Stress-Strain Behaviour of Compacted Pond Ash Reinforced with Stone Column

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Abstract. Ash pond deposits are characterized by its high compressibility and low bearing capacity which is unappropriated for the construction of engineering structures over it. There are several techniques to improve the bearing capacity of ash deposits. Stone column is one of the effective techniques employed to increase the bearing capacity for construction of engineering structures over soft soil deposits. Stone columns are extensively used to improve the bearing capacity of poor ground, time rate of settlements, stiffness, reduce the settlement of structure, and liquefaction potential of soft ground. This paper reports the load settlement behaviour of compacted pond ash beds reinforced with stone columns. Both end bearing and floating stone columns of different length ratios and area ratios were introduced in compacted pond ash beds having different densities. The load-settlement behaviour of footings supported on different configurations of stone columns was studied.

1. Introduction
Fly ash is a derivative of burning minced coal in power plants. In India, around 71 % of electricity expended is generated by thermal power plants, of which nearly 90 % is coal-based generation and remaining 10 % is based on diesel, gas, steam and wind. Usage of bituminous or sub-bituminous coal that produces huge amounts of fly ash in thermal power stations, many captive power plants. The high ash content of Indian coals (30-40%) leads to these large amounts of fly ash. Almost 184.14 million tonnes of coal ash are currently produced in India annually and more than 70,000 acres of land are currently occupied by ash ponds. India is heavily dependent on coal as an electricity source that will continue into the next century, so fly ash management will remain an essential field for national concern and will require vast quantities of land to be disposed of along with water and resources. The high compressibility of pond ash deposit has poor bearing potential for which vast acres of land are lost. Fly ash can be cured using various methods for soil development, one of which is the stone column. By using the condensed stone column, the bearing capacity of the ash pond can be enhanced and structures can be constructed cost-effectively on the ash pond [1-14].
This paper reports the stress-strain reaction of compacted pond ash reinforced with stone column in footing load test. Stone columns were inserted at the center of cylindrical specimens of compacted pond ash. The area ratio of stone columns are varied as of 10%, 20%, 40% and 60% (Area ratio=$\frac{A_s}{A_c}\times100$, $A_s=$Area of stone column, $A_c=$Area of pond ash specimen). Similarly, the lengths of the stone columns are varied as of 0.25L, 0.50L, 0.75L, and 1.0L, where L is the length of cylindrical specimen.

2. Material Used
Pond ash is collected from Rourkela Steel Plant, Rourkela, Odisha, India which was sieved over 2 mm sieve and dried at temperature of 105°C-110°C. Stone aggregates collected from local crusher available near to Rourkela which were washed and dried at the temperature of 105°C-110°C. The two size of aggregate use for preparation of stone column which is having size between 2 mm-4 mm and 1mm-2 mm.

3. Experimental Programme
During this work, two arrangements of research were controlled. The basic arrangement of tests pointed to the determination of the index and engineering properties of pond ash, which joins pond ash’s record properties such as G (specific gravity), particle size distribution and hence indices of consistency. Additionally, with the aid of compaction studies, the similarity of pond ash under different compact energy levels was selected. In addition, direct shear tests and triaxial shear tests have carried out on compacted pond ash specimens at OMC and saturation conditions. The essential aspect of the experiments performed is sketched out below, and hence the methodology. In order to analysis the effects of stone columns embedded on pond ash bed, the second series of tests was controlled. The work was done to calculate the kind of strain reaction of stone column hardened pond ash beds.

The diameter of 2.6 cm, 3.3 cm, 4.8 cm and 5.7 cm stone columns were embedded in pond ash bed which so as to give the area ratio of 10%, 20%, 40% and 60%. The adequacy of length of stone sections on bearing limit of pond ash beds was concentrated by changing the length proportion as 1.00, 0.75, 0.5, and 0.25. The important part of tests directed and in this manner the technique are laid out underneath.

3.1. Index properties determination
The specific gravity test was conducted for the pond ash according to IS: 2720 (Part-III, Section-1, [1]) and the result is found to be 2.30. To determine the grain size distribution, Sieve analysis and hydrometer analysis was conducted for the coarse and finer particles according to IS: 2720 part (IV) and IS:2720 part (IV) [10] respectively and it is found that the pond ash particles are silt in size and the value of Cu and Cc of the pond ash are as 6.13 and 2.61 respectively.

| Compaction energy (kJ/m³) | OMC (%) | Dry density (gm/cm³) | C at OMC (kg/cm²) | C at saturation (kg/cm²) | $\phi$ at OMC (degree) | $\phi$ at saturation |
|---------------------------|---------|---------------------|-------------------|--------------------------|------------------------|---------------------|
| 119                       | 43.23   | 0.984               | 0.13              | 0.018                    | 22                     | 16                  |
| 357                       | 41      | 1.031               | 0.14              | 0.11                     | 27                     | 25                  |
| 595                       | 35.5    | 1.134               | 0.17              | 0.13                     | 29.46                  | 27                  |
| 1604                      | 32.22   | 1.15                | 0.21              | 0.16                     | 36.86                  | 33.45               |
| 2674                      | 31.7    | 1.23                | 0.25              | 0.2                      | 38.6                   | 36.76               |

Where $\Phi$ is angle of internal and C is unit cohesion.
Table 2. Footing Load Test by Variation of Area Ratio and Length Ratio

| Lr | Ar | Stress | Strain | Stress | Strain | Stress | Strain |
|----|----|--------|--------|--------|--------|--------|--------|
| 0  | 0  | 2.675  | 11.33  | 4.816  | 19.3   | 5.331  | 25.33  |
| 0  | 10 | 4.258  | 24.1   | 4.876  | 18     |
| 0  | 20 | 3.554  | 24.6   | 3.954  | 22.66  |
| 0  | 40 | 2.844  | 24.6   | 3.26   | 12     |
| 0  | 60 | 2.675  | 11.33  | 2.675  | 11.33  |

Table 3. Footing Load Test by Variation of Area Ratio and Length Ratio

| Lr | Ar | Stress | Strain | Stress | Strain | Stress | Strain |
|----|----|--------|--------|--------|--------|--------|--------|
| 0  | 0  | 2.675  | 11.33  | 5.963  | 19.33  | 6.739  | 26.66  |
| 0  | 40 | 5.574  | 24.66  | 6.261  | 33.33  |
| 0  | 60 | 4.937  | 15.33  | 5.658  | 30.66  |
| 0  | 40 | 4.133  | 14     | 4.767  | 19.33  |
| 0  | 60 | 2.675  | 11.33  | 2.675  | 11.33  |

Where, Lr= Length ratio and Ar= Area Ratio

3.2 Engineering properties determination

The Protector tests were conducted as per IS: 2720 (Part VII) – [2] and IS: 2720 (Part VIII)-[3]. The blows number of each layer is managed so as to impart energy of 119, 357, 595,593, 1604 and 2674 kJ/m3 of compacted volume. The OMC and MDD is mentioned in the Table 1. The Direct shear test is conducted as per IS: 2720 (Part X)- [4] to evaluate the strength parameter of pond ash. Pond ash specimens were arranged equivalent to their MDD and OMC which results are shown in Table 1.

4. Footing Load Tests

This test was performed for studying load settlement behavior of pond ash which is embedded with stone column conducted on strain regulated loading apparatus. To conduct the test pond ash samples of density 0.90 Kg/cm³ is prepared within the cylindrical tank size of inside dia. of 39.6 cm and length of 40 cm. At the middle of pond ash, stone column was embedded by cylindrical steel road for offering specified area ratio and for compacting aggregate with the help of iron rod. The test was directed to survey the viability of length ratio 10 %, 20 %, 30 %, 40 % and 60 % the test was conducted to study the adequacy of differing length proportion 0.25, 0.50, 0.75, and 1.0. These specimens were tried during a Strain controlled loading apparatus with strain pace of 1.25 mm/min until the sample fails. Test outcomes were introduced in Table 2 and Table 3 and consequently the example arrangement and instrument were wont to make the samples were given in Figure 1-4 respectively.
5. Results And Discussion

5.1 Stress Strain behaviour of reinforced pond ash bed

Footing load tests were conducted where the untreated pond ash specimens compacted to their corresponding MDD and OMC. This test was conducted to study the load settlement behaviour of pond ash reinforced with stone column in varying length ratio to their corresponding area ratio mentioned earlier and therefore the test result and behaviour has plot in Figure 5 and 6. From these figures, it's shown that,

- For a specific length of stone column the primary stress is maximum at upper area ratio, the initial stress increases linearly with the rise of length ratio. Also, the utmost failure stress depends on the utmost area ratio and length ratio. After reaching the utmost failure stress, the failure zone rises to the upper side of pond ash bed.
- Bearing capability increase proportionally with the increase of length of stone column of a particular area ratio. It shows that the angle of internal friction increases linearly with the rise of stone column diameter and its reinforcing length which leads to increase its compacted density in result bearing capacity get increases linearly. In this case diameter and length of the stone column plays a major part to increase the bearing capacity of stone column.
- At 0.75 length of reinforced pond ash shows closer results with full length ratio stone column so with the consideration of the use of materials, 0.75 length of stone column has more in effect as compared to other.
6. Conclusions
In this study the behaviour of various compacted pond ash reinforced materials with stone column structure, there are some conclusions are drawn and enlisted below:

i. In the footing load test, failure stress increased linearly with the increase of area ratio and decrease in length ratio.

ii. It is detected that when we consider the low length ratio, stone column particles along with pond ash settles due to load application.

iii. It is witnessed that it gives higher stress to the respective higher area ratios. Correspondingly, it shows maximum stresses for precise area ratio were perceived to its higher length ratios.

iv. It is seen that bearing capacity increases linearly with the expansion of length proportion to their respective area ratio. The expansion of diameter of the stone column and its reinforcing length
result shows that bearing capability increases linearly due to high compacted density of sample specimen which leads to increase its angle of internal friction.

v. It shows closer bearing capacity value when it is considered for the length ratio of full length and 0.75 length ratio reinforced pond ash. Hence the necessity of stone aggregate substantial is more in full length ratio stone column as compare to 0.75 length ratio, so 0.75 length ratio (0.75L) can be considered as more effective and economic as compare to other length ratio.

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