INFLUENCE OF CEMENT ON TRIAXIAL RESPONSE OF FLY ASH-ADMIXED SAND

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ABSTRACT: A series of triaxial compression tests has been conducted to investigate the strength characteristics of a sandy soil blended with fly ash and cement, paying special attention to the influence of cement in this mixture. Fly ash content used in this study is 35% and the cement content varies from 1% to 4% with curing periods of 0, 7 and 28 days for the various mixtures. It has been observed that addition of cement to fly ash-soil mixes changes the stress-strain response of the mixes. Curing time also influences the strength behaviour of the mixes.

INTRODUCTION
The increase in the demand for power has led to the commissioning of large coal-fired power stations in India. The generation of fly ash at present is about 100 million metric tons per year, but its use is less than 10%. The management and disposal of the remaining huge quantity of fly ash has created tremendous environmental stress. Bulk use of fly ash is possible in geotechnical engineering applications such as construction of embankments, dams, back-fill material behind retaining walls, base or sub-base material, or land fill reclamation.

Experiments were conducted on specimens having the fly ash soil proportions of 25:75, 50:50, 75:25, and 100:0 by dry weight [1]. The cement contents used were 3 and 6%. The gain in strength and modulus is dependent on the fly ash and cement content as fly ash content increases both are decreases but increases as the cement content increases. Experimental work on expansive soil was carried out with the addition of fly ash and lime content [2]. On the addition of 20% fly ash the swelling potential decreased at 8% lime addition.

An experimental work was conducted to study the strength and dilatancy of a silt stabilized with the addition of a cement and fly ash mixture in a slurry form [3]. It has been found that the cementing agent always led to an increase in peak strength via an increase in dilatancy at failure.

The effect of the addition of ordinary Portland cement on the California bearing ratio (CBR) of fly ash and fly ash-black cotton (BC soil) soil mixes was studied for different curing periods [4]. It has been found that addition of a small percentage of cement to fly ash-soil mixes brings about significant changes in the strength in terms of the CBR. Significant improvement in the shear parameters of the cement added fly ash-soil mixes has also been observed. In another investigation it has been found that high calcium fly ash and cement can effectively be used by enhancing various mechanical properties of the soil [5]. By using fly ash alone with soft fine grained soil [6] it was observed that the addition of fly ash resulted in appreciable increases in the CBR and resilient modulus of soil.

An experimental study on expansive and non-expansive clays with fly ash as an additive was conducted [7]. It has been found that addition of fly ash reduces the swelling potential of expansive soil. From testing results [8], the unconfined compressive strength and elastic modulus were found to be improved with increasing fly ash content. With the cement portions of greater than or equal to 10%, ground disposed fly ash could be employed as a pozzolanic material for partial replacement of cement in cement column construction.

The literature review indicates that several studies have been carried out related to use of fly ash and cement for improving soil properties. An experimental investigation has been conducted with the aim of understanding the amendment of a local soil using fly ash and cement. The results of the study are presented herein.

EXPERIMENTAL INVESTIGATION

Test Materials
Three types of materials were used in this experimental investigation, i.e., sand, fly ash and cement. The sand used in this study was collected from a nearby location. The soil was characterized using laboratory characterization test as per Indian Standards. From gradation analysis, the sand was classified as SP (poorly graded fine sand) according to Unified Soil Classification System. Specific gravity of sand used was found to be as 2.70. Again from Standard Proctor Test the maximum dry density of the soil was calculated as 17.08 kN/ m³. The fly ash used in this study was collected from Farakka power plant of West Bengal. From the grain size distribution test it has been found that the fly ash consists predominantly of silt size particles. The fly ash obtained has CaO content in the range of 1.7% to 2.7% and can thus be classified as F type as per ASTM C 618-08. A commercially available 53 Grade ordinary Portland cement was used.

Preparation and Testing of Specimens
All the specimens tested were prepared by mixing the relevant quantities of dry soil, fly ash, cement and water, according to the mixture proportions and moulding parameters summarized in Table 1. Fly ash content used in
this study is 35% taking into account compaction difficulties found using higher amounts of fly ash. The cement content adopted in the experimental work varies from 1% to 4%. Higher amount of cement content has been avoided considering the economic point of view.

The required amounts of soil, fly ash, cement, and water were measured. The soil-fly ash-cement mixes were first mixed together in the dry state and then mixed with optimum water amount. The specimens were moulded at the maximum dry unit weight, according to the values obtained from the standard Proctor compaction tests. Then, it was extruded from the mould immediately and cured at room temperature, but were exposed to ambient constant humidity within desiccators during the curing period.

The curing periods adopted were 0, 7 and 28 days for the unconsolidated undrained triaxial compression tests. The triaxial tests were carried out using confining pressures of 1, 2, 3 and 4 kg/cm², which are consistent with realistic assumptions made in some important engineering applications. Table 1 shows the testing program. Here, BS, FA and C indicate Brahmaputra sand, fly ash and cement respectively. 35%FA and 1%C means 35% and 1% by weight of fly ash and cement respectively. Again 1p means confining pressure of 1 kg/cm².

<table>
<thead>
<tr>
<th>Mix proportions</th>
<th>Proportions of cement used (%)</th>
<th>Curing period (days)</th>
<th>Confining pressure (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS+35FA</td>
<td>0,1,2,3,4</td>
<td>-do-</td>
<td>-do-</td>
</tr>
<tr>
<td>BS+35FA+1C</td>
<td>-do-</td>
<td>0, 7, 28</td>
<td>1p, 2p, 3p, 4p</td>
</tr>
<tr>
<td>BS+35FA+2C</td>
<td>-do-</td>
<td>-do-</td>
<td>-do-</td>
</tr>
<tr>
<td>BS+35FA+3C</td>
<td>-do-</td>
<td>-do-</td>
<td>-do-</td>
</tr>
<tr>
<td>BS+35FA+4C</td>
<td>-do-</td>
<td>-do-</td>
<td>-do-</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Effect of Cement Content
During an investigation [8] it was observed that the strength of cement-fly ash admixed clay at high water content increased with increasing amount of cementitious material content and duration of the curing time.

Figs. 1-10 compare typical deviatoric stress-axial strain response for all compacted mixtures with and without cement, for the curing periods of 0 and 28 days. It is readily observed that the overall soil behaviour was significantly influenced by the addition of cement. Peak strength, stiffness, and brittleness were changed as a consequence of either the separate or the joined effects of cement and fly ash contents. The gain in strength is found to be greater in case of BS+35%fly ash+3% cement mix especially for 28 days of curing. In the same time inclusion of cement incorporates the brittle behaviour to the mix.

![Graph 1](image1)

**Fig. 1 Stress-strain plots of BS+35%FA (0 days)**

![Graph 2](image2)

**Fig. 2 Stress-strain plots of BS+35%FA+1%C (0 days)**

![Graph 3](image3)

**Fig. 3 Stress-strain plots of BS+35%FA+2%C (0 days)**
Cement treatment leads to significant increase in triaxial compressive strength of the soils and the behaviour is mostly controlled by cementation, as indicated by its high initial stiffness. Then, as the bonds are gradually broken, localized structure collapses and compression are likely to occur. Thus, improvement in mechanical behaviours of fly ash treated sand with cement treatment was noticeably higher than fly ash treated soil alone. There was a general trend of an increase in the axial strain at failure, with an increase in the confining stress. Thus, stress–strain curves so observed were brittle in nature, with the peak resistance mobilized at an axial strain of about 2–4% in most of the cases.

**Effect of curing period**

From Fig. 11 it is evident that for 0 day of curing period the strength gain is almost same irrespective of cement content.
Fig. 11 Peak strength envelopes for soil+35%FA+different percentages of cement for 0 day curing period

Again for 7 days and 28 days of curing period the strength increases up to 4% and 3% cement content respectively as shown in Figs. 12-13. After the 28 days the peak strength has been found to be more in 3% cement content compared to other cement treated fly ash mixes of sand.

Fig. 12 Peak strength envelopes for soil+35%FA+different percentages of cement for 7 days curing period

Fig. 14 shows the effect of curing period on soil+35% FA+3% cement for the different curing periods. It is observed that strength gain is continued steadily up to 28 days of testing. The strength increase due to cementation reactions and flocculation mechanisms in fly ash treated soils develops after long curing periods. Hence longer curing periods increased the shear strength of these soils. The behaviour described so far mainly reflects the effect of curing time on strength with the degree of cementation and is qualitatively in agreement with triaxial test results reported in the literature for cemented soils [9, 10].

Fig. 13 Peak strength envelopes for soil+35%FA+different percentages of cement for 28 days curing period

CONCLUSIONS

Addition of cement in the fly ash admixed sand enhances the shear strength of the soil. But inclusion of cement transforms the material behaviour from ductile to brittle to some extent. Curing period has also great influence in the triaxial response of the soil mixed with fly ash and cement. The strength of the mix generally increases with increasing curing period. At 28 days of curing period sand mixed with 35% fly ash and 3% cement shows significant improvement in peak strength obtained from triaxial test.

REFERENCES