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Stability Analysis of Fly Ash over Burden Backfill Structure Using Physical Modeling Techniques

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Abstract- Due to rapidly growing energy needs and the resultant rise in the use of coal to meet them, exploration and exploitation of coal resources has seen exponential growth. Global concerns about the environmental impact of coal exploitation have led to an increasing shift to open-cast mining of coal, in place of the traditional deep-pit mining. This has led to search for a suitable method of handling the large quantity of soil – termed overburden – that is a by-product of open-cast coal mining. The most practical method of disposal of overburden has been to dump it in nearby open areas, which causes concern about the stability and mechanical behavior of the resultant hillocks.

This thesis attempts a study of the operations of the open-cast mines of Singareni Collieries Company Limited (SCCL) in the Godavari Valley coalfield, which are spread over four districts of Andhra Pradesh, viz. Adilabad, Karimnagar, Khammam and Warangal. In pursuance of the objective of this study, a comprehensive field data-collection exercise was undertaken to collect details of mining practices, geology, rainfall pattern, ground water conditions and other relevant factors. This was followed by a field study, conducted to ascertain the foundation characteristics of the soil at the external dumps of the open-cast mines. Samples of soil were procured from the open-cast mines and subjected to laboratory study for evaluating the physico-mechanical and geo-technical characteristics of soil for determining various attributes such as specific gravity, bulk density, porosity, permeability, granulometric distribution of different size fractions, Atterburg's limit, cohesion, angle of internal friction, California bearing ratio etc. Numerical modeling was then conducted to determine the structural stability of dump configuration on the basis of data obtained from laboratory studies. Lastly, field trials were carried out using physical modeling, to evaluate dump stability when backfilling using an admixture of pond ash and overburden.

This study establishes the suitability of mixing overburden with pond ash due to its various advantages keeping in mind the civil engineering aspects viz. bearing capacity, geotechnical parameters etc of the mix and existing ground conditions. Additionally, since substantial quantity of pond ash gets used up in creation of admixture dumps, the extent of an ecological and health hazard is reduced. Thus, mixing pond ash to overburden prior to backfilling provides dual benefit; increase in the stability of dumps and reduction in the free quantity of an environmental pollutant.

Index Terms- Open-Cast Mining, Physico-Mechanical, Physical Modeling, Pond Ash, Overburden

I. INTRODUCTION

At present, the power sector in India is dominated by coal. Coal currently accounts for more than 50% of total primary commercial energy supply in the country and for about 70% of total electricity generation. Coal is likely to remain a key energy source for India, for at least the next few decades, as India has significant domestic coal resources (relative to other fossil fuels) and a large set of existing installed base of coal-based electricity capacity, although recent experiences have thrown into sharp relief the uncertainties and concerns regarding the adequacy of coal supplies to satisfy the growing hunger for power. At the same time, with the growth of

the coal-based power, local environmental and social challenges relating to coal mining, processing, and use are becoming more pressing.

The SCCL had put up a pioneering effort in the introduction of mechanization in coal mining industry in India. SCCL has been putting in relentless efforts to modernize the extraction technologies in its mines. Technology occupies the top position among the priorities of perspective plan which holds the key to the objectives and targets of the plan.

Ramagundam Super Thermal Power Station (RSTPS) is a coal based thermal power plant and its coal requirements are met through transportation of coal on a large scale from the nearby Singareni Collieries Company Limited (SCCL), a Government Company. The coal is transported using the MGR(Merry-go-round) system wherein, a train comes on one rail route, delivers coal and returns on another route. This thermal power plant consumes about 13 Million Tonne of coal for power generation thereby resulting in ash generation in the tune of about 4.2 Million Tonne (coal having ash content of 30 – 35%) of which about 80-82% is fly ash and 18-20% is bottom ash.

This ash is transported hydraulically at water to ash ratio of 3-4:1 to ash ponds. The ash pond consists of four Lagoons and occupies a total area of 607.04 hectares. Wet disposal of this huge amount of ash in ponds is not a cost effective method of disposal.

Ramagundem Area of SCCL has four of its largest mechanized opencast mines in close proximity to RSTPS, National Thermal Power Corporation. Out of above mentioned opencast projects of SCCL, Medapalli Opencast Project is located at close proximity (at a distance of about 30 -32 Km) to the ash ponds of RSTPS, NTPC, Ramangundam. Keeping the above facts in mind and to avail the opportunity of bulk utilization of coal ash as mine fill material/ reclamation of surface mines located in close vicinity of the power plant, a project entitled “Stability and structural evaluation of Fly Ash-Overburden backfill using numerical modeling techniques”

Table 1: List of Ramagundam Mechanized Opencast Mines

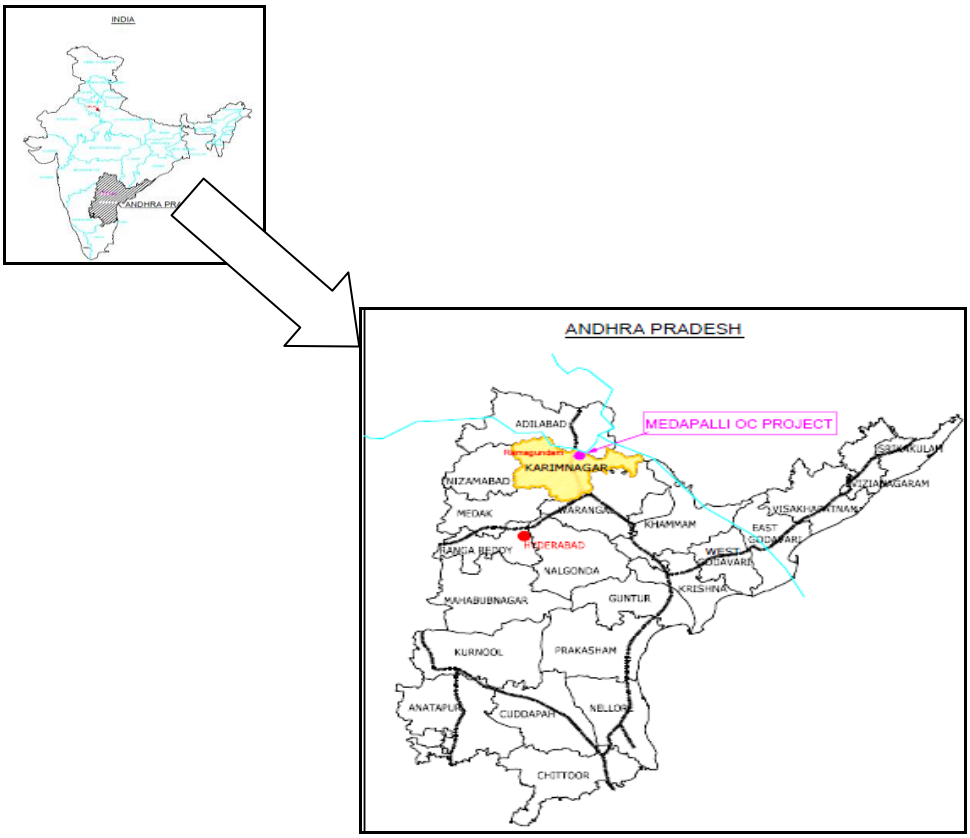
Sl. No.	Name of The mine	Coal Production(Lakh Tones/y)	O/B removal (Lakh Cu. m./y)
1	OC – I	8.87574	48.11684
2	OC – II	1.76549	6.09740
3	OC – III	6.19693	32.65048
4	Medapalli OCP	7.13894	1.24590

(*Source: http://scclmines.com/prod_report.asp area=12-Jun-2012, updated till June 2012*)

II. SAMPLE COLLECTION

A detailed survey of the ash pond of RSTPS, NTPC was carried out before uplifting pond ash samples for scientific investigation. To obtain representative samples of pond ash, an excavation of 1m x 1m cross-section up to 1m depth was made and the excavated ash was thoroughly mixed and one bag (30 Kgs aprox.) representative sample was taken after coning and quartering from each point.

A survey of external overburden dumps of Medapalli Opencast was also carried out and representative samples of soil and overburden material were collected from all the external dumps. A total of 6 bag samples of overburden material and 2 bag samples of soil were collected.



(a)

Figure (a): Map Showing the Location of OCIII Mine

(1) METHODOLOGY

The methodology adopted to accomplish the objective of the project is given below in chronological manner:

(a) Sample collection

(b) Laboratory study to evaluate the physico-mechanical/ geotechnical characteristics of pond ash and overburden material which includes determination of specific gravity, bulk density, porosity, permeability, granulometric distribution of different size fractions, Atterburg's limit, cohesion, angle of internal friction, California bearing Ratio etc.

(b) Field data collection regarding mining details, geology, rainfall pattern, ground water conditions etc.

(c) Field study to determine the foundation characteristics of the soil at the external dumps of Opencast Mines.

(d) Numerical modeling to determine the structural stability of dump configuration/stability with pond ash and overburden on the basis of data obtained during laboratory studies.

(e) Field trials to carry out physical modeling to evaluate dumb stability when backfilling with pond ash overburden admixture.

(2) PHYSICAL CHARACTERISTICS

The physical characteristics of ash depend on the quality/rank of coal used, degree of pulverization, furnace temperature, its chemical composition etc. Similarly, physical characteristics of overburden are mainly influenced by the geology of the area, mining method adopted, general topography etc. Storage, transportation, re-handling and reclaiming of pond ash and overburden material at opencast

mine have been found to be greatly influenced by physical characteristics viz., specific gravity, bulk density, porosity, angle of repose, permeability, compressibility, granulometric distribution and other geotechnical parameters.

Hence, the physical properties of pond ash samples of RSTPS, NTPC and Medapalli, SCCL were tested at CIMFR.

(3) PHYSICAL MODEL STUDY FOR BACKFILLINGPOND ASH – OVERBURDEN ADMIXTURE AT MEDAPALLI, SCCL

Survey of the area near external dumps of Medapalli was carried out by CIMFR scientists to select the site for carrying out model studies on backfilling using pond ash – overburden admixture in the ratio of 1:4 by weight. A suitable site at the dip side of the CHP near the water discharge point of the mine was selected.

KEY

1 – 1.5m high overburden, 2 – 0.5 m high pond ash, 3 – 0.5 m high overburden

H – Total height = 2.5m, L – Dump length = 12m, W– Dump width = 10m

Slope angle of the dump = 37^0

The model study was planned to be carried out in stages. It was decided to dump a layer of overburden at the base of the model followed by a layer of pond ash and subsequently another layer of overburden. The volume of pond ash and overburden dumped in the model study is in the ratio of 1: 4, i.e. 108 m^3 of overburden and 26m^3 of pond ash. The top two layers of overburden and pond ash was mixed properly and leveled by means of a dozer.

To assess the effect of water on the dump stability, it was decided to sprinkle water on it and observe the dump behavior. Hence, a water sprinkler truck having a capacity of 28 Lakh liters was allowed to mover over the model dump from the model study it was observed that the fines were slowly coming out of the dump resulting in creation voids at some locations. At some places it has been observed that there were minor movements of the OB due escape of ash from the dump. Based on this it is concluded that the escape of ash along with water must be restricted.

(4) MINING DETAILS

Table 2: Envisaged Mining Schedule of Medapalli, SCCL

	Year	**Year**	**Coal by Shovel – Dumper Combination (Mt)**	**Coal by High Wall Mining (Mt)**	**Total Coal (Mt)**	**OB (M.Cum)**	**SR (Cum/T)**
Excavated Quantities	Upto 2006-07		11.83			78.17	6.61
Balance Quantities As per	2007-08	1	2.50		2.50	16.25	6.50
	2008-09	2	3.00		3.00	17.50	5.83
	2009-10	3	3.00		3.00	18.25	6.08

FR of Medapalli OCP expansion	2010-11	4	3.00	0.97	3.97	17.79	5.93
	2011-12	5	3.00	1.09	4.09	18.82	6.27
	2012-13	6	3.00		3.00	18.70	6.23
	2013-14	7	3.00		3.00	18.93	6.31
	2014-15	8	3.00		3.00	18.92	6.31
	2015-16	9	3.00		3.00	18.53	6.18
	2016-17	10	3.00		3.00	16.50	5.50
	2017-18	11	3.00		3.00	15.15	5.05
	2018-19	12	3.00		3.00	14.40	4.80
	2019-20	13	3.00		3.00	13.85	4.62
	2020-21	14	3.00		3.00	13.50	4.50
	2021-22	15	3.00		3.00	13.45	4.48
	2022-23	16	2.82		2.82	13.23	4.69
		Total	47.32	2.06	49.38	263.77	5.57
Total			59.15		61.21	341.94	5.78

The estimated Geological reserves in Medapalli block are 68.05 Mt. The total mineable reserve including proposed high wall mining is 61.21Mt. OC-3 OCP is presently working with Partial hiring option i.e. the Overburden removal is by hiring of HEMM and the coal is by departmental equipment i.e., with 2.8 Cum Hydraulic backhoes in combination with 35T dumpers with targeted production of 3.0 Mt. per annum. The life of mine with this targeted production since its inception is 29 years (final year of operation is 2022 – 23).The mine does not provide for internal dumps since high wall mining is introduced for the first time in India to extract the coal reserve locked up in the high wall faces. Envisaged mining schedule including High wall Mining reserves as given in Table 2. The Mining area is divided into two quarries i.e. Quarry-I and Quarry-II. The Mining operations will be carried out in both the quarries till end of life of the project.

Table 3: Planned Dump Configuration

Parameters	**Dump yard No.1**	**Dump yard No.2**	**Dump yard No.3**
Total Area (hectares)	88.62	242.03	93.65
Dump height (m)	90	90	90
Quantity (M.Cum.)	40.678	119.154	72.09
Top RL (m)	930	930	930

Slope angle (degree) Individual deck	37	37	37
Slope angle (degree) Overall	27	27	27

Dumping strategy includes separate spoil dumps for Topsoil and other Overburden. There are three external dumps. Dump yard-1, Dump yard-2 and Dump yard-3 for Overburden and three topsoil dumps i.e., BC dumpyard-1, BC dumpyard-2 and BC dumpyard-3. The maximum height of topsoil dump is planned to be 10m. The overburden dumps is planned for a height of 90m in three decks of 30m each with 30m berm width for allowing safe transport. Dump slope for each deck is as per the natural angle of repose of 37 and overall slope is 26. Details of planned dump quantities with dump configuration are given in Table 3.

(4.1) SUBSOIL CHARACTERIZATION

Soil characterization and classification is of utmost importance when dealing with engineering problems as it act as a language of communication. Classification of soil will help grading them to be used for specific engineering project according to their merit. For this, soil core samples were collected from 3 boreholes (BH 3, BH 4 and BH 5) drilled near Dump yard No.3 and 2 during previous study carried out at MOCP. The core collected from the sampling boreholes was analyzed for Index properties which are given in Table 4.

Table 4: Index Properties of Medapalli Opencast Soil Sample, SCCL

Depth (m)	Borehole Number	Soil Description / Classification	Water Level (m)	Index Properties					Grain Size Analysis (%)				
				Natural Moisture Content (NMC), %	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index.	Free Swell Index, %.	Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt & Clay
3.0	BH4	Brown Silty Sand (SM)	3	18	35	16	19	33	7	21.5	14	19	38.5
4.5	BH4	Black Medium Sand		10	Non Plastic				1	28	71	-	-
6.0	BH4	Black Clay (CH)		20.5	51	22	29	60	3	1	22	12	62
7.5	BH4	Brown Medium Sand		-	Non Plastic				21	20	46	13	-
9.0	BH4	Brown Medium Sandy Gravel		-	Non Plastic				34	22	44	0	-
13.5	BH4	Whitish Medium Sand		-	Non Plastic				5	20	41	33	1
6.0	BH3	Brown Sandy Gravel	3	18	Non Plastic				46	22	28	4	-

8.5	BH5	White Medium Sand	3.5	-	Non Plastic	28	17	38	17	-

(4.2) TOPOGRAPHY DRAINAGE AND RAINFALL

The area forms the southern bank of the Godavari River and is characterized by flat to gently undulating terrain with general elevation varying from 130m to 140m above mean sea level with a gentle slope towards south East. River Godavari forming North Eastern boundary of the block, drains the area along with its ephemeral tributaries. The highest Flood Level of Godavari River was recorded as 138.55m above MSL (Corresponding to 838.55m of assumed Level) during the monsoon on 20.10.1995. Large portion of the block is covered under this HFL of the river.

The slope stability of any opencast mines is critically influenced by the infiltration of rainwater into the slopes and consequent buildup of the pore water pressure. In order to understand the rainfall pattern at MOCP, SCCL, rainfall data for the last four years (2008 -11) were analyzed to know the general trends. The month-wise rainfall data for the last four year is depicted in Fig. 1.

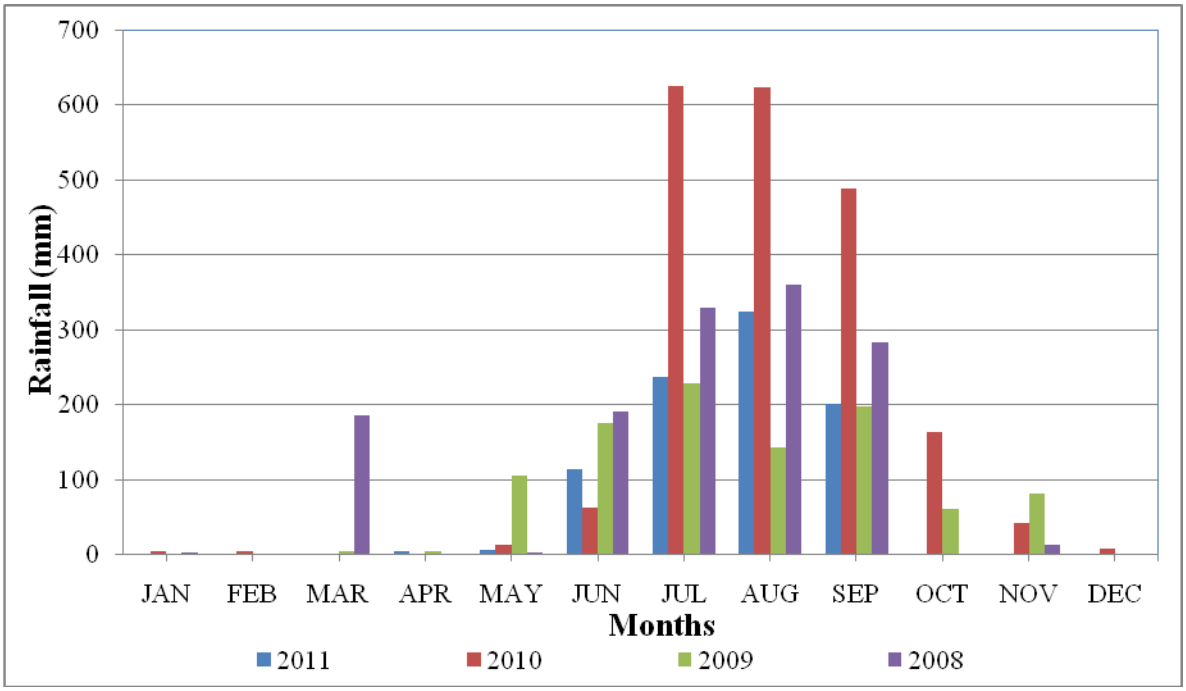


Fig. 1: Rainfall Pattern for the Last Four Years (2008 – 2011)

Fig. 1 indicates that the rainy season of this region is mainly spread over a period of four months mainly between June and September. The maximum monthly rainfall during this period is 625.25mm (July, 2010), while the minimum monthly rainfall is 62.55mm (June, 2010). The annual rainfall for the last twelve years (2000-12) is show in Fig.2

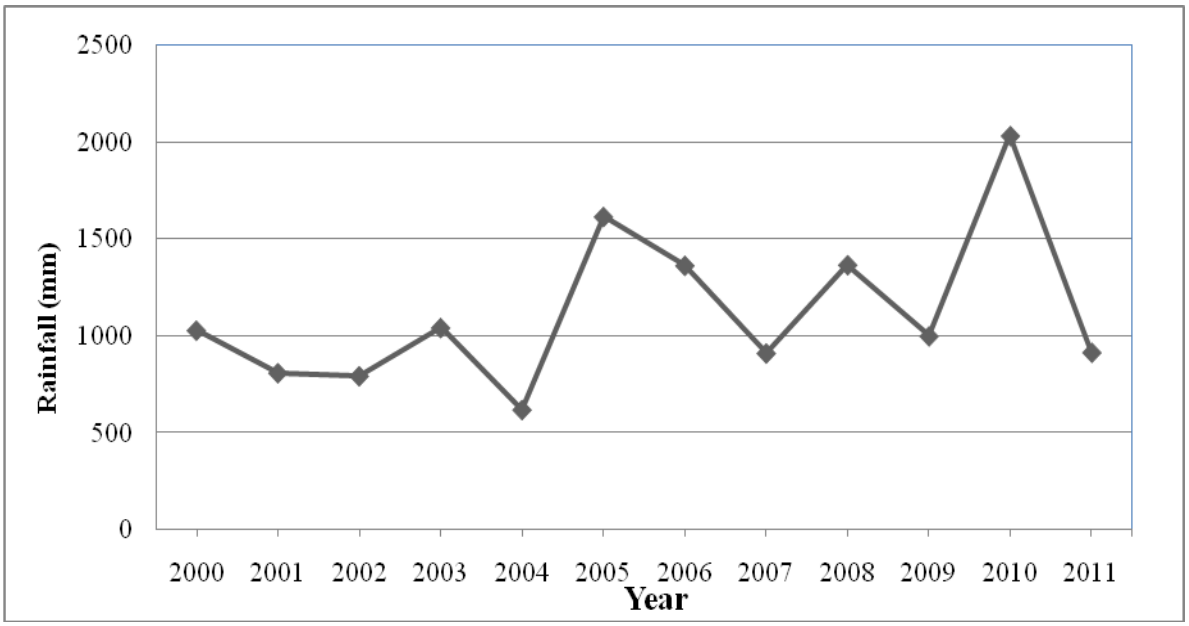


Fig. 2: Annual Rainfall over the Last Twelve Years

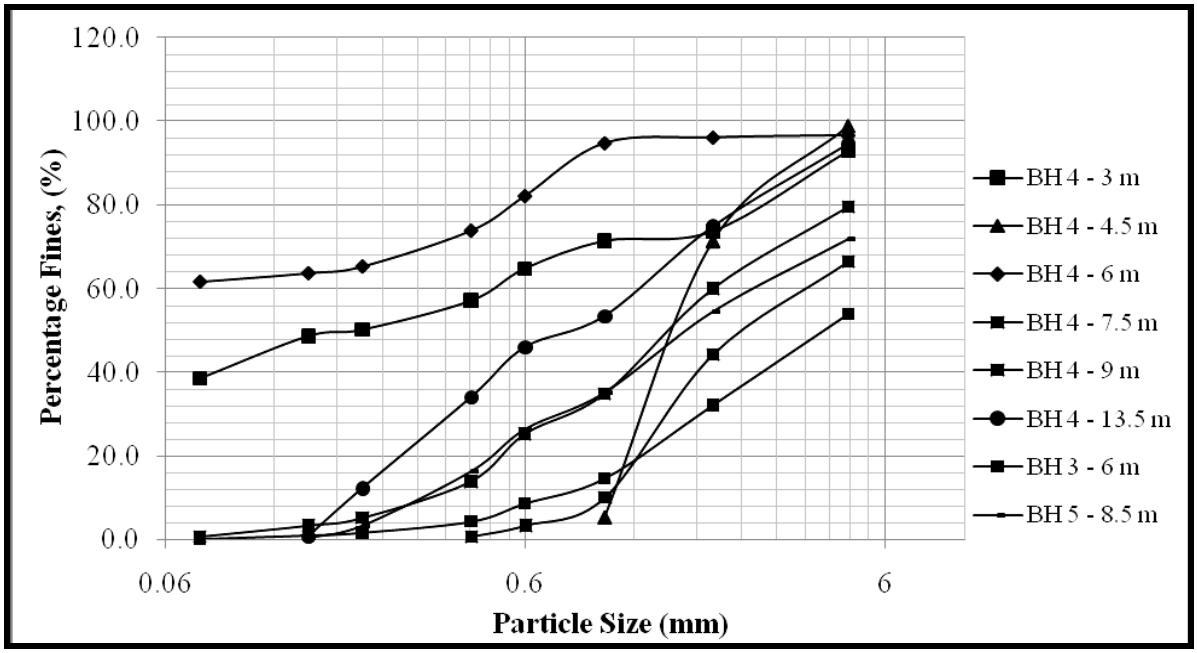


Fig. 3: Grain Size Distribution of Medapalli Soil sample

The grain size distribution of the core sample was also carried out and the results are shown in Fig. 3. The grain size distribution has a flat curve which indicates that the soil is well graded and will offer more resistance to displacement and settlement than one with uniformly graded particles.

III. RESULT AND DISCUSSION

From the results of laboratory investigation, physical modeling and model study carried out in field, following inferences and recommendations can be drawn.

- The specific gravity of RSTPS pond ash has been found to be 1.99, which means that it is about 27% lighter than overburden (Avg. Sp.Gravity 2.54) therefore the energy requirement for its transportation by any means (mechanical or hydraulic) will be less.

  The bulk density of ash overburden admixture was found to decrease with the increase in percentage of pond ash content and then it becomes constant at 40% pond ash. This indicates that with the increase in ash content the density and therefore the strength of backfill admixture decreases. This also indicates that more volume of ash –overburden admixture can be stored in pre-defined area when compared with overburden alone.

- From the grain size analysis it was found that 19.2% of overburden representative sample and 9% of pond ash particles are below 106 micron size and fines (< 20 microns) are found to be 2% for overburden and 3.2% for pond ash under scrutiny. The C_u and C_c value of pond ash indicates that it is uniformly graded, whereas for overburden samples it indicates that they are well graded. The grain size distribution of soil samples have a flat curve, which indicates it is well graded. A well graded soil and will offer more resistance to displacement and settlement than one with uniformly graded particles, therefore it can be concluded pond ash alone will be more compressible then overburden material, foundation soil as well as ash – overburden admixture.
- The permeability of water through the fill packed mass of pond ash and overburden was found to be less for over overburden material alone, but it was found out that with the increase in the pond ash percentage in the backfill admixture the value of "k" also increases. The natural angle of repose was found to be about 35^0 for overburden material alone, but it decreases when pond ash is added to it. From the above observation two conclusions can be draw, firstly that addition of overburden material to pond ash increases its porosity and therefore is permeability and secondly, there is a decrease in angle of repose of the pond ash – overburden admixture due to decrease in particle size gradation and therefore this will result in reduction in its strength characteristics.
- The Results of Liquid limit and plastic limit test carried out on overburden, pond ash, pond ash-overburden admixture in different percentage indicated that they are non-plastic in nature, but for soil samples it was found that Brown Silty Sand and Black Clay portion of core exhibits plasticity. Direct shear test results indicated that the cohesion increases with the increase in pond ash percentage of the admixture up to 30% which indicates that the calcium content of pond ash increases the cohesive strength of the admixture.
- The compressibility of MOCP overburden was found to highest (15.45 %) followed by RSTPS pond ash (12.68%) at the pressure of 90 Kg/cm^2. But when pond ash is mixed with overburden at a ratio of 1:3 the compressibility decreases slightly (14.52%). A marginal decrease in compressibility was observed as ash increases the density of the fill (acts as a filler material).
- The foundation characteristics at MOCP was determined by carrying out Standard Penetration Test (SPT) at the selected site for a depth of 1.0 m, 2.0 m and 3.0 m. and the ultimate safe bearing capacity of ground was found to **647.845 kN/ m^2 (or) 64.78 t/m^2**. From the calculation on bearing capacity it was concluded that ground possessing a bearing capacity of **64.78 t/m^2** can store following quantity of pond ash – overburden admixture :

  BD = bulk density

Parameters	Total Area (hectares)	Quantity (M.Cum.) ash – overburden admixture	
		20% Ash (BD = 1.63 T/m^3)	30%Ash(BD=1.48 T/m^3)
Dump yard No.1	88.62	35.21	38.78
Dump yard No.2	242.03	96.18	105.93
Dump yard No.3	93.65	37.22	40.99

- Stability analysis to optimize bench configuration for ash-overburden admixture was carried out by using numerical modeling. The study involved carrying out in detail slope stability analysis in terms of angle of slope, height and berm with. The study was done using Bishop's slip circle analysis. The stability analysis was done for benches of 30m height and width of 30.0m in three decks for overall dump height of 90.0m. A factor of safety of about 1.15 - 1.2 is considered for formulating slope designs. Based on the stability analysis results, the following bench configuration for backfilling in external OB dumps of MOCP are recommended for two different pond ash – overburden admixture having an overall height of 90m.

Mix ratio	Bench configuration		
	Slope angle (degree)	Deck height (m)	Berm width (m)
20% Pond ash + 80% MOCP Overburden	30 - 32	30	30
30% Pond ash + 70% MOCP Overburden	28 - 29	30	30

- From the physical model study undertaken at MOCP, it was observed that the fines were slowly coming out of the dump resulting in creation voids at some locations. To avoid such fiasco it suggested that the dump should be made in such a form that there is no direct contact of ash material will water as it will lower the cohesion and stability. Following recommendation is made regarding dumping pond ash along with overburden.
  - Pond ash may be dumped randomly in stages such that alternate layer of ash and overburden is formed. The total height of the deck should be 30 m and in each deck alternate layer of ash and OB of 5 meters height should be dumped. After the completion of the 1st stage of dumping. Dozing, compaction and leveling is required to be done (by dozers) so as to mix the ash and overburden as thoroughly as possible. Similarly, subsequent stages are formed so as to attain a total height of 5m to complete full deck of dump.
  - Dumping of overburden alone is to be carried out to ensure that the ash-OB admixture is totally covered and protected from the OB dumps all-around. At the top of the dump i.e. at the finishing stage, the dump shall be covered with 2m thick soil and adequately compacted by dozing.
  - The sides of the OB dumps shall be kept benched and height thereof shall not exceed 30m at an angle of slope not exceeding the angle of repose of the dumped materials viz. 28^0, as obtained in the laboratory for mixtures of 25% RSTPS pond ash and 75% MOCP overburden

- Width of the OB dump shall not be less than 30 m which shall also be compacted. The benches shall be laid in such a manner that the overall slope of the dump shall not exceed 21^0 from horizontal.

IV. CONCLUSION

Geotechnical tests were performed for the coal mine refuse samples of different mines to evaluate the suitability as filling material. These tests include CBR, Standard Proctor Compaction test, Direct shear test, Permeability test and Atterberg limits test. From the result of these tests it may be concluded that mixing of fly ash can be used for the purpose of backfilling without much treatment. Dumping of overburden alone is to be carried out to ensure that the ash-OB admixture is totally covered and protected from the OB dumps all-around. Width of the OB dump shall not be less than 30 m which shall also be compacted. The benches shall be laid in such a manner that the overall slope of the dump shall not exceed 21^0 from horizontal.

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