CHAPTER 3

Laboratory Testing

3.1 Selection of Sites and Mines Details

The Singrauli Coalfield area has been selected for the study (Figure 3.1). It has eight huge operational opencast coal projects. The area comes under Northern Coalfields Limited (NCL). The Singrauli Coalfield comprises two separate sedimentary domains, covering an area of about 2202 sq. km. It consists of a Main basin in the western part covering an area of 1890 sq. km. The northeastern part covers an area of 312 sq. km. known as the Moher Sub-Basin. Singrauli's main basin lies in the western part of the coalfield and is largely unexplored. The NCL's coal mining activities and future blocks are concentrated in the Moher sub-basin. Most of NCL's mines use dragline and shovel dumper combinations to extract mineral resources with high production (Yadav and Hopke, 2020).

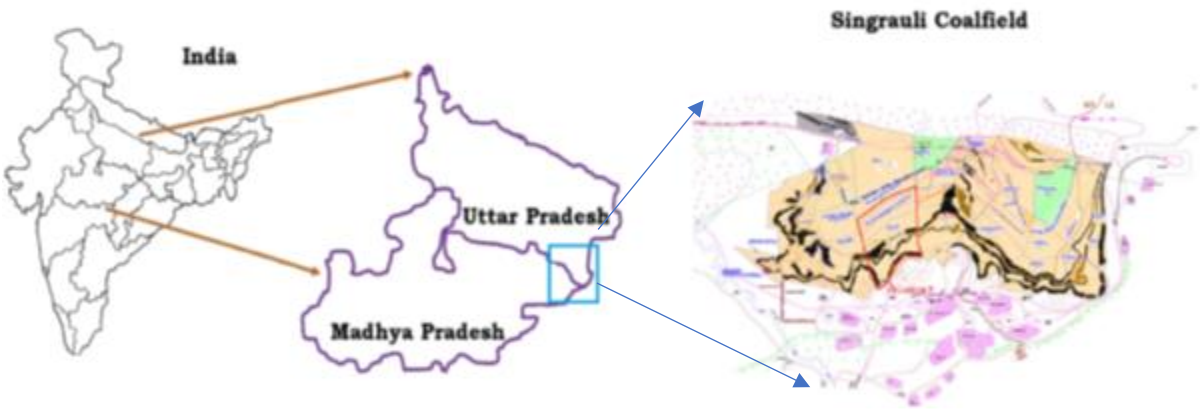


Figure 3. 1 Location map of Northern coal field limited

The amount of dipping, in general, is about 2 to 3 degrees. However, higher dips of about 8-10 have been observed in the eastern part of the basin. The lithology of the area is given in Table 3.1.

Table 3. 1 Lithology of the area

Lithology	Thickness Range (m)	
	From	**To**
Sand and subsoil	0.00	95.00
Sandstone with 2 to 3 clay bands and 1 to 2 thin impersistent carbonaceous horizons.	0.82	91.85
Coal Seam: Purewa Top	0.93	10.15
Sandstone with thin shale bands	1.29	29.35
Coal seam: Purewa Bottom	9.2	14.46
Coal seam: Purewa Merged	15.5	28.3
Sandstone with thin carb shale	55.3	77.8
Coal Seam: Turra	4.4	22.5

The coal seams in the Barakar Formation are primarily made up of coarse-grained sandstone, an arenaceous facies rock with varying grain sizes. Fine to coarse-grained, light grey feldspathic sandstone, shale, clay, and coal seams make up the majority of the Barakar series. Typically, kaolinized feldspar is used as cement. Within the upper horizon of the Barakars, there are two to three clay beds. Most of the dirt bands within the seams are made up of shale bands, typically interbedded with coal. Sandstone has occasionally been found containing thin shell bands.

The seam pattern is essentially the same throughout all mines. The two primary seams are the Purewa and Turra seams. The Turra seam is present at a depth of roughly 134 m to 313 m. Turra seam's total thickness, including all soil bands, ranges from 4.4 to 22.50 meters. Purewa seam is divided into Purewa top and Purewa bottom. The Purewa Bottom seam represents the area's middle workable coal horizon. The depth of occurrence ranges from 67.7 to 138.6 meters. In the block's northwest corner, the seam joins the Purewa top seam. The Pure Bottom seam's total thickness, including all dirt bands, ranges from 9.2

to 14.46 meters. Between 55.3m and 61.78m is the separation thickness between the Turra seam and the Purewa bottom seam.

The Purewa Top Seam is thinner than Turra, and the Purewa Bottom seam and its in-crop generally occur on the plateau just above the escarpment. The outcrop of the seam is always burnt and is represented by clay/clayey soil. It overlies Purewa Bottom Seam after a parting of 30.34m to 43.70m. The Lithology of the parting between Purewa Bottom and Purewa Top seams is medium to coarse-grained sandstone. The full thickness of Purewa Top Seam, including all dirt bands, varies from 4.85m to 10.35m (Sengupta and Roy, 2015; Sengupta et al., 2016; Singh 2010).

The height of the main Overburden bench over the Turra seam is excavated and side-casted by dragline in the previous de-coaled cut. The de-coaled cut would vary from 28m to 30m at a production level of mines. The width of the cut for coal benches has been adopted as 20m width of the working bench in coal seam has been considered as 45m, while the width of the non-working bench has been kept at 25m. The slope of each bench is proposed as 70° in OB and 30^0 in coal. The overall running slope in working faces is about 15^0-18^0. Shovel-dumper overburden dumps will be formed in benches of 30m, and the slope of the Individual dump bench will be 37° (equal to the angle of natural repose of OB material). The width of the berm between two adjacent benches will be 40m. The overall slope of the dump works out to 28°. System parameters are given in Table 3.2 below.

Table 3. 2 System Parameters

SI NO.	Particulars	Unit	Overburden		Coal	
			D/L	Shovel	Shovel	Surface Miner
1.	Bench Height	m	28-30	15-18	10-15	0.25-0.35
2.	Working Bench Width	m	120	57-63	45	60

3.	Non-Working Bench Width	m	40	37-43	25	60
4.	Bench Slope	Deg.	70	70	80	80
5.	Blast Hole Dia	mm	311	250	160	-
6.	Inclination of Boreholes		Inclined	Vertical	Vertical	-

3.2 Data collection and In-situ field testing

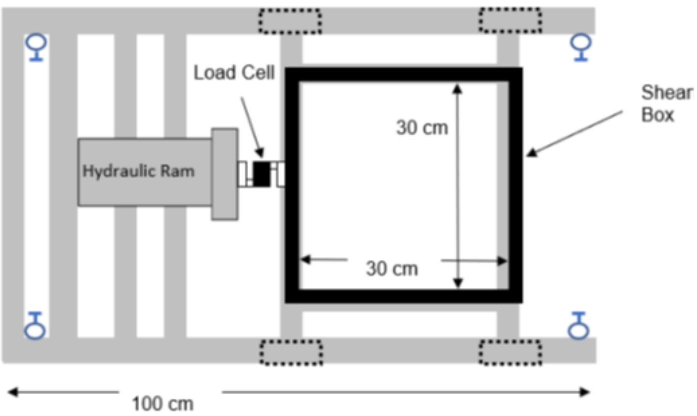
3.2.1 Sample collection from mines

Four mines have been selected for data and sample collection, i.e. Dudhichua, Jayant, Nigahi, and Amlohri. The overburden sample has been collected from different places in the mine of the overburden dump at the dragline sitting level. 10 to 15 kg of overburden samples have been collected in one tightly packed bag. Care has been taken to collect enough samples to represent the various conditions of strata in the mines. A total of 10 bags have been taken from individual mines. The overburden samples are brought to the Department of Mining IIT (BHU) laboratory in tightly packed condition (to avoid contamination or moistening). Representative samples were then prepared by coning and quartering in the laboratory for analysis. Moisture content and bulk density have also been measured in the field to prepare the sample in the laboratory at the same compaction and moisture content.

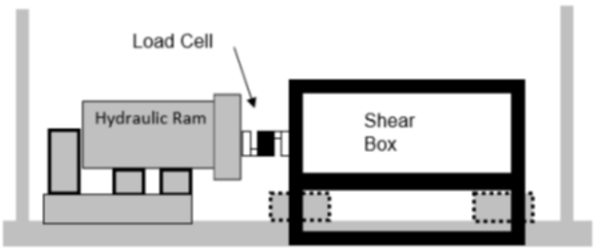
3.2.3 Shear strength

Shear strength is the most important parameter for the stability analysis of dump slopes. The loose and broken material usually has very low cohesion. However, it gets compacted gradually, and consequently, its cohesion increases. The gradual increase of cohesion depends on many parameters such as the weight of overlying strata, water and moisture content, type of dump material with its characteristics, etc. The large size of the shear box instrument has been fabricated in the department to determine the shear strength of dump material.

Figure 3.3 shows the Field Shear Box (FSB). It has been made in three parts: Frame with lower shear box, upper shear box, and loading device. The shear box has been kept cubical with two parallelepipeds, each with a size of 0.3 m x 0.3 m x 0.15 m. The box's lower and upper parts have an open top and bottom. A plate of the size of the internal dimensions of the shear box has been placed on the top of the sample. It has been used to apply the normal load on the sample. The open parts of both the boxes have been forced to slide with respect to each other so that the material fails at the interface of the two parts. This box is made of a thick iron sheet of 0.005 m thickness. The frame has been constructed as shown in Figure 3.2. The shear box containing the sample has been kept at the lower level, whereas the hydraulic ram is placed at a higher level of the frame. The total length of the frame is 1 m. The hydraulic ram has been attached to apply horizontal forces at the upper shear box. The lower shear box has been firmly secured with a frame by nuts and bolts, whereas the upper shear box is free to move. A load cell has been placed between the hydraulic ram and the shear box. It directly gives the load when applied



(a). Plan



(b). Side View

Figure 3. 2 Small In-situ Shear Box Instrument (SISBI)

Figure 3. 3 Field Shear box with load cell and data logger

3.2.2 Sample preparation in the in-situ condition

The area in the dump site has been selected for the in-situ sample preparation and testing. The area of 0.3 m x 0.3 m has been marked on the surface. A square box of 0.3 m x 0.3 m has been kept on the testing surface. The area around this rectangular box has been dug, and the muck was removed very carefully with the help of small hand equipment. The rectangular box slides downward as the ground has been cut around the sample. This process prepares a sample size of 0.3 m x 0.3 m x 0.15 m, as shown in the Figure 3.4. A 0.5 m wide, 1.0 m long, and 0.3 m deep trench has been prepared in the final arrangement.

The sample lies slightly at the end side, as shown in Figure 3.4. The hydraulic jack has applied the horizontal force, and the generated shearing resistance and displacement have been noted down by the data logger. The setup is placed on the sample prepared in the field so that the open box can slide. The sample is prepared, and the equipment is ready for the test.

The debris of the sheared sample and the testing equipment has been removed after the completion of testing. The trench has been made even and flat by removing and cutting undulating surfaces, if any. The square iron box used above is put again on the sample surface to prepare a new sample. Care has been taken that the new sample to be prepared is just vertically below the one tested above. The area around this rectangular box has been dug, and the muck is removed carefully with the help of small hand equipment, as discussed above. The new sample, thus prepared, is again tested, and shear strength is determined. This shear strength represents the shear strength of the second layer below the first layer tested earlier. After completion of this test, the third layer was tested. This procedure has been followed to 2 m depth. The cohesion and friction angle of dump material calculated is 54 kPa and 32 Degrees.

Figure 3. 4 Field setup of equipment for testing

3.3 Laboratory Testing

Samples collected during field investigation have been used in the laboratory for the identification index property (Grain size distribution, specific gravity, OMC, and MDD) and shear strength properties of dump material. The laboratory tests have been performed as per ASTM or ISRM standards. A direct shear test was conducted in reconstituted/disturbed soil specimens.

3.3.1 Specific Gravity and bulk density

The specific gravity of soil is the ratio of the mass of a given volume of the material at a stated temperature. The specific gravity of soil is used in relating the weight of soil to its volume. It is obtained using a specific gravity bottle (50ml) for fine-grain soils or a pycnometer (1000ml) for coarse-grain soil. The following formula obtains the specific gravity of soil (Gs):

$$G_S = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$$

Where W_1 (gm) is the weight of sp. gr. bottle, W_2(gm) is the weight of sp. gr. bottle + soil, W_3(gm) is the weight of sp. gr. bottle + soil + water, and W_4(gm) is the weight of sp. gr. bottle + water. The complete test procedure is in IS: 2720 part 3: Sec 1:1980.

Bulk density is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm^3. Bulk density is measured using a proctor compaction mould. The Bulk Density(γ_{Bulk}) is obtained using the following formula:

$$\gamma_{Bulk} = \frac{W_2 - W_1}{V_m}$$

Where W_2(gm) is the Weight of mold + compacted soil, W_1 (gm) is the weight of empty mold, and V_m (cc) is the volume of the mold. The complete test procedure is given in IS-2720-PART-7-1980. Table 3.3 shows the specific gravity of various samples taken from mines. The specific gravity varies from 2.33 to 2.73.

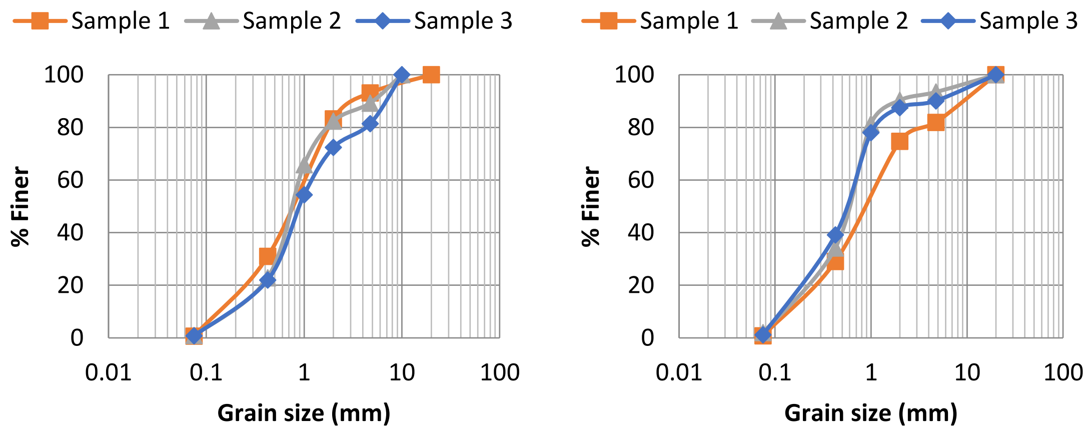
Table 3. 3 Specific gravity of samples taken from mines

Name of the Mine	Specific gravity
Dudhichua	2.33
Jayant	2.73
Nigahi	2.37
Amlohri	2.39

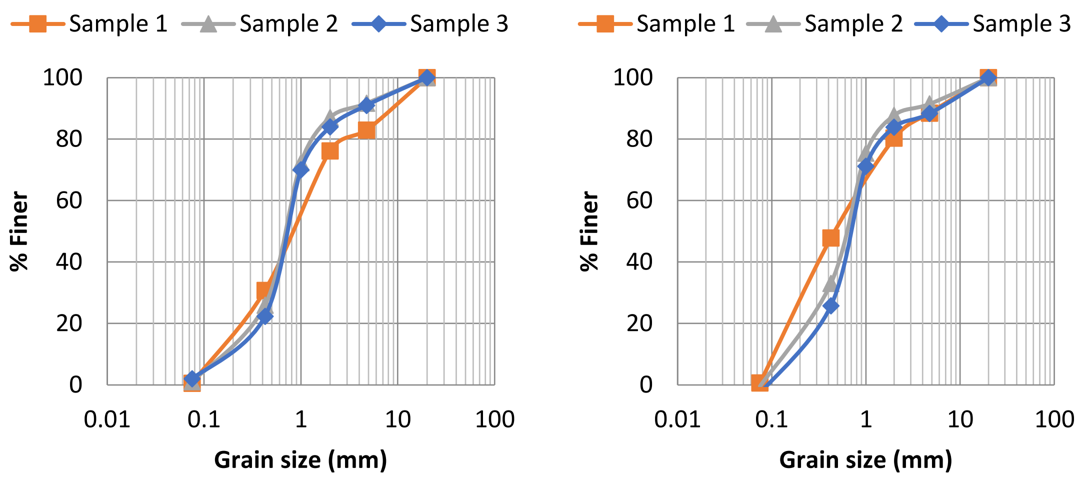
3.3.2 Grain Size Distribution

The distribution of particle sizes in soil, expressed as a percentage of the total dry weight, is known as soil gradation. It is calculated by weighing the material retained on each sieve after the material has been passed through a sequence of sieves with increasingly narrower apertures from top to bottom. Sieve analysis is performed according to ASTM standard procedure ASTM-C 136-06 (2006).

The sieves of different standard IS sizes (4.75mm, 2.00mm, 1.00mm, 425µm, 75µm) are used for analysis. Samples were placed in the top sieve (4.75mm) and covered. A receiver, a pan with no opening, was placed at the bottom of the smallest-sized sieve. The set of sieves was kept on a mechanical shaker, and the machine was started. Mechanical shaking was done for 15-20 minutes. The mass of the samples retained on each sieve and the pan was weighed, and percentages of different sizes were calculated. Figure 3.5 shows the size distribution of three samples from the overburden dump. The percentage of medium size sand has a range of 32 to 53%, fine size sand has a range of 28 to 43%, respectively, and the percentage of the fines has varied from 1 to 5% approximately.



(a) (b)



(c) (d)

Figure 3. 5 Size distribution of overburden samples of mines (a) Dudhichua (b) Jayant (c) Nigahi (d) Amlohri

3.3.3 Procter Compaction Test

The Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density (γ_d). Higher the dry density of the material, higher the stability. Determination of the relationship between the moisture content and density of soils compacted in a mold of a given size with a 2.5 kg rammer dropped from a height of 30 cm. This test is performed according to ASTM (2007) ASTM D698-07.

$$\gamma_d = \frac{W - W_m}{(1 + w) * V}$$

Where W (gm) is the weight of the mold and the soil mass, W_m (gm) is the weight of the empty mold, w (%) is the water content of the soil, and V (cc) is the volume of the mold.

After obtaining the maximum dry density for different water content, the curve (compaction curve) between dry density and moisture content is plotted to determine the maximum dry density and optimum moisture for the soil. The peak point of the compaction curve is the point with the maximum dry density γ_d. Corresponding to the maximum dry density γ_d, water content is known as the optimum water content (also known as the optimum moisture content, OMC). Figure 3.6 show the relation between water content and maximum dry density of overburden material. A list of results of OMC and MDD of different mines for different samples has been shown in Table 3.4.

Table 3. 4 OMC and OMD of Four mines of the Northern Coalfield Area

Nigahi		Jayant		Dudhichua		Amlohri	
Density (g/cc)	Water cont. (%)	Density (g/cc)	Water cont. (%)	Density (g/cc)	Water cont. (%)	Density (g/cc)	Water cont. (%)
1.96	5.8	1.86	6.3	1.83	5.6	1.91	6.5
1.99	7.6	1.98	7.8	1.90	6.4	1.97	7.9
2.03	9.7	2.01	9.2	1.98	7.4	1.99	9.4
2.01	12.1	1.94	10.8	1.97	9	1.94	11.2
1.98	14.3			1.91	10.3		

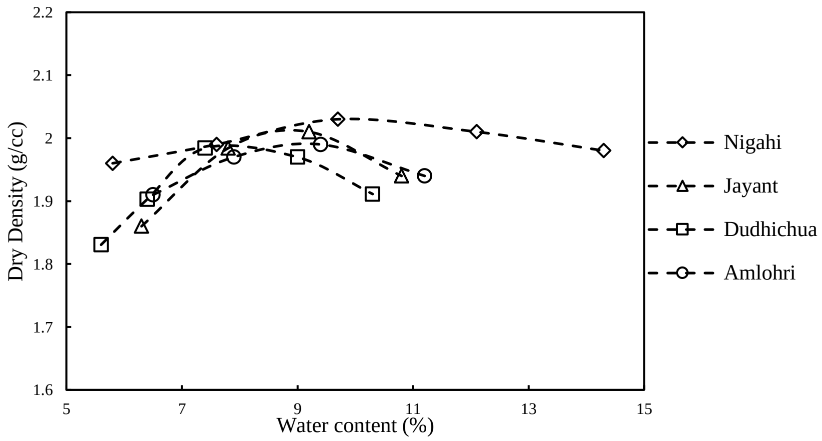


Figure 3. 6 Compaction curve of different overburden sample

3.3.4 Shear strength of dump material

Shear box is used to determine the shear strength of a soil sample. Since granular soils cannot be retrieved undisturbed, the soil is re-compacted inside a shear box. Shear strength testing is carried out to analyze short-term and long-term slope stability. The shear strength is evaluated using the Mohr-Coulomb (M-C) Failure Criterion. The M-C Criterion assumes that the shear strength depends on three factors:

1. The normal effective stress (σ_n)
2. The friction angle of the material (φ)
3. The cohesion of the material (c)

The qualitative correlation of those components is expressed as:

$$\tau = c + \sigma_n * tan(\varphi)$$

Shear strength parameters are the most crucial in deciding the stability of dump slopes. Therefore, to determine the shear strength property of the dump material, the unconsolidated undrained triaxial test is performed ASTM (2003) D2850-03, and the tri-axial samples are prepared at the respective MDD of the mines. The results of the triaxial test indicate that cohesion ranges from 28 to 56 kPa, while the friction angle ranges from 23° to 31°.

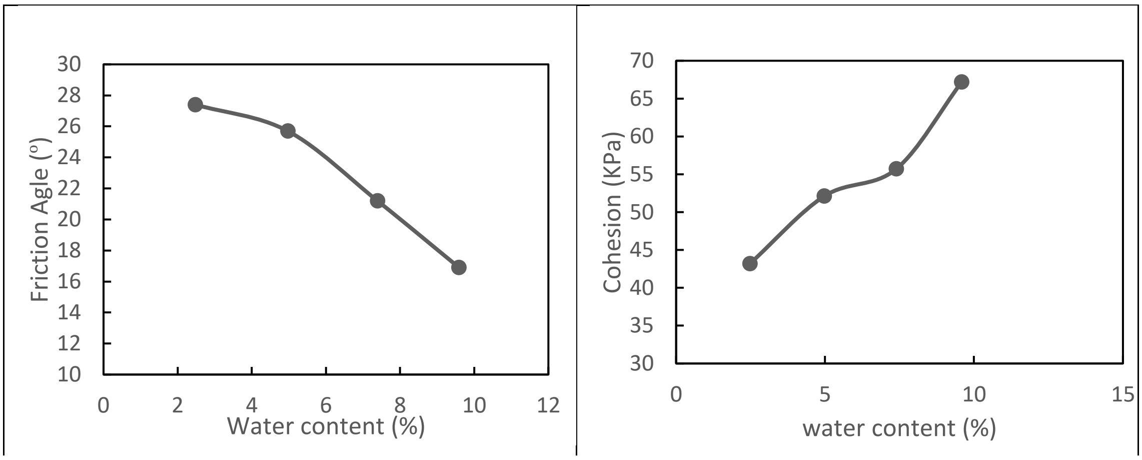
Table 3.5 shows the cohesion and friction angle of the overburden sample of four mines.

Table 3. 5 Triaxial testing of Overburden dump material

S. No.	Mine	Cohesion (kPa)	Friction Angle (°)	OMC (%)	MDD (g/cm^3)
1	Amlohri	28	31	9.2	1.99
2	Nigahi	45	26	9.7	2.14
3	Jayant	53	28	8.8	2.01
4	Dudhichua	56	23	7.8	1.98

3.3.5 Effect of water content on shear strength

The shear strength is maximum at the optimum moisture content of dump material. However, the water content often varies due to rainwater or the summer season during the dumping of overburden material in the dump. The artificial compaction methods have not been used to get optimum dry density. The heavy earth-moving machinery compacts the overburden dump, which continuously moves dump material. Various tests have been conducted to determine water content's effect on dump material.

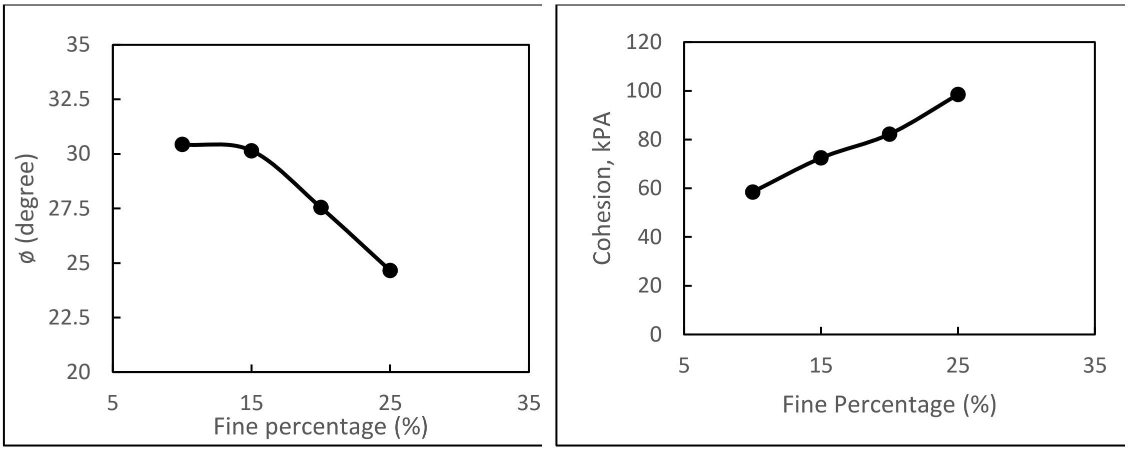


(a) (b)

Figure 3. 7 Effect of water content on (a) Friction angle and (b) Cohesion of dump material

3.3.6 Effect of fine contents on shear strength of dump material

The shear strength of soil has two components, i.e., cohesion and friction angle. The friction angle mainly depends on particle size and structure. The cohesion will mainly depend on which binding material is present in the dump/soil. The overburden dump material and the binding material are mainly clay particles. However, the clay is also reducing the friction angle of the material due to its very fine structure. Various tests have been conducted to determine clay content's effect on dump material.



(a) (b)

Figure 3. 8 Effect of varying fines on (a) Friction angle and (b) Cohesion of dump material

3.4 Discussion

Mines of Northern coalfields limited, which is in Singrauli, have been selected for the in-situ and laboratory test. Amlohri, Nigahi, Jayant, Dudhichua and Khadia opencast projects have been selected for the sampling and testing. These are the mega projects of Northern coalfield limited and the dragline dumps formed in these are huge, therefore it is very crucial to know the physico-mechanical behavior of the material.

The shear box which has been designed for the field testing is used to assess the actual strength properties of the overburden material. Along with the field testing, samples have also been collected for the laboratory testing in order to know the various other geotechnical parameters. By using the shear box, geotechnical conditions of only surface of the dragline dump could be predicted, therefore strength testing of the material was also performed in the laboratory.

In various laboratory testing, sieve analysis has been performed to assess the grain size distribution of the overburden material. The percentage of medium size sand has a range of 32 to 53%, fine size sand has a range of 28 to 43%, respectively, and the percentage of the fines has varied from 1 to 5% approximately.

Various other geotechnical parameters from the remoulded overburden material samples were obtained, which includes, optimum moisture content, maximum dry density, bulk density, cohesion and friction angle of the overburden material. Remoulded samples were tested under varying percentage fines (0%, 5%, 10%, 15%, 20%, 25%) and water content (0%, 2%, 4%, 6%, 8%, 10%) in the overburden material sample. The range of the fine percentage and water content is selected based on the laboratory investigation.

The results, which has been obtained from in-situ and laboratory testing for different geo-mechanical parameters of the overburden material shows the highly variable nature. The data obtained from the laboratory testing along with literature study have been used to perform the numerical simulation in further chapters.