STRESS-STRAIN BEHAVIOR OF FLY ASH COMPACTED AT DIFFERENT MOISTURE CONTENTS

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ABSTRACT: This paper deals with the stress-strain behaviour of fly ash compacted at different moisture contents. Box shear tests were conducted at different moisture contents corresponding to wet and dry of optimum moisture content. Fly ash shows cohesion in partially saturated condition. Cohesion increases with increase in water content. At higher water contents above optimum moisture content, the increase in cohesion gradually becomes small. The peak stress increases dry of optimum moisture content and thereafter decreases, wet of optimum. Further, to study the behaviour of time dependent availability of moisture, curing of the samples before testing has been done for 7 days and 28 days respectively. The samples for curing have been compacted at optimum moisture content and maximum dry density. Curing the samples for more number of days gave better results.

INTRODUCTION
Most of the present day thermal stations have furnaces designed to burn powdered coal at fuel for generation of power. The waste product of these plants is predominantly a finely powdered ash which, because of its tendency to fly when in dry state, is often referred to as ‘FLY ASH’. Attention of research workers in our country and in United States of America is now mainly towards study of engineering properties of compacted and stabilized fly ash, which can be used as a replacement for conventional earth fill material in load-bearing fills and sub-bases and light weight back fills [1].

PROPERTIES OF FLY ASH
Fly ashes from different power plants differ widely in their particle size and chemical composition. The variations are due to i) Type of coal used, ii) The treatment to which coal is subjected prior to combustion, iii) The method of combustion, iv) The amount of air circulation and v) The method of collection of fly ash.

Pozzolanic reactivity of fly ash plays an important role in the use of fly ash for most of geo-technical applications. Fly ash is a non-plastic material by nature. Types of fly ash that develop good strength without addition of lime are widely used. In fly ash the reactivity is due to reaction between non-crystalline silica and lime. They are self-pozzolanic without addition of lime.

INDEX PROPERTIES
Some important index properties of typical fly ashes reported in literature [1, 2, 3, 4] are as summarized below:

Fly ash is mainly a silt-sized material and the grain size curves are poorly graded. The average specific gravity for the fly ash falls between 2.15 and 2.45 respectively. The reason for such low average specific gravity is that particles of fly ash are cello spheric or hollow particles. On examination under electron microscope, virtually all the particles are found to be spherical in shape. The specific gravity of fly ash depend upon carbon and iron oxide contents. High carbon content will result in a low specific gravity. The hollow nature of the spherical particles also contributes to lower specific gravity.

ENGINEERING PROPERTIES OF COMACTED FLY ASH

Compaction Characteristics

Fly ash responds to compaction in the same way as any fine-grained soil [4]. Table 1 shows the range of optimum moisture contents and MDD values for two types of fly ash.

<table>
<thead>
<tr>
<th>Property</th>
<th>Standard AASHTO Test</th>
<th>Modified AASHTO Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max % of OMC</td>
<td>32%-21%</td>
<td>21.5%-16.55%</td>
</tr>
<tr>
<td>M.D.D. in Mg/m³</td>
<td>1.25 -1.52</td>
<td>1.27 – 1.53</td>
</tr>
</tbody>
</table>

According to [1], the average value of 1.18 Mg/ m³ to 1.52 Mg/m³ of MDD and 17 % to 32 % of OMC was obtained for some other fly ashes also as indicated by modified AASHO compaction tests.

UNCONFIED COMPRESSIVE STRENGTH

The unconfined compressive strength values of compacted fly ashes were found to be quite low, ranging from 105.6 kPa to 422.4 kPa even for samples compacted at MDD.

SHEAR STRENGTH PARAMETERS

Drained triaxial tests were run on samples of gravity compacted Michigan fly ashes compacted to MDD at OMC, according to modified AASHTO specifications.
Angle of internal friction of fly ash varied from 38 to 43 degrees and cohesion intercepts varied from 70 kPa to 105 kPa. These values may be compared with strength tests on a number of compacted Britain fly ashes. Virtually in most of the cases, the observed shear strength parameters would be sufficient to provide adequate bearing capacity for a load bearing fill or embankment. A relative compaction equal to 90% of MDD is probably a more realistic limit for compaction in the field [1].

It was reported [3] that fly ash possessed self hardening properties due to the presence of unburnt carbon. Further, it was also reported [3] that strength of compacted fly ash samples increased from 38.3 kPa at 29 degrees to 614 kPa at 45 degrees width in a period of one week of curing.

C.B.R OF COMPACTED FLY ASH
Laboratory investigations done by different research workers [3, 4, 5, 6] have shown that soaked CBR values of fly ash are very much affected not only by the type of fly ash samples but also by curing periods. Curing for higher number of days has resulted in considerably high values of CBR at longer period of curing. Further, it has been observed that laboratory CBR decreases rapidly for small increases in moisture content above the optimum value, change in CBR with moisture content on dry side of optimum being much rapid.

Compressibility and Settlement Behaviour
It was observed [4] that settlements computed in one-dimensional laboratory tests do not correlate with the results of plate bearing tests in the field or with observations on actual foundations.

The consolidation test data on fly ash samples obtained from Kansas State of U.S.A [3] indicate that fly ash does not undergo compression significantly under small load intensities. The value of compression index (Cc) and swelling index or rebound index (Cs) for the samples tested for 3 days were found to be 0.061 and 0.004 respectively.

PERMEABILITY AND DRAINAGE
Laboratory determination of permeability on British fly ash, compacted at MDD (Standard Proctor test) showed that the drainage characteristics range from practically impervious to porous despite air voids ranging from 8% to 14%. Low permeabilities of fly ashes mean a high degree of runoff. Therefore precautions need to be taken to prevent erosion of side slopes.

EXPERIMENTAL STUDY

Materials used:
Fly Ash: Fly ash which is mixed at varying water contents and MDD to achieve the objective of the test programme has been collected from Vijayawada thermal power station (VTPS), Krishna District of Andhra Pradesh, India.

Variables Studied
The effect of the following variables on strength characteristics of fly ash has been studied (see Table 2):

Table 2. Variables of the study

<table>
<thead>
<tr>
<th>Water Content (%)</th>
<th>9.0</th>
<th>11.0</th>
<th>13.0</th>
<th>14.5</th>
<th>16.0</th>
<th>18.0</th>
<th>21.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Density (kN/m³)</td>
<td>11.78</td>
<td>11.90</td>
<td>12.02</td>
<td>12.08</td>
<td>12.02</td>
<td>11.90</td>
<td>11.78</td>
</tr>
</tbody>
</table>

Table 2 shows the index properties of fly ash used.

Table 3. Index properties of fly ash

| Specific Gravity | 2.08 |
| Liquid Limit (%) | - |
| Plastic Limit | - |
| Plasticity Index (%) | N.P. |
| Gravel (%) | 0 |
| Sand (%) | 0 |
| Silt (%) | 92 |
| Clay (%) | 8 |
| Free Swell Index (%) | - |

PROCTOR COMPACTION TESTS
The optimum moisture content (OMC) and the maximum dry unit weight (MDD) of the fly ash were determined upon conducting standard Proctor compaction tests. Shear box tests were conducted on fly ash samples compacted at γ₀ and w % shown in Table 2.

Compaction characteristics of Fly Ash:
Fig.1 shows the dry unit weight-water content curve for the fly ash as determined from the Proctor compaction test. The optimum moisture content of the fly ash was 14.6% and the maximum dry unit weight, 12.08 kN/m³.

STRENGTH CHARACTERISTICS OF FLY ASH
The strength characteristics of fly ash have been studied performing shear box tests on samples prepared at different water contents, wet of optimum and dry of optimum and corresponding dry unit weights. Strength characteristics at OMC & MDD have also been determined. The strength parameters, namely, cohesion (c) and angle of internal friction (φ) were determined. Stress strain characteristics have also been studied. The points on the compaction curve corresponding to which the samples were prepared are shown in Fig.1.

Triaxial compression tests could not be conducted, as preparation of cylindrical samples was extremely difficult since the material has no cohesion to offer binding property. Sample was not intact at any dry unit weight and water content. Hence, only shear box tests could be performed.

Table 4 shows the values of cohesion (c, kN/m²) and angle of friction (degrees) obtained from shear-box tests on fly
Stress-strain behavior of fly ash compacted at different moisture contents

ash samples compacted at OMC & MDD, dry of optimum and wet of optimum.

Fig 1. Compaction characteristics of fly ash

Table 4 SHEAR PROPERTIES OF FLY ASH

<table>
<thead>
<tr>
<th>Water Content (%)</th>
<th>Dry unit Weight (KN/M³)</th>
<th>Cohesion c (KN/m²)</th>
<th>Angle of Internal friction (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.0</td>
<td>11.78</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>11.0</td>
<td>11.90</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td>13.0</td>
<td>12.02</td>
<td>7</td>
<td>34</td>
</tr>
<tr>
<td>14.5</td>
<td>12.08</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>16.0</td>
<td>12.02</td>
<td>11</td>
<td>29</td>
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<td>18.0</td>
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<td>13</td>
<td>27</td>
</tr>
<tr>
<td>21.0</td>
<td>11.78</td>
<td>14</td>
<td>25</td>
</tr>
</tbody>
</table>

Fig 2 shows the variation of cohesion with water content. It can be seen from the figure that cohesion increases with water content. Below OMC cohesion reduces, and above OMC, it increases.

It is interesting to note that though fly ash is a silt material, cohesion was observed, which may be mainly because of surface tension in capillary water, and it is seen only in partially saturated fly ash. When fly ash becomes saturated this amount of cohesion is lost. This can be clearly observed from the figure.

All the water contents, at which tests have been done, correspond to an unsaturated condition. At higher water contents above OMC, the increase in cohesion gradually becomes small.

Fig. 3 shows the variation of angle of internal friction with water contents with particular reference to OMC. It can be seen from figure that angle of friction increases up to OMC and thereafter it decreases. This depends upon the initial state of compaction. The void ratio at which the fly ash samples have been compacted indicate that, the initial state of compaction refers to dense to very dense state. Hence the angle of friction is maximum at OMC &MDD which gives denest state, and attains lower values at other points. The decrease in angle of friction wet of optimum is sudden and steep compared to the decrease in its value dry of optimum.

Fig 4 shows the variation of peak shear stress with water content at a confining stress of 51 kN/m². It can be seen from the figure that the peak shear stress increases up to OMC and thereafter it decreases wet of optimum.
CONCLUSIONS
The following conclusions can be drawn from the experimental study conducted: Fly ash shows cohesion in partially saturated condition. Cohesion increases with water content in partially saturated condition. At higher water contents beyond OMC, the increase in cohesion gradually becomes low, indicating that it may be lost at water contents corresponding to saturation. Angle of friction of fly ash increases dry of optimum up to OMC and thereafter it decreases rapidly. In dense to very dense states of compaction, fly ash can exhibit an angle of friction between 25° to 35°. The peak stress increases dry of optimum up to OMC and thereafter it decreases wet of optimum.

REFERENCES