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Utilisation of Fly Ash and Coir Geonets in Improving the Geotechnical Properties of Clayey Soil

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***Abstract*: Since last many decades as well as in upcoming decades, India is predominantly dependent on coal based power plants for electricity generation. The average fly ash produced is between 35-38% by weight of Indian coal burnt. 184.14 million tons of fly ash was produced for the year 2014-15, of which only 55.69% was utilised. Hence, a huge amount of fly ash is yet to be consumed. Further, fly ash possesses toxic threat to our health as well as environment. Thus, its proper disposal becomes very much essential for the mankind. Since past few years, many attempts have been made to utilise the fly ash in stabilising the soil. Also, coir fibre is a natural waste available in abundance nearby holy cities of India. The annual coir production by India is approx. 150,000 tons. Present article features the experimental study on the utilisation of fly ash and coir geonets in locally available soil and to analyse the changes occurred in the geotechnical properties of the selected soil.**

Keywords: Fly ash, clayey soil, sieve analysis, OMC-MDD, hydrometer test, CBR test, falling head permeameter test

I. INTRODUCTION

Management of fly ash at coal/lignite based thermal power stations in the country is a challenging task in view of large quantity of ash being generated and targets of achieving 100% utilization of fly ash in time bound manner as prescribed in MoEF Notification of 3rd November, 2009. The land for creating ash dykes for ash disposal facilities at thermal power plants is becoming difficult to be acquired. Fly Ash Mission, a Technology Project in Mission Mode of Government of India was commissioned during 1994 as a joint activity of Department of Science & Technology (DST), Ministry of Power (MOP) and Ministry of Environment & Forests (MoEF) with Department of Science & Technology as nodal agency. The Fly Ash Mission was set up to promote research in the area of fly ash utilization so that fly ash could be gainfully utilized instead of its disposal in ash ponds. MoEF & CC has issued draft notifications on 25.05.2015 with a view to enhancing fly ash utilization. These initiatives and policy decisions by Government of India have led to increased utilization of fly ash in various construction activities like making of fly ash based building products, manufacturing of portland pozzolana cement, construction of roads/highways/flyovers, reclamation of low lying areas, back filling and stowing of mines, waste land development, construction of Roller Compacted concrete dams etc. Though, in 2014-15, the ash utilization level has reached to about 55.69% (102.54 MT) of total amount of fly ash generated during the year as compared to less than 10% (6.6 MT) of the ash generated during the year 1996-97, a lot more needs to be done.

Similarly, the annual production of coir is approx. 150,000 tons by India. Also, coir fibre is a natural waste available in abundance nearby holy cities of India. Coir is used in various forms and shapes such as randomly distributed fibres, geo-nets, geo-foams, geo-sheets, etc. This article presents the experimental study of the combined effect of fly ash and coir fibre on the geotechnical properties of locally available clayey soil.

II. LITERATURE REVIEW

Among the different studies available, few major research works carried out in this field has been discussed as below:

1. M. Michael, P. Vinod (2009) examined the beneficiaries of various coir geo-textiles to reinforce the sub-grade. Soaked California Bearing Ratio tests were conducted on reinforced and unreinforced soil. The effects of placement position and stiffness of geo-textile on the performance of reinforced sections were examined using five different types of geo-textiles. The maximum CBR improvement ratio is found to be in the range of 1.37 to 1.97 times for different varieties of coir geo-textiles tested.
2. K. Meshram et. al. (2013) proposed the construction of rural roads using geo-textiles. Specifically coir as a geo-textile material is proposed with three different grades as per BIS that are grade 1: 400 GSM, grade 2: 700 GSM, grade 3: 900 GSM respectively. Also, the placement of coir geo-textiles in embankment length was specified such as at depth one-third, one-half and two-third respectively.
3. S. K. Singh, S. M. Arif (2014) conducted an experimental study on local soil i.e. silty sand (SM)

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mixed with varying percentage of coal ash and coconut coir fibre. Unconfined compressive strength (UCS) and California bearing ratio (CBR) tests are conducted on the soil mixed with coal ash/coir fibre/ both. The percentage of coal ash by dry weight of soil is taken as 20%, 30%, 40% and 50%. A significant increase in UCS and CBR value is observed for addition of 20% of coal ash in the soil. UCS value is maximum (1.81 kg/cm^2) for 20% coal ash mixed with soil. The un-soaked and soaked CBR values as 10.5% and 5.6% increase to 27.7% and 14.6%, respectively. Rate of increase in CBR values decreased after further addition of coal ash beyond 20%. Randomly mixed coconut coir fibre is included in optimum soil-coal ash mix (i.e. 80% soil and 20% coal ash) and varied as 0.25, 0.50, 0.75 and 1.0%. UCS value increases substantially with inclusion of coconut coir fibre in soil - coal ash mix. The optimum percentage of soil-coal ash-coir fibre mix is arrived at 79.75:20:0.25 (by weight).

4. R. P. Abhijith (2015) carried an experimental study on the utilization of natural coir fibres on unpaved roads. CCM-400 coir geo-textile which is a woven type coir mat was placed at one-fourth, one-third, one-half, two-third and three-fourth positions from the top of soil sample and CBR test were conducted. The results concluded that placing geo-textiles at two-third depth seems to be more effective.

Based on the literatures available, the present paper focus to study the effect of replacement of clay soil by fly ash experimentally and further changes due to placement of coir geo-nets at variable depths.

III. MATERIALS USED

Three different materials, mainly soil, fly ash and coir geo-nets are used for the present study. The soil is obtained from a site situated in Lambhua taluka, Sultanpur (U.P.). The fly ash used is obtained from NTPC - Tanda, Akbarpur (U.P.). Coir was obtained from Mandvi market of Vadodara city (Gujarat) which was then transformed into coir geo-nets as per the specified IS code. All the experimental data has been obtained by conducting laboratory tests in Civil Engineering Department, KNIT Sultanpur. The data has been obtained as per the standard procedures as prescribed in respective IS codes.

The experimental data for various tests performed on selected soil are shown in Table 1. It is clear from the table that the soil is of CI group as per IS: 1498 – 1970 which can be commonly called as silty clay of medium plasticity. CBR value of the soil is as low as 3.72 and is a weak soil. The permeability value ranges between 10^{-7} mm/s to 10^{-6} mm/s showing poor drainage property.

TABLE 1: PHYSICAL PROPERTIES OF SOIL

Sr. No.	Soil Properties	Corresponding Values
1	Specific gravity	2.727
2	Gravel-sand	13.78%
	Silt	41.62%
	Clay	44.60%
3	Liquid Limit, LL	37
4	Plastic Limit, PL	26
5	Plasticity Index, PI	11
6	Soil Classification as per IS: 1498-1970	CI (Silty clay of medium plasticity)
7	OMC	16.97%
	MDD	1.693 g/cc
8	CBR value	3.72
9	Permeability, K	4.94×10^{-6} mm/s

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The particle size distribution of the selected CI soil is shown in Figure 1.

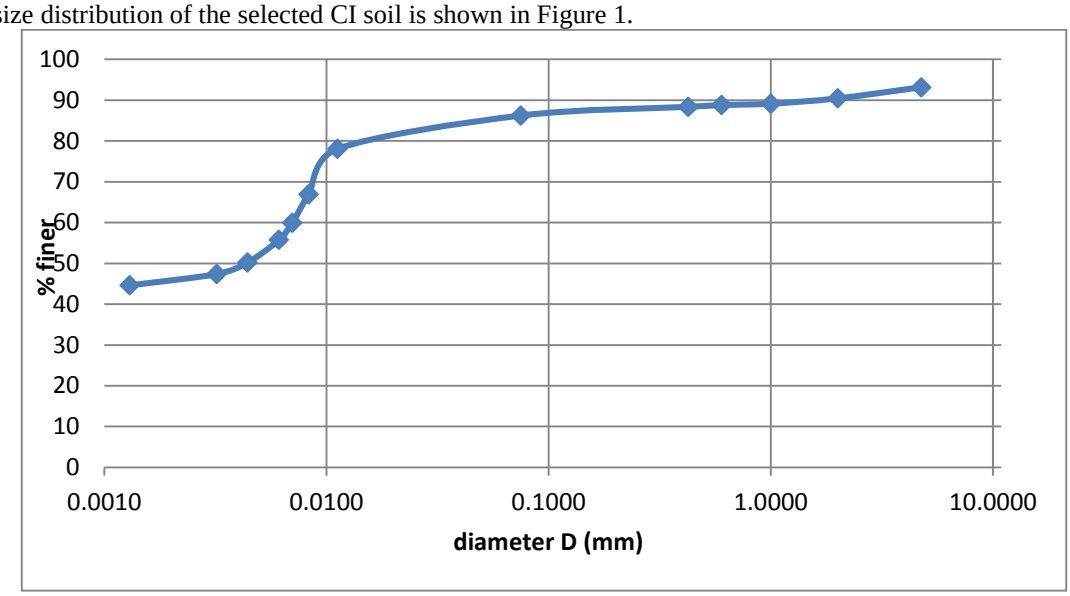

Figure 1: PSD curve for the soil used

Fly ash properties can be mentioned as below:

Table 2: Fly ash properties

Properties	Value
Sp. Gravity	2.027
LL	Non-plastic
PL	Non-plastic
OMC	20.08%
MDD	1.412 g/cc
Colour	Grey

Coir geo-nets are available in 3 different mass densities as per BIS i.e. grade 1: 400 GSM, grade 2: 700 GSM and grade 3: 900 GSM respectively. Standard Code referred for coir bhoovastra is IS: 15869-2008.

IV. EXPERIMENTAL TESTS METHODOLOGY

A work schedule was prepared, accordingly tests were carried out to analyse the effect of fly ash and coir geo-nets on the different properties of soil. The work plan can be briefed as under:

Mix proportions adopted for soil: fly ash (FA) mix:

1. FA: Soil = 00%: 100%
2. FA: Soil = 04%: 096%
3. FA: Soil = 08%: 092%
4. FA: Soil = 12%: 088%
5. FA: Soil = 16%: 084%

Tests on Soil: FA mix:

1. Proctor Compaction Test
2. California Bearing Ratio
3. Falling Head Permeability Test

Mix proportions adopted for composite soil: fly ash (FA): coir geo-nets mix:

1. FA: Soil: Geo-net = x%: y%: 400 GSM
2. FA: Soil: Geo-net = x%: y%: 700 GSM
3. FA: Soil: Geo-net = x%: y%: 900 GSM

Where x% – % Fly ash, y% – % Soil (Best results from Soil: Fly Ash mix combinations)

Tests on Soil: FA: Geo-net composite:

1. Proctor Compaction Test
2. California Bearing Ratio
3. Falling Head Permeability Test

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V. RESULTS AND DISCUSSIONS

To analyse the effect of fly ash on the properties of soil-fly ash mix, Particle size distribution (PSD), Standard proctor test for determination of OMC-MDD, California bearing ratio test for determination of CBR and Falling head permeameter test for permeability determination, are conducted. The different proportions of soil replaced by fly ash used in the study are 0%, 4%, 8%, 12% and 16% by weight. Particle size distribution of different soil-fly ash mix and soil classification of soil sample is obtained as per suggested Indian Standard codes IS: 2720 -1985 (Part 4) and IS: 1498-1970 respectively. To determine the particle size distribution of soil, wet sieving as well as mechanical sieving is done. The hydrometer analysis is used after wet sieve analysis. Compaction is done as per IS: 2720 – 1980 (Part 7) using proctor compaction test. In the test, the weight of the hammer used is 2.6 kg whereas the mould weights 4.677 kg. The mould was filled in three equal layers which are then rammed with the hammer for 25 blows dropped from a height of 310 mm. The water content at which the maximum density is achieved is referred as optimum moisture content (OMC) whereas the corresponding density is referred as maximum dry density (MDD). CBR test in the laboratory can be carried out either by un-soaked sample method or by soaked sample method as per the specifications mentioned in IS: 2720 – 1987 (Part 16). In the soaked sample method, first of all the soil or soil-fly ash mix is filled in CBR mould at OMC in three different layers where each layer is hammered for 56 blows. After the mould is completely filled, it is then kept under water tank for 96 hours i.e. 4 days. Then, the mould is tested for CBR value. Permeability test in laboratory can be carried out either by falling head method i.e. for finer soils or by constant head method i.e. for coarser soils. As per IS: 2720 – 1986 (Part 17), determination of permeability is done. As the soil in this case is of fine nature, hence the permeability has been determined by using falling head test and is determined by using standard formula i.e. Coefficient of permeability, $K = \frac{2.30aL}{At} \times \log(\frac{h1}{h2})$ with standard symbols used. The data collected is further analysed as below.

The particle size distribution curves for soil mixed with different proportions of fly ash (4%, 8%, 12% and 16%) are experimentally determined but for the sake of brevity, the PSD curve is shown for 8% fly ash mixed with soil in figure below:

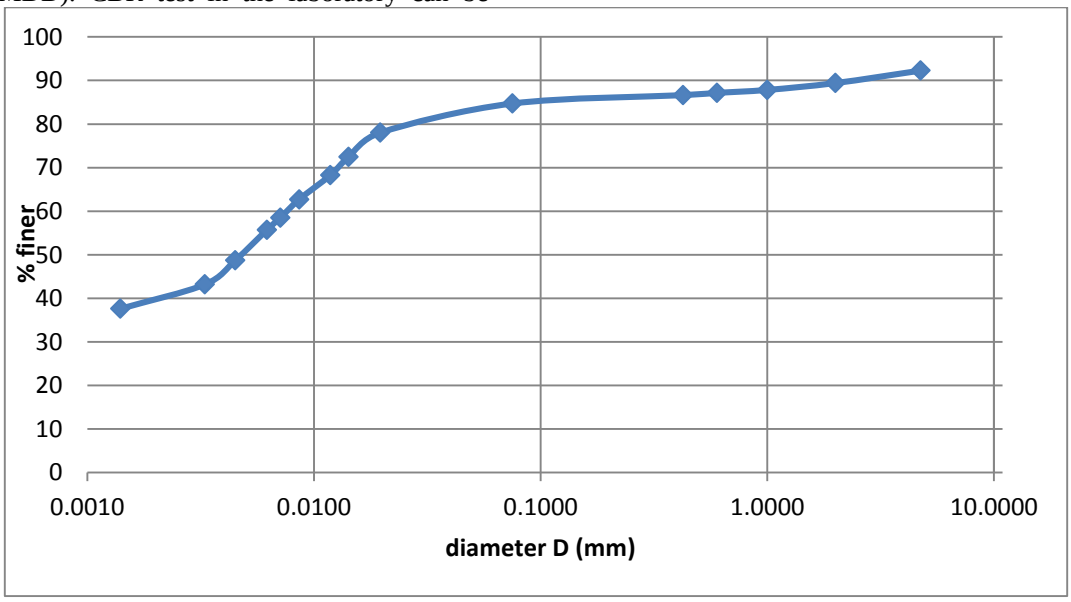

Fig. 2: PSD curve for addition of 8% FA

From figure 1 and 5, it can be clearly seen that the redistribution of particles has been taken place as the fines (fly ash) is mixed in soil.

The combined data for PSD, OMC-MDD, CBR and Permeability is given in Table-3 for soil replacement by fly ash in different proportions. From Table-5, it has been observed that with increase in % of fly ash added in clayey soil, the silt particles are increasing and clay particles are decreasing. This also exhibits the decrease in OMC and increase in MDD gradually with increase in % fly ash added.

Effect of fly-ash on the soil properties can be shown below in a tabular manner as under:

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Table 3: Effect of fly ash on soil

Properties	Soil + 4 % FA (S-04FA)	Soil + 8 % FA (S-08FA)	Soil + 12 % FA (S-12FA)	Soil + 16 % FA (S-16FA)
Sp. Gravity	2.691	2.679	2.661	2.649
Gravel – sand	14.61 %	15.26 %	16.01 %	16.84 %
Silt	43.58 %	47.11 %	49.15 %	52.50 %
Clay	41.81 %	37.63 %	34.84%	30.66 %
Soil type	Clayey silt	Clayey silt	Clayey silt	Clayey silt
OMC	16.59 %	15.86 %	15.77 %	15.59 %
MDD	1.698 g/cc	1.718 g/cc	1.745 g/cc	1.756 g/cc
CBR value	4.84	5.77	6.70	7.63
Permeability, K	6.26×10^{-6} mm/s	7.58×10^{-6} mm/s	8.89×10^{-6} mm/s	1.02×10^{-5} mm/s

It has been observed from the above results, that the addition of fly ash causes fall in the value of specific gravity, the reason being the redistribution of soil particles. With continuous addition of fly ash, clayey content is reducing while silt content is increasing. The variation can be shown in the figure below:

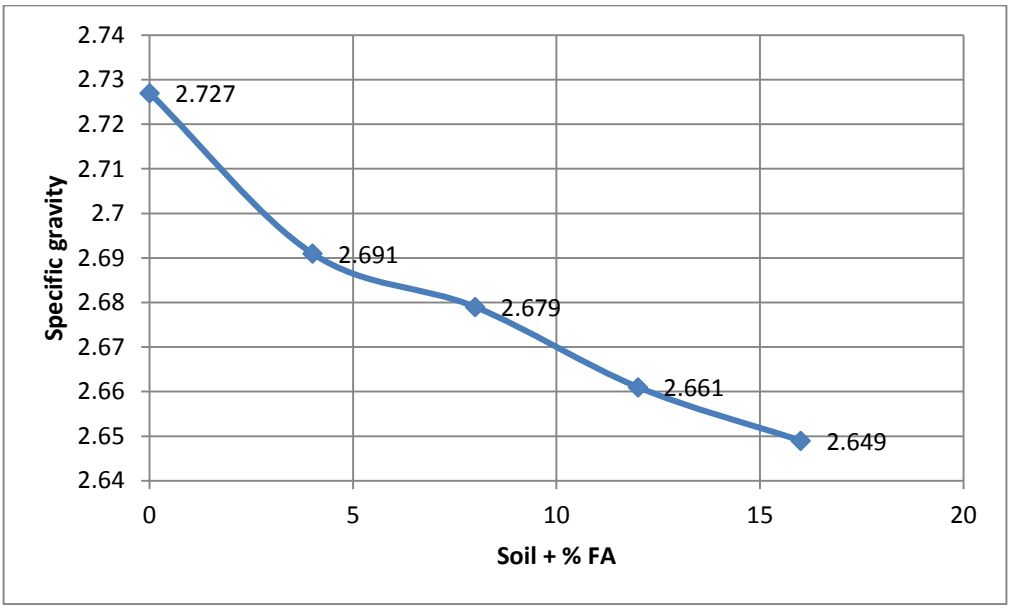

Fig. 3: Change in specific gravity due to continuous addition of FA

With the continuous increase in content of FA in the soil-fly ash mix, there is almost linear increment in the CBR value. The CBR value raised to 7.63 from 3.72 for 16% FA added. The cause for the rising phenomena can be attributed to the particle redistribution and comparatively well graded soil gradation compared to the soil gradation of original soil. The percent increase in the CBR value with the addition of fly ash to the soil is compared in Figure-08 and the %increase is about 105%.

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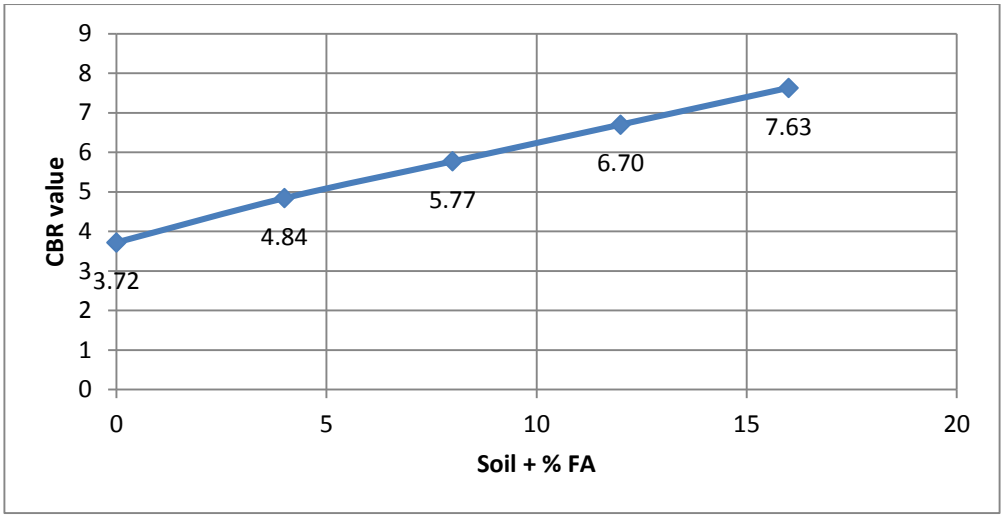

Fig. 4: Change in CBR value due to continuous addition of FA

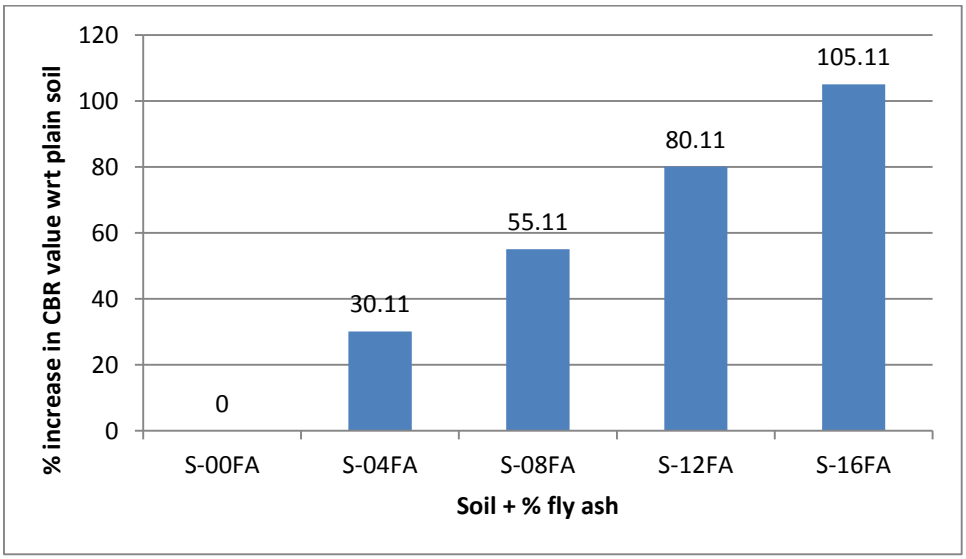

Fig. 5: % increase in CBR value due to continuous addition of FA

Finally, it has been observed that the permeability for the selected clayey soil is increasing with increase in % fly ash proportions throughout the test range. The reason for this may be attributed for the replacement of clay particles by silt particles. The percent increase in the permeability value with the addition of fly ash to the soil is compared in Figure-10. From figure it can be clearly seen that the maximum increase in permeability is about 106% for 16% addition of fly ash compared to the permeability of original soil i.e. 4.94×10-6 mm/s.

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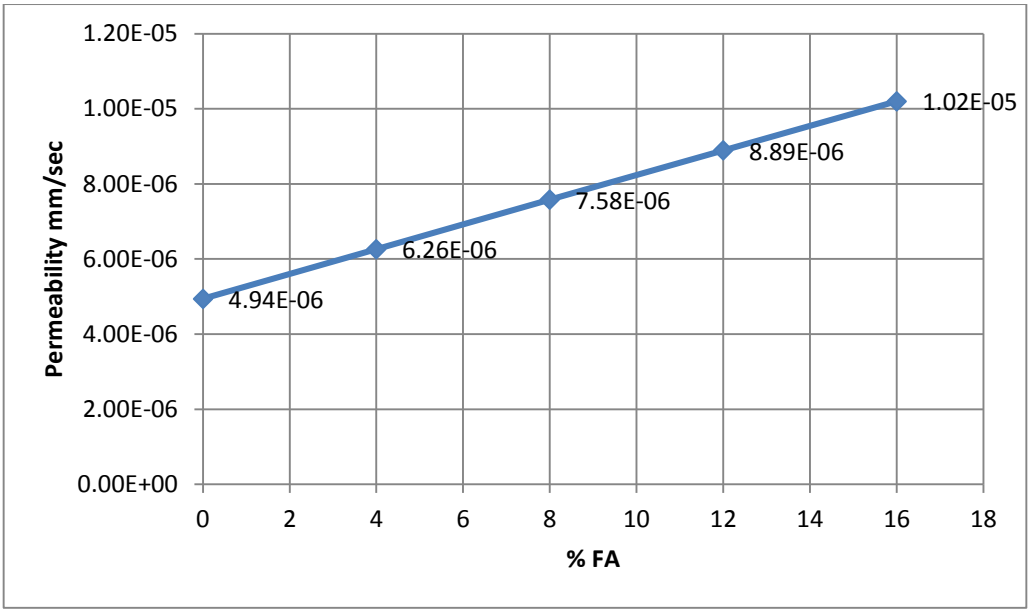

Fig. 6: Change in permeability value due to continuous addition of FA

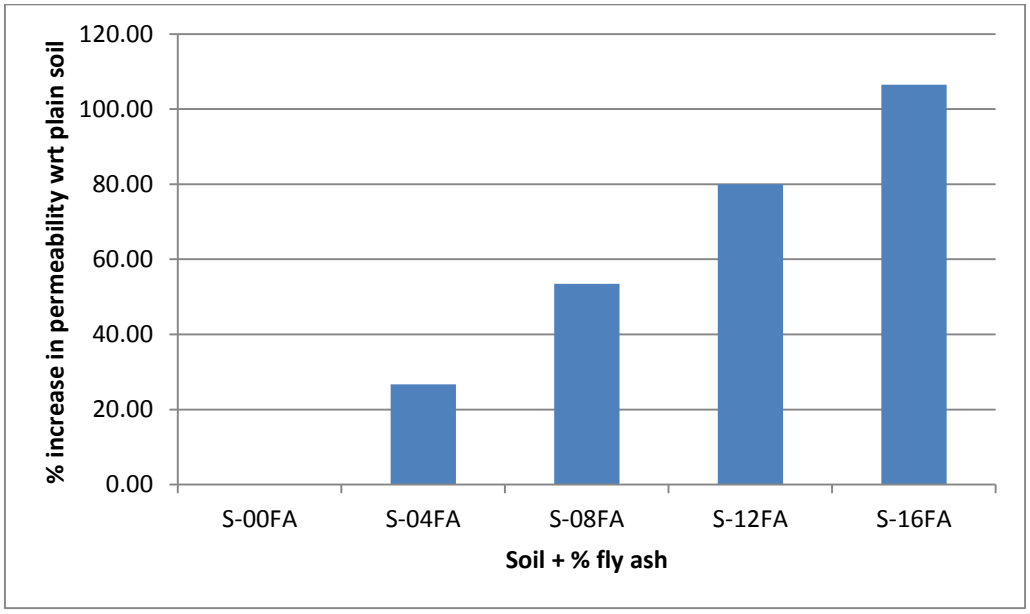

Fig. 7: % increase in permeability value due to continuous addition of FA

Thus, best results were obtained for addition of 16% fly ash in the soil. Further investigation with coir geo-nets was carried out for the S-16FA (soil: fly ash mix = 84%: 16%).

The effect of coir geo-nets can be shown in a table as below:

Table 4: Effect of coir geo-nets on soil-fly ash mix

Soil	CBR value
S-16FA	7.63
S-16FA-400GSM (1/3)	8.00
S-16FA-700GSM (1/3)	8.37
S-16FA-900GSM (1/3)	8.56
S-16FA-900GSM (1/2)	8.74
S-16FA-900GSM (2/3)	9.11
S-16FA-900GSM (1/3, 2/3)	9.49

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From the above table, it can be clearly seen that the CBR value varies first of all by varying the grades of geo-nets and then the variation is observed by placing the same geo-nets at various depths. Figure-11 explains the change in CBR value when different geo-nets were placed at one-third depth. It is clear from figure-11 that maximum strength is achieved when 900 GSM geo-nets is placed at one-third depth. Figure-12 explains the change in CBR value when 900 GSM geo-nets are placed at various depths i.e. one-third, one-half, two-third and one-third & two-third depths respectively.

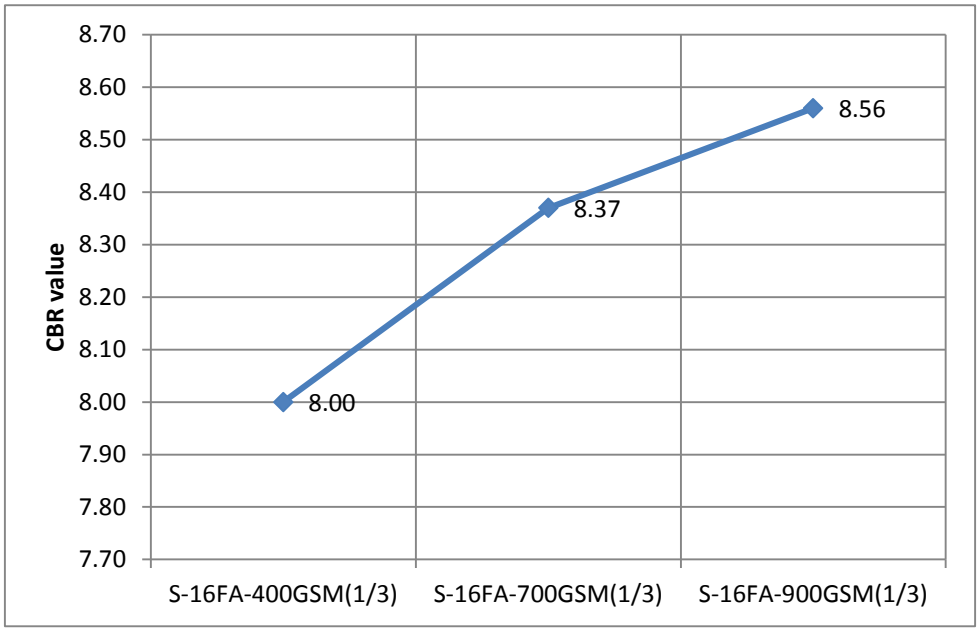

Fig. 8: Change in CBR value after placing different geo-nets at one-third depth

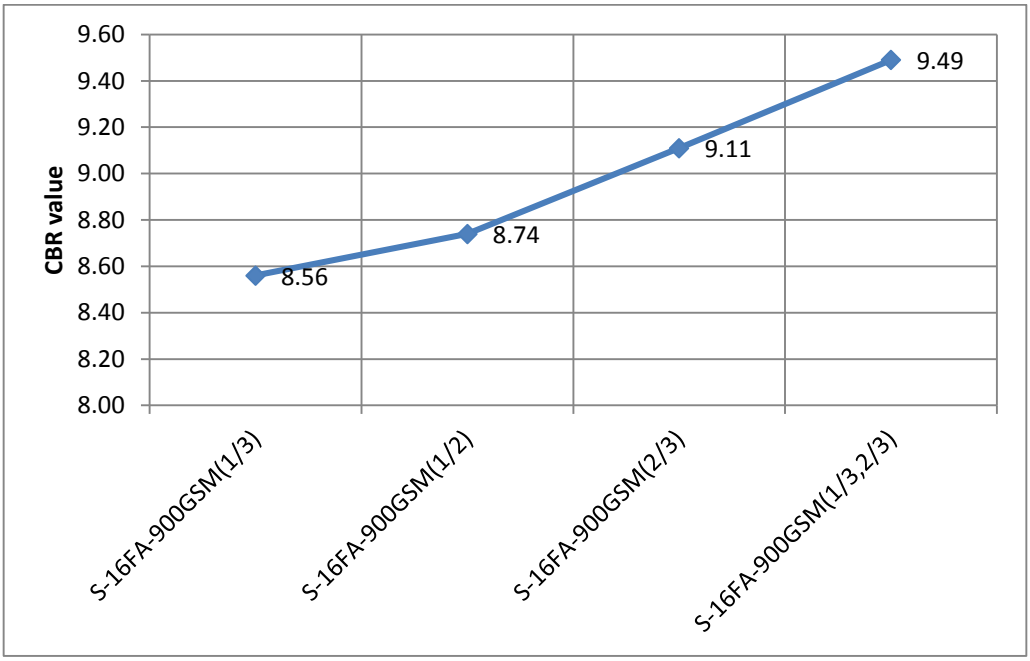

Fig. 9: Change in CBR value after placing 900 GSM geo-nets at different depths

The percentage increase in CBR value after placing geo-nets in S-16FA soil sample can be shown below in following figures. Figure-13 shows the percentage increase in CBR value only with respect to S-16FA whereas Figure-14 shows the percentage increase in CBR value with respect to original soil S-00FA. The maximum % increase with respect to S-16FA was about 25% whereas it was about 155% with respect to S-00FA.

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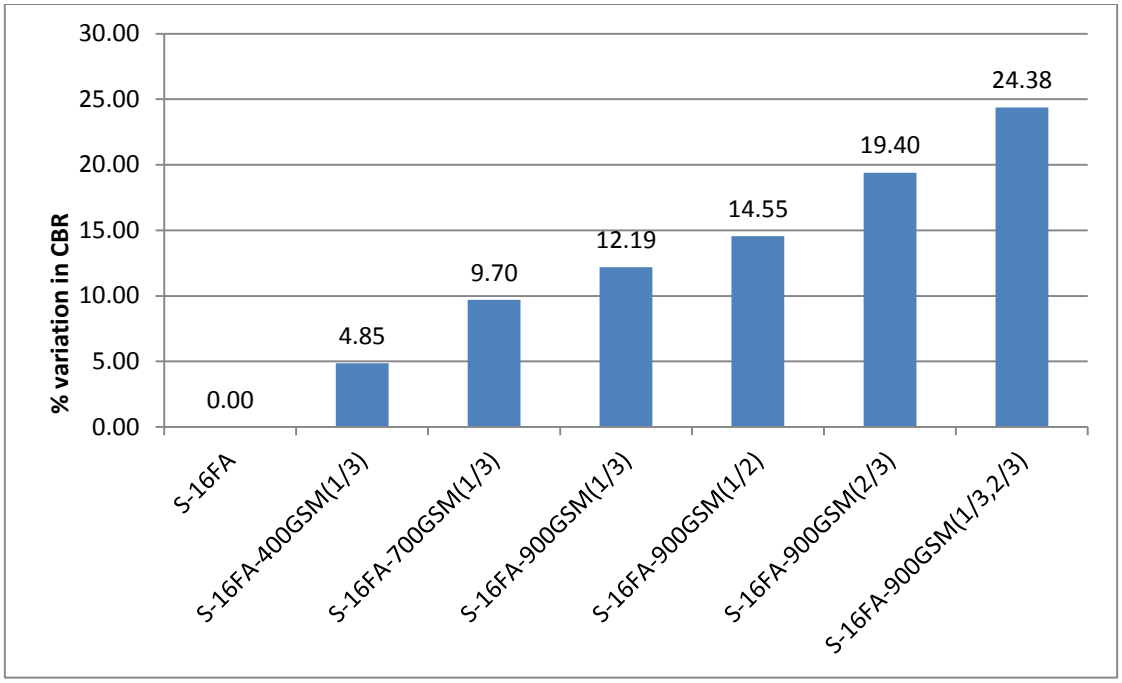

Fig. 10: % increase in CBR value wrt. S-16FA

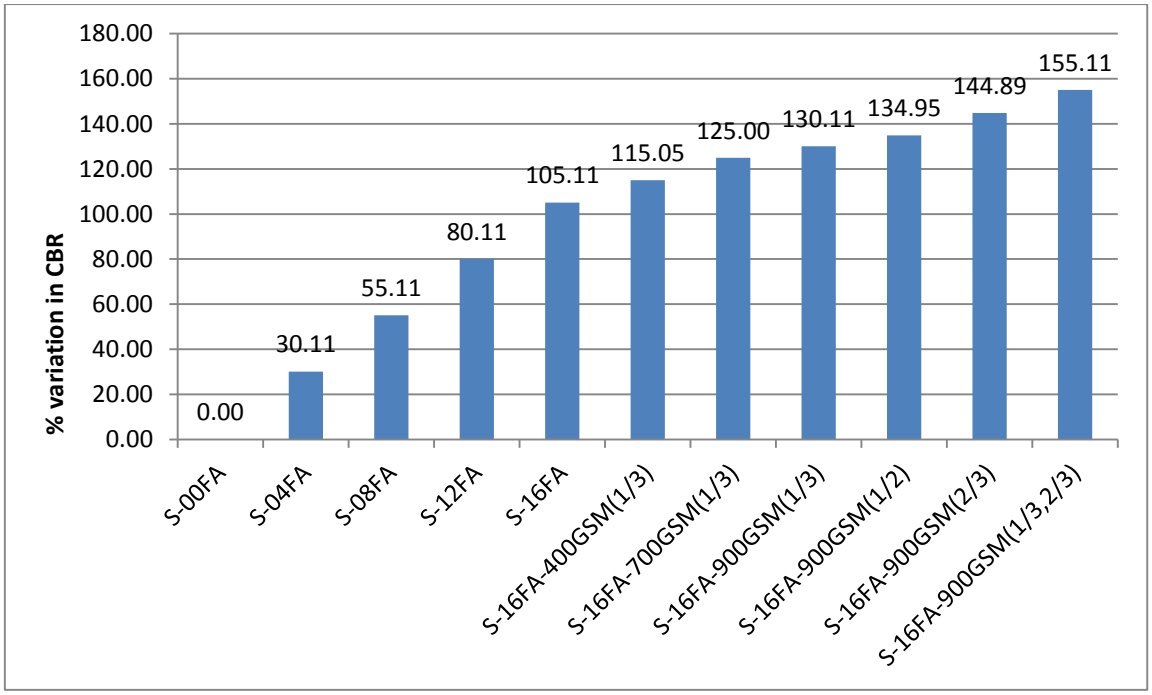

Fig. 11: % increase in CBR value wrt. S-00FA

VI. CONCLUSIVE REMARKS AND FUTURE SCOPE

Based on the experimental data collected and analysed as in section V, for soil (CI in present case), replaced with fly ash in five different proportions (0-16%) and further reinforced by using coir geo-nets of three different grades (400, 700 and 900 GSM) and placed at four different depth positions (1/3, ½, 2/3, 1/3 and 2/3 from top of the mould), the main conclusions may be drawn as given below:

1. Soil data:

a. The specific gravity of the soil used is 2.727 and has been classified as CI soil (Silty clay with medium plasticity) with LL, PL, PI, OMC and MDD as 37, 26, 11, 16.97% and 1.693 g/cc respectively.

b. The CBR value obtained experimentally are 3.72.

2. Soil mixed with fly ash in different proportions:

a. The specific gravity changes from 2.727 to 2.649 and shows a continuous decreasing trend with increase in % addition of fly ash from 0% to 16%. This may be attributed to increase in silt content as compared to reduction in clay content.

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b. The experimentally obtained CBR values shows a continuous increasing trend with maximum value as 7.63 for S-16FA which is about 105% more compared with S-00FA.
c. The above two points (a) and (b) suggests that S-16FA to be taken as the sample to be analysed for further reinforcement with coir geo-nets of different grades and placed at various depth positions for CBR analysis.

3. Selected S-16FA reinforced with coir geo-nets: Based on the analysis shown as in section V, the following conclusions may be drawn in terms of strength for the selected soil mixed with fly ash S-16FA and reinforced with coir geo-nets:

a. CBR value: The maximum CBR value among the three grades of coir geo-nets used and placed at different depth positions is obtained for 900 GSM coir geo-nets placed at 1/3 and 2/3 depths from top of mould and the respective CBR value is 9.49 which is about 155% higher as compared to S-00FA and about 25% higher in comparison to S-16FA.

Based on the experimental test ranges and detailed discussions as mentioned above, the addition of fly ash or reinforcement with coir geo-nets has shown significant and positive improvement of CI soil. Hence, this study may further be extended either with higher proportions or change in geo-net grades for stabilizing embankment as well as for improvement of drainage properties.

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