-favourable, NOTE: *laboratory test results are considered

Table 3
Engineering Properties of Rock mass (Bieniawski, 1989)

Sl.no.	Properties of rock mass	Rock mass rating (Rock class)				
		81-100	61-80	41-60	21-40	< 20
1	Classification of rock mass	Very good	Good	Fair	Poor	Very Poor
2	Cohesion of rock mass (C) (MPa)	> 0.4	0.3 - 0.4	0.2 - 0.3	0.1 - 0.2	< 0.1
3	Internal friction angle (φ)	> 45	35 - 45	25 - 35	15 - 25	< 15

C. Installation of the normal loading equipment

A truncated square pyramid of size 700 mm^2 X 500 mm^2 and 200 mm height is placed on the test block. A roller system was then placed on the top part of the plate. A plate with one side square and the other part circular of 660 mm diameter was then placed over the roller bearing system with ram jack base plate. Three hydraulic cylinders each 100 tons capacity were placed above the ram jack base plate with the spherical seats. The extension columns were placed above another up to the top leaving enough space to accommodate a bearing plate, a load distribution plate of the same diameter as the bottom one and a particleboard. All the hydraulic cylinders were connected to the hydraulic pump through a manifold. A pressure gauge and a pressure transducer were attached to the hydraulic pump to monitor and log the normal pressure.

D. Installation of the shear loading equipment

Two numbers of jacks each of 100-ton capacity were placed inclined to the shear surface of the test block. The other side of the jacks was placed against concrete pad specially made against the wall of the drift to receive the reaction from the wall. The shear loading was produced by a hand pump system.

E. Installation of the displacement measuring equipment

A measuring frame with three LVDT's (range 50 mm, L.C = 0.01 mm) were mounted on the rods to measure the shear displacement. The measuring frame was made of rigid galvanized steel pipes, which were anchored in the rock formation at an appropriate distance from the test location.

3.2 Test procedure:

After installation of the equipment, the normal load was applied through jack assembly of each 100-ton capacity and maintained the same load throughout the test. View of the direct shear test equipment setup at test location is given in Figure 2. The shear pressure was then applied through the 2 X 100-ton hydraulic cylinders. Each increment of shear pressure was maintained constant till the displacement of the block was stabilized. The shear force along with horizontal displacement is recorded during the test. The observations were continued after the failure of the block for studying the residual shear strength parameters. The pressure and displacement readings were directly recorded continuously on a laptop using PICO 24-bit high resolution data logger. The blocks are then overturned, to understand the nature of the shearing and to know area of the shear surface overlap.

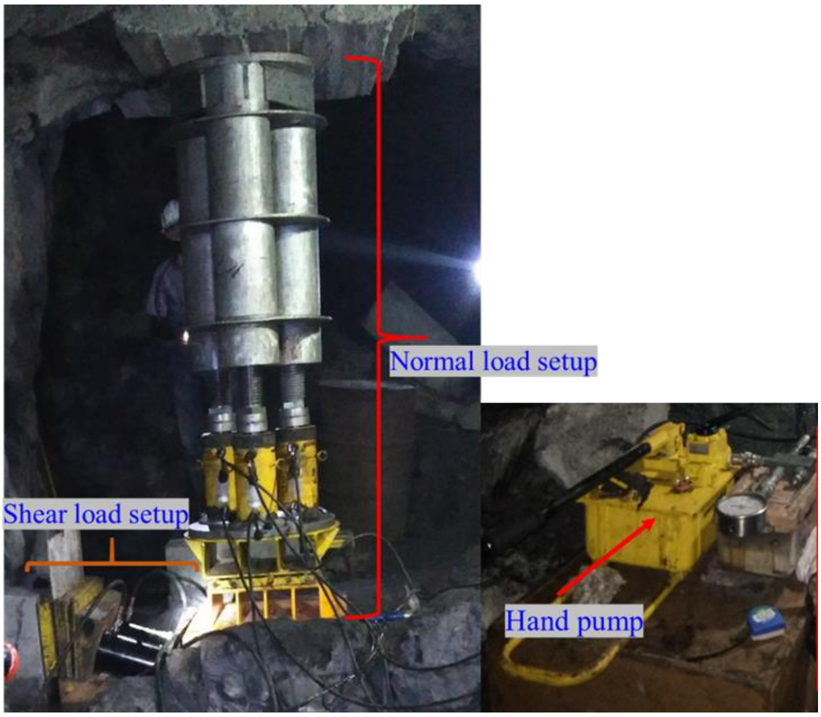


Figure 2 Direct shear test equipment setup at test location, Chasnalla deep mine

3.3 Calculations:

Normal stress and shear stress are obtained from normal load and shear load recorded during the *in-situ* shear test. The shear stress and normal stresses are calculated from the following equations (ISRM, 1974):

Shear stress $\tau = \frac{P_S}{A} = \frac{(P_{sa}\ \mathrm{Cos}\ \alpha)}{A}$ 1

Normal stress $\sigma_n = \frac{P_n}{A}$ 2

where, P_S = total shear force
P_n = applied normal force
P_{sa} = applied shear force
α = inclination of the applied shear force to the shear plane (if, α =0, cosα =1)
A= area of the shear surface overlap

3.4 Results:

Total thirty *in-situ* direct shear tests were carried out for each rock type. Five shear tests on sandstone to sandstone interface considered as rock-to-rock interface and five shear tests concrete to sandstone interface considered as concrete to rock interface were conducted. Similarly, for shale to shale interface and concrete to shale interface and coal to coal interface and concrete to coal interface were conducted. The shear stress versus shear displacement curves for all blocks are shown in Figures 3a, 3b, 4a, 4b, 5a, 5b. to determine peak and residual shear stresses. The results of *in-situ* shear tests vis-à-vis field observations are given in Table 4.

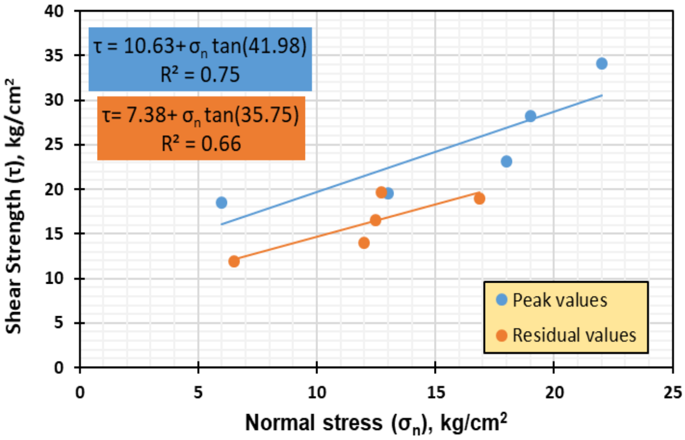


Figure 3a. Shear stress v/s Normal stress (concrete to rock interface – Sandstone)

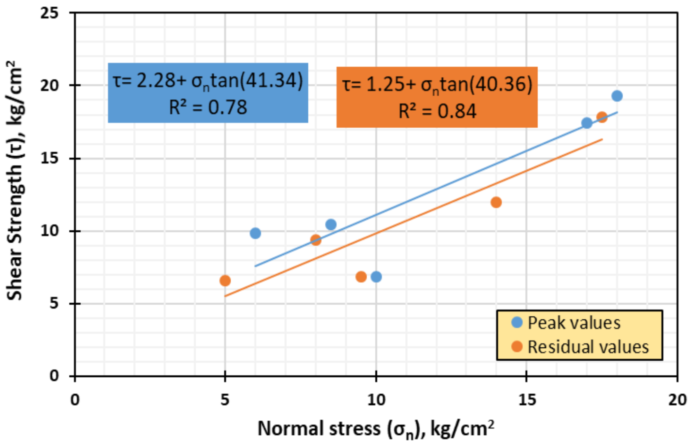


Figure 3b. Shear stress v/s Normal stress (rock-to-rock interface – Sandstone)

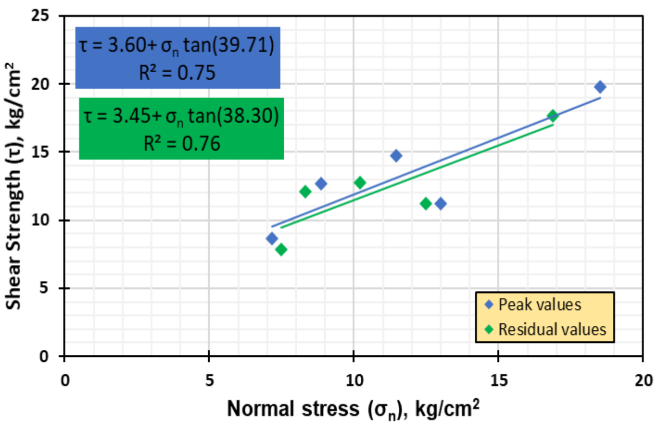


Figure 4a. Shear stress v/s Normal stress (concrete to rock interface – Shale)

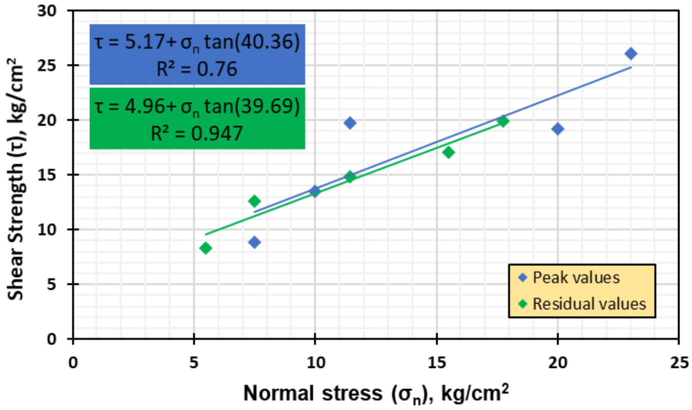


Figure 4b. Shear stress v/s Normal stress (rock-to-rock interface – Shale)

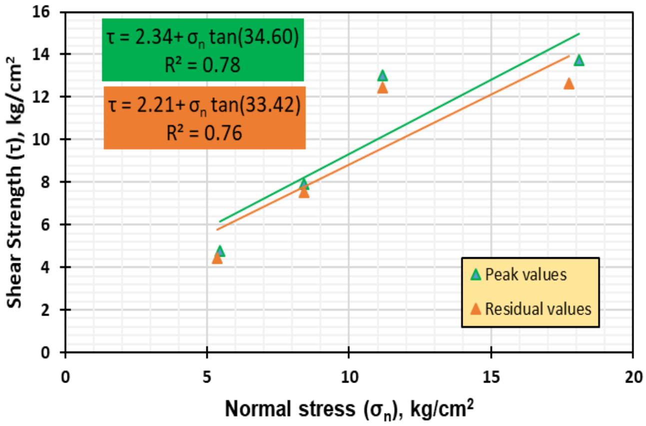


Figure 5a. Shear stress v/s Normal stress (concrete to rock interface – coal)

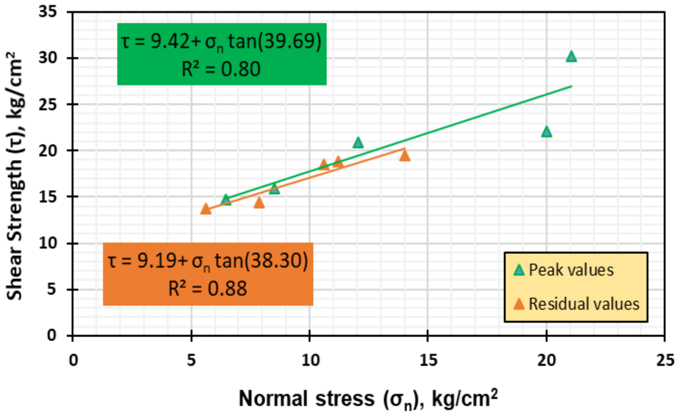


Figure 5b. Shear stress v/s Normal stress (rock-to-rock interface – coal)

Table 4
In-situ direct shear test results vis-a-vis field observations

Sl. no	Rock type	Interface	Peak shear parameters		Residual shear parameters		UCS* kg/cm^2	Observations/Inference
			Cohesion (C) kg/cm^2	Internal friction angle (φ)	Cohesion (C) kg/cm^2	Internal friction angle (φ)		
1	Coal	Coal to Coal	9.42	39.69°	9.19	38.30	245	Two sets of prominent cleats dipping N 30° and N 300°
		Concrete to Coal	2.34	34.60°	2.21	33.42		Slickensides were observed in the coal which would have led to weak bonding b/w concrete and coal
2	Shale	Shale to Shale	5.17	40.36°	4.96	39.69	332	Fine grained carbonaceous shales which is characterized by steeply dipping bedding planes (35°-45°) towards N180° to N200° with prominent vertical joints are present at tested location. Surface of bedding joints and vertical joints are smooth planar and spacing of these discontinuities varies between 2 cm and 30 cm. Rock mass is blocky in nature and due to presence to cleats which is friable it is easily ruptured along the contact between shale and cleats
		Concrete to Shale	3.60	39.71°	3.45	38.30		
3	Sandstone	Sandstone to Sandstone	2.28	41.34°	1.25	40.36	350	• The test samples were inundated in water (before investigations) • In test sample SSRR-2 thin coal inter-bedding along the interface of the test samples was encountered • In test samples SSRR-3 & 5 the shearing interface was along the shale intercalations and not along the interface/weakest plane

		Concrete to Sandstone	10.63	41.98°	7.38	35.75		• Sandstone is porous in nature hence cement grouting of the interface cannot be ruled out • The rock type in the weakest plane/interface was sandstone alone not coal nor shale

* Report on determination of rock mass rating for development working of 12, 13 and 14 seams at Chasnalla Colliery

4. Probabilistic Study of Cohesion (c) and Angle of Internal Friction (φ):

Probability study is a process to obtain quantifiable results. This is an experimental study to know the number of all possible outcomes. It may be finite or infinite or continuum (Andjelkovic, V. etal, 2015). In this paper, probability analysis of cohesion and angle of internal friction for sandstone – rock-to-rock interface is given. Similarly, the studies on sandstone – rock-to-concrete interface, shale and coal for both interfaces can be furnished.

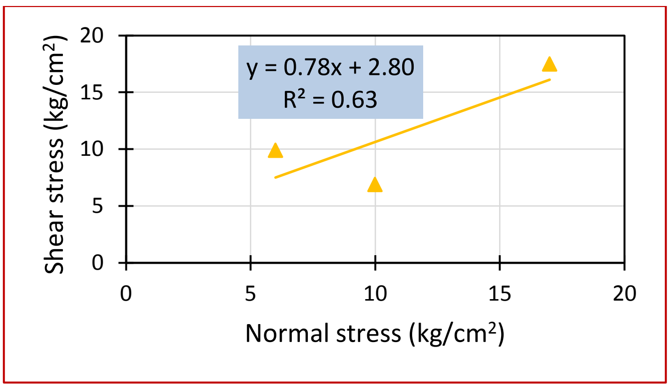
4.1 Probabilistic values of C and φ for Sandstone:

Sandstone – Rock-to-rock interface

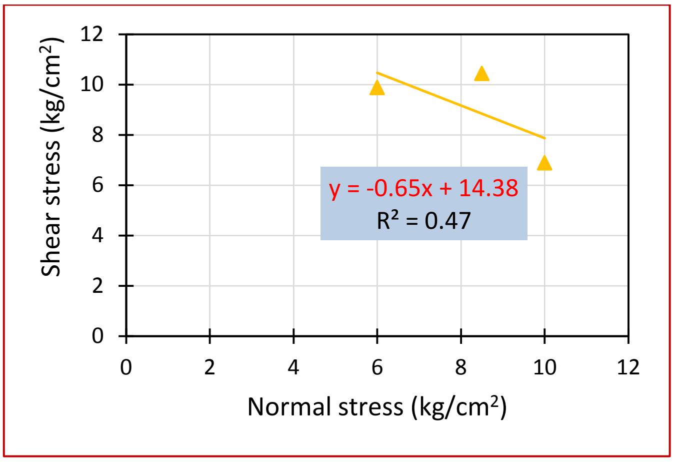
Five specimens are tested for rock-to-rock interface in sandstone. Considering all the five specimens the peak cohesion and angle of internal friction values is 2.28 kg/cm^2 and 41.35° respectively which is giving a confidence of 88.32 %. However, to draw a regression line a minimum of three points are required. So, in order to understand the variability of C and φ values for the rock-to-rock interface in sandstone different combinations of the samples are tried to fit in a straight line. The combinations considered are given as follows.

- Taking three combinations at a time out of five tested samples
- Taking four combinations at a time out of five tested samples
- Taking all the five tested samples at a time

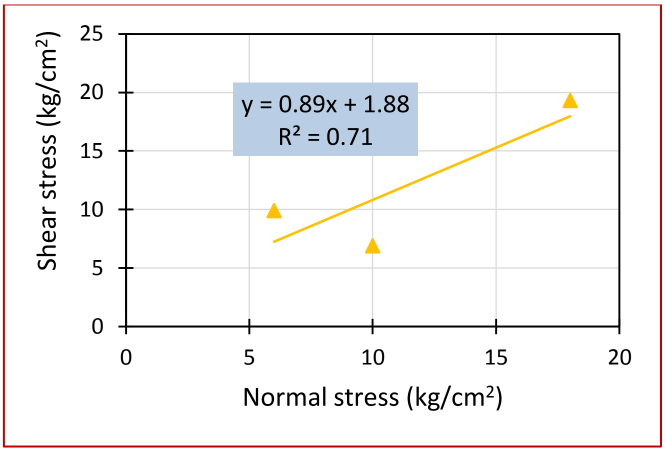
The regression equations for all the combinations along with the graphical plot are given below.



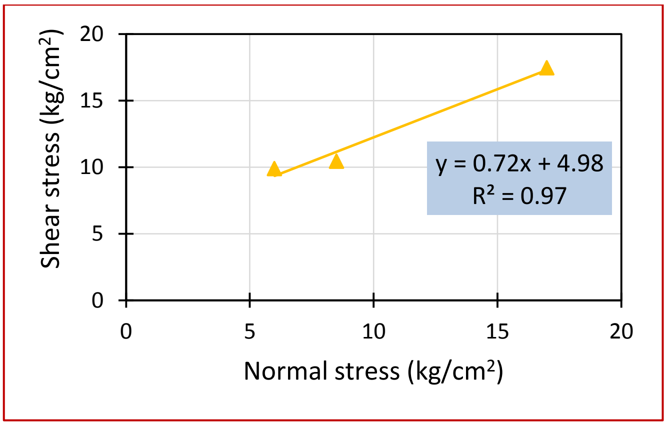
Plot b/w shear strength and normal stress for SSRR1, SSRR2 & SSRR3



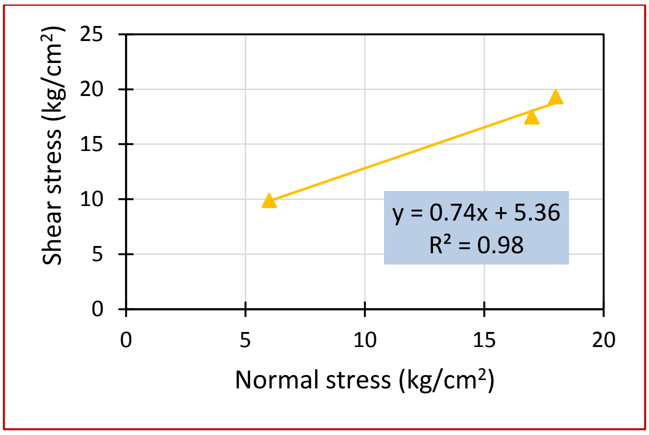
Plot b/w shear strength and normal stress for SSRR1, SSRR2 & SSRR4



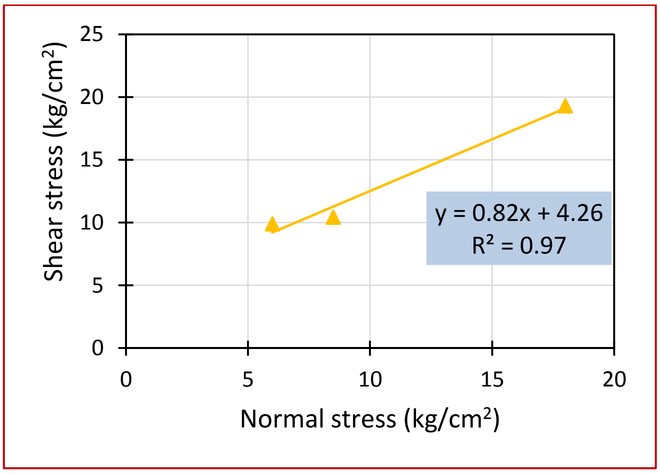
Plot b/w shear strength and normal stress for SSRR1, SSRR2 & SSRR5



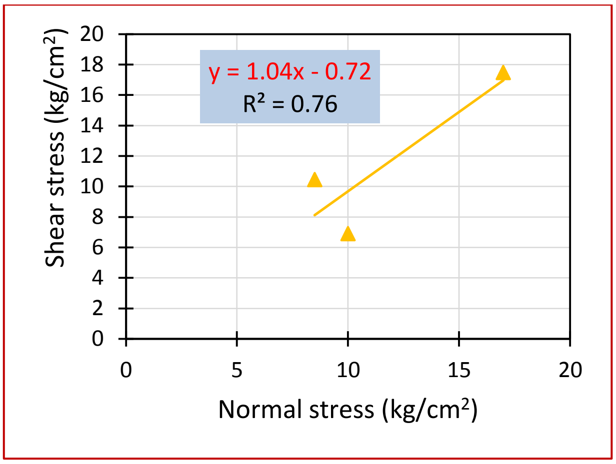
Plot b/w shear strength and normal stress for SSRR1, SSRR3 & SSRR4



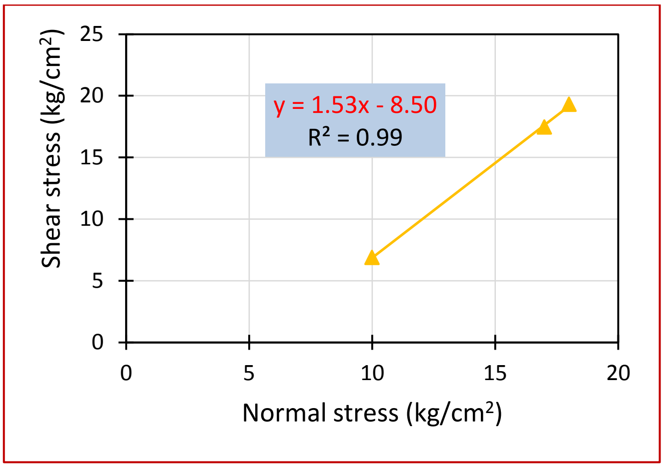
Plot b/w shear strength and normal stress for SSRR1, SSRR3 & SSRR5



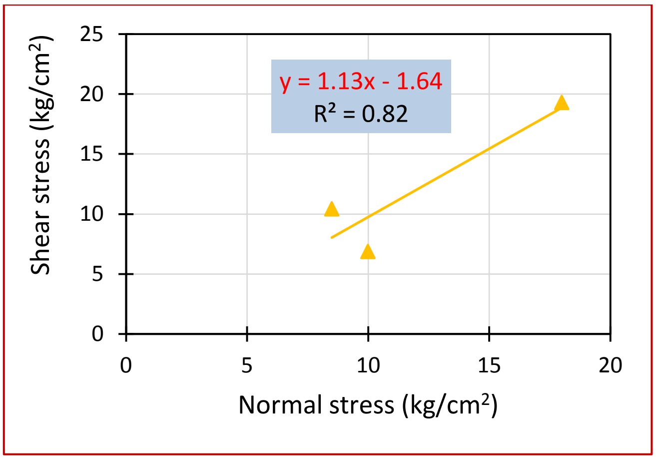
Plot b/w shear strength and normal stress for SSRR1, SSRR4 & SSRR5



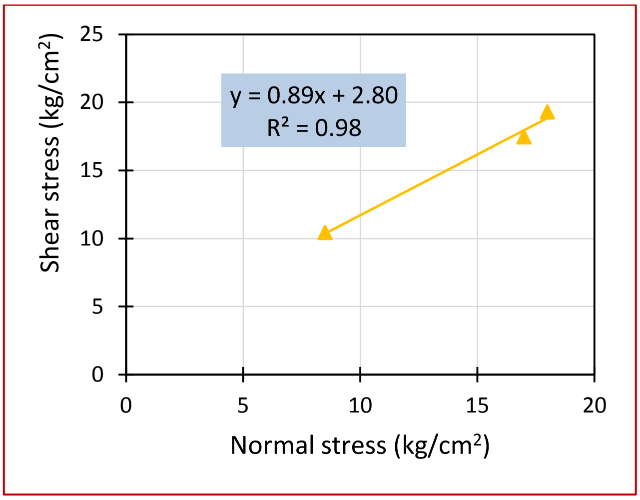
Plot b/w shear strength and normal stress for SSRR2, SSRR3 & SSRR4



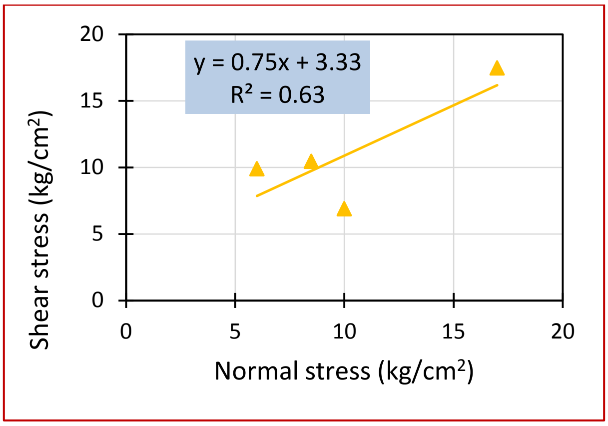
Plot b/w shear strength and normal stress for SSRR2, SSRR3 & SSRR5



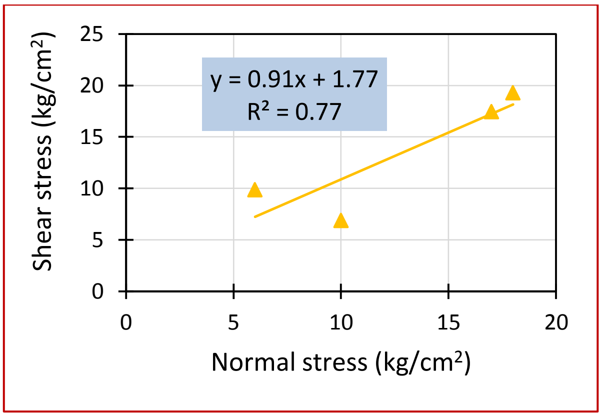
Plot b/w shear strength and normal stress for SSRR2, SSRR4 & SSRR5



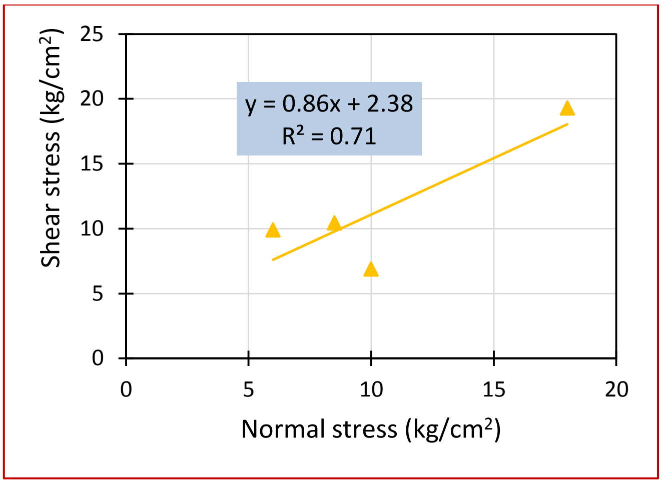
Plot b/w shear strength and normal stress for SSRR3, SSRR4 & SSRR5



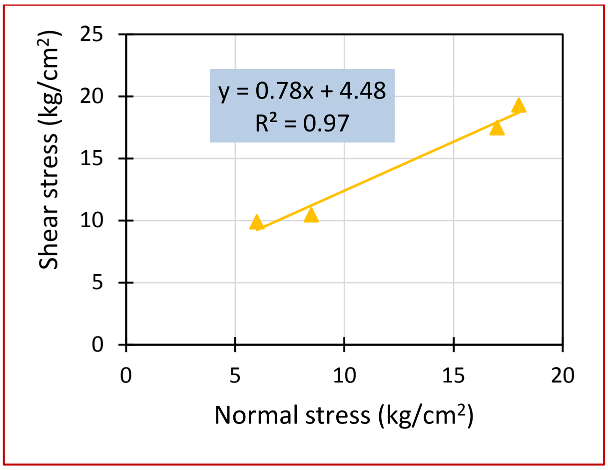
Plot b/w shear strength and normal stress for SSRR1, SSRR2, SSRR3 & SSRR4



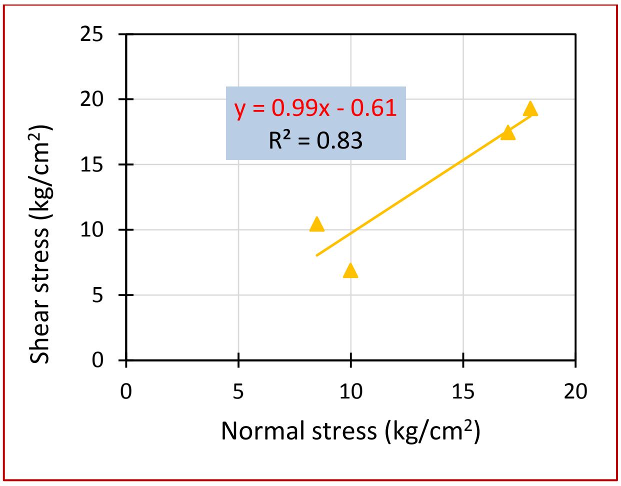
Plot b/w shear strength and normal stress for SSRR1, SSRR2, SSRR3 & SSRR5



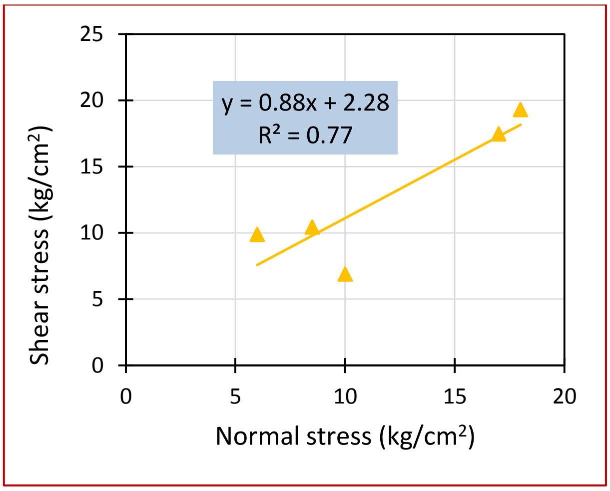
Plot b/w shear strength and normal stress for SSRR1, SSRR2, SSRR4 & SSRR5



Plot b/w shear strength and normal stress for SSRR1, SSRR3, SSRR4 & SSRR5



Plot b/w shear strength and normal stress for SSRR2, SSRR3, SSRR4 & SSRR5



Plot b/w shear strength and normal stress for SSRR1, SSRR2, SSRR3, SSRR4 & SSRR5

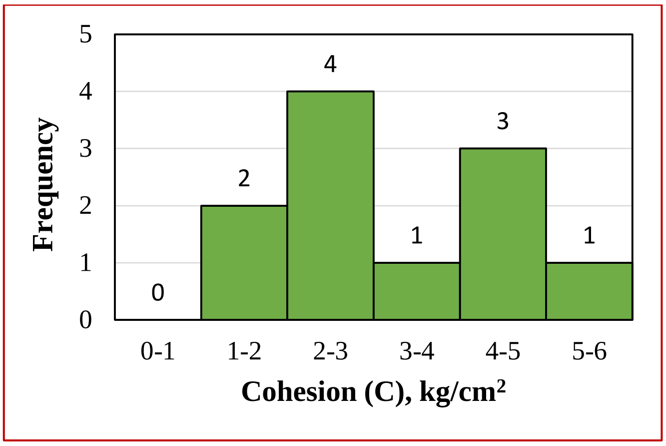


Figure 6.1 Histogram of cohesion values for RR interface in sandstone

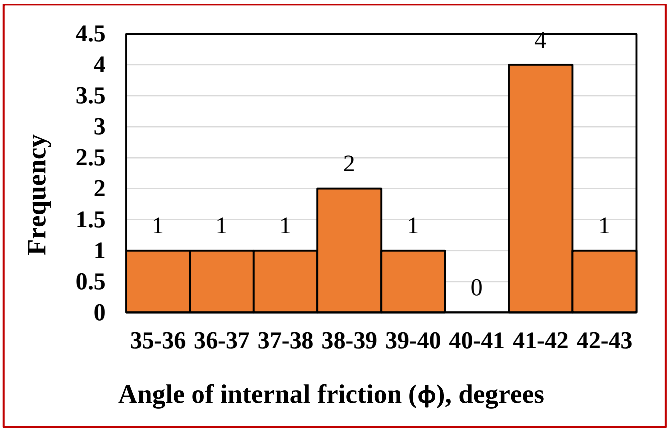


Figure 6.2 Histogram of angle of internal friction values for RR interface in sandstone

Considering the above-mentioned combinations, the positive values of C and ϕ obtained are given in Table 5. Those combination/s giving negative values of cohesion or angle of internal friction is/are omitted for evaluation of the probabilistic values of C and ϕ. A histogram plot of all the valid combinations of C and ϕ is given in Figure 6.1 and Figure 6.2 respectively.

Table 5
Values of C and φ of valid combinations for RR interface in sandstone

Sl. No.	**Combinations**				**Cohesion kg/cm^2**	**Friction angle**
1	SSRR1	SSRR2	SSRR3		2.80	38.03
2	SSRR1	SSRR2	SSRR5		1.88	41.80
3	SSRR1	SSRR3	SSRR4		4.98	35.90
4	SSRR1	SSRR3	SSRR5		5.36	36.69
5	SSRR1	SSRR4	SSRR5		4.26	39.52
6	SSRR3	SSRR4	SSRR5		2.80	41.73
7	SSRR1	SSRR2	SSRR3	SSRR4	3.33	37.02
8	SSRR1	SSRR2	SSRR3	SSRR5	1.77	42.30
9	SSRR1	SSRR2	SSRR4	SSRR5	2.39	41.02
10	SSRR1	SSRR3	SSRR4	SSRR5	4.49	38.27
11	SSRR1, SSRR2, SSRR3, SSRR4, SSRR5				2.28	41.35

5. Conclusion and Discussion:

Test results show that in peak shear for the rock-to-rock interface cohesion values varies from 2.28 kg/cm^2 to 9.42 kg/cm^2 and friction angle varies from 39.69° to 41.34°, whereas for concrete to rock interface cohesion values varies from 2.34 kg/cm^2 to 10.63 kg/cm^2 and friction angle varies from 34.60° to 41.98°. In residual shear for the rock-to-rock interface cohesion values varies from 1.25 to 9.19 kg/cm^2 and friction angle varies from 38.30° to 40.36°, whereas for concrete to rock interface cohesion values varies from 2.21 to 7.38 kg/cm^2 and friction angle varies from 33.42° to 38.30°.

The results also exhibit that cohesion values between rock-to-rock contacts are 9.42 kg/cm^2, 5.17 kg/cm^2 and 2.28 kg/cm^2, for coal, shale and sandstone respectively decreases, whereas for contact between concrete to rock cohesion values 2.34 kg/cm^2, 3.60 kg/cm^2 and 10.63 kg/cm^2 for coal, shale and sandstone respectively increases. Higher cohesion value for concrete and sandstone interface indicates strong bonding between these two materials, possibly because sandstone being porous in nature some cement would have migrated into the pores of the sandstone leading to strengthening of the concrete rock interface. Low cohesion value of rock-to-rock contact for sandstone is possible due to presence of interbedded layer (Figure 7) of shale characterized by smooth planar surfaces.

Figure 7 Toppled sandstone interface test sample

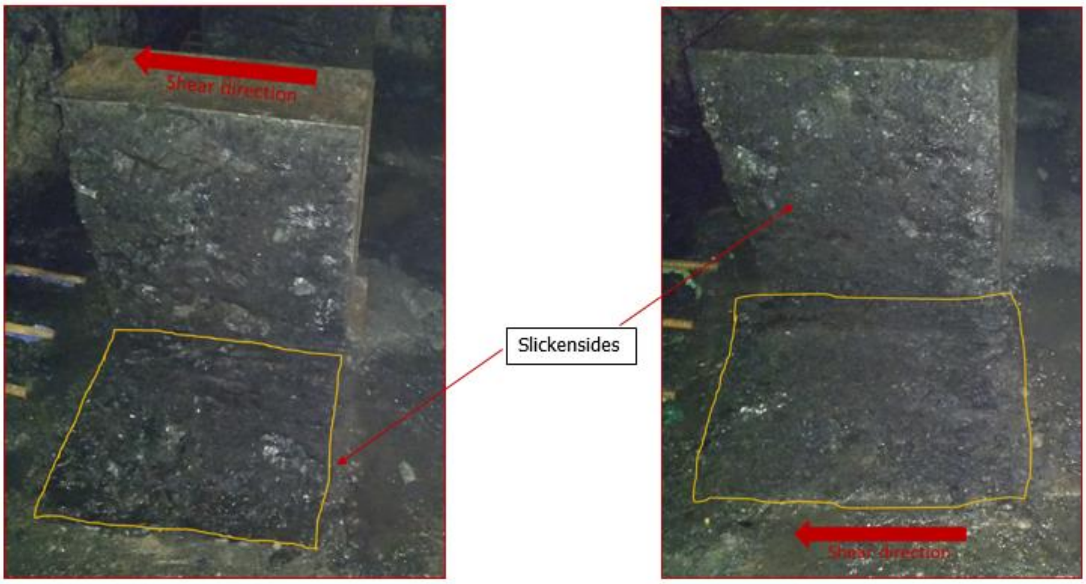


Figure 8 Toppled concrete coal interface test sample

In coal the slickensides (Figure 8) would have weakened the bonding of concrete and coal resulting in low cohesion value 2.34 kg/cm^2. In shale the surface of bedding joints is smooth and planar. Hence, the concrete to shale interface test samples have sheared at less pressure when compared to shale to shale samples.

Even though the UCS of Shale (332 kg/cm^2) is more than Coal (245 kg/cm^2) the shear parameters obtained of the later is higher (Table 4). This may be attributed to the cleats which are friable ensuing in easy rupturing along its contact with shale.

Acknowledgements:

The author is thankful to the management and ground staffs at the test sites of SAIL, Chasnalla Colliery, Jharkhand for their co-ordination and concentrated efforts. Authors are also thankful to Director, NIRM for providing permission to publish this paper.

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