Use of lime cement stabilized pavement construction

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Expansive clay is a major source of heave induced structural distress. Swelling of expansive soils causes serious problems and produce damages to many structures. Many research organizations are doing extensive work on waste materials concerning the feasibility and environmental suitability. Fly ash, a waste by product from coal burning in thermal power stations is abundant in India causing severe health, environmental and disposal problems. Attempts are made to investigate the stabilization process with model test tracks over expansive subgrade in flexible pavements. Cyclic plate load tests are carried out on the tracks with chemicals like lime and cement introduced in fly ash subbase laid on sand and expansive subgrades. Test results show that maximum load carrying capacity is obtained for stabilized fly ash subbase compared to untreated fly ash subbase.

**Keywords:** Expansive soil, Fly ash, Lime, Cement, Flexible pavement

Soils, which exhibit a peculiar alternate swell-shrink behaviour due to moisture fluctuations, are known as expansive soils. This behaviour is attributed to the presence of clay minerals with expanding lattice structure. Among them, Montmorillonite clay mineral is very active and absorbs water many times more than its volume. The soil is hard as long as it is dry but loses its stability almost completely on wetting. On drying, the soil cracks very badly and in the worst cases, the width of cracks is almost 150 mm and travel down to 3 m below ground level\textsuperscript{14}.

Fly ash is a waste by-product from thermal power plants, which use coal as fuel. It is estimated that about 100 million tons of fly ash is being produced from different thermal power plants in India consuming several thousand hectares of precious land for its disposal causing severe health and environmental hazards\textsuperscript{5,6}. In spite of continuous efforts made and incentives offered by the government, hardly 5-10% of the produced ash is being used for gainful purposes like brick making, cement manufacture, soil stabilization and as fill material\textsuperscript{7,8}. In order to utilize fly ash in bulk quantities, ways and means are being explored all over the world to use it for the construction of embankments and roads\textsuperscript{7,9,11}. However, when it is used as subbase in flexible pavements, it is completely confined and also the thickness of such layer is relatively small, where by the above problems can be eliminated. Fly ash settles less than 1% during the construction period and not afterwards. Its low density makes it suitable for high embankments\textsuperscript{12}. Fly ash has a tendency to react with lime to form different lime bearing silicates/aluminates hydrates due to its pozzolanic properties. These hydrates possess cementitious properties and are responsible for the development of strength in fly ash-lime compacts which are used as structural products\textsuperscript{13}.

Krupavaram\textsuperscript{14} had made an attempt to use lime stabilized fly ash subbase course in model field pavement stretches. Cyclic plate load tests were conducted on fly ash subbase and lime stabilized fly ash subbase stretches constructed on different subgrades (i.e., Sand and Expansive soil) and observed that lime stabilized fly ash stretch showed better performance in load carrying capacity and reduction of heave laid on expansive soil subgrade.

In another investigation\textsuperscript{15} an attempt was made to use cement stabilized fly ash subbase course in field pavement stretches, and compared the performance with fly ash subbase. Cyclic plate load tests were conducted on fly ash subbase and cement stabilized fly ash subbase stretches constructed on different subgrades (i.e., sand and expansive soil) and found that cement stabilized fly ash stretch had shown better performance in load carrying capacity and reduction of heave compared to conventional stretch, laid on expansive soil subgrade.
Kumar et al.\textsuperscript{16} had conducted an experimental program to study the effects of fiber inclusions and lime stabilization on geotechnical characteristics of fly ash-soil mixtures. From the results it was observed that the expansive soil can be successfully stabilized by the combined action of fibers, lime and fly ash.

Zha et al.\textsuperscript{17} studied the potential use and the effectiveness of stabilization of expansive soils using fly ash and fly ash-lime as admixtures. The test results showed that the plasticity index, activity, free swell, swell potential, swelling pressure and axial shrinkage percent decreased with an increase in fly ash or fly ash-lime content.

Rao et al.\textsuperscript{18} carried out a study on the performance of lime stabilized fly ash cushion and found that it was quite effective in arresting volume changes in expansive soils. A fly ash cushion, stabilized with 10% lime and with thickness equal to half that of the active zone in an expansive soil bed, reduces heave by about 68% initially. With subsequent cycles of swelling and shrinkage the percentage reduction in swelling is as much as 99.2%.

Research was carried out by Rama Rao et al.\textsuperscript{19} using cement-stabilized fly ash as a cushioning material, on the expansive soil bed. The results showed that it was quite effective in arresting heave also fly ash cushion, stabilized with 10% cement with thickness equal to that of the expansive soil bed reduces heave by about 75% in the first instance and at the end of fourth cycle of swelling, the reduction in the amount of heave is as high as 99.1%.

In the present work, an attempt is made to study the performance of lime-cement stabilized fly ash layer in subbase course of the flexible pavement system in comparison to the fly ash subbase layer.

**Materials and Methods**

**Expansive soil**

The soil used for subgrade is expansive soil collected from ‘Godilanka’ near Amalapuram, East Godavari District. This soil is classified according to I.S. classification as inorganic clay of high compressibility (CH). The properties are given in Table 1.

**Sand**

The sand is used as subgrade material for the test track. The properties obtained from the laboratory tests are furnished below in Table 1.

**Fly ash**

Fly ash is used as subbase material collected from Vijayawada thermal power station. The properties of fly ash are given in Table 1 and the chemical properties in Table 2.

**Road metal**

Road metal of size 20 mm conforming to WBM – III was used as base course material.

**Chemicals**

Different chemicals, viz., lime and cement were used as stabilizing materials in the experiment.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Expansive soil</th>
<th>Sand</th>
<th>Fly ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>2.72</td>
<td>2.68</td>
<td>1.95</td>
</tr>
<tr>
<td>Grain-size distribution:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel (%)</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Sand (%)</td>
<td>4</td>
<td>96</td>
<td>25</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>34</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Clay (%)</td>
<td>62</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Maximum dry density (kN/m(^3))</td>
<td>15.69</td>
<td>17.0</td>
<td>13.24</td>
</tr>
<tr>
<td>O.M.C. (%)</td>
<td>23</td>
<td>10</td>
<td>24</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shrinkage limit (%)</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Swell Index (%)</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IS Classification:</td>
<td>CH</td>
<td>SW</td>
<td></td>
</tr>
<tr>
<td>Soaked CBR (%)</td>
<td>2</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Coefficient of uniformity((C_u))</td>
<td>6.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coefficient of Curvature((C_v))</td>
<td>1.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeability (cm/sec)</td>
<td>(1.5 \times 10^{-7})</td>
<td>(2 \times 10^{-3})</td>
<td>(0.5 \times 10^{-6})</td>
</tr>
</tbody>
</table>

Table 2—Chemical properties of fly ash (Courtesy VTPS, Vijayawada)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of chemical</th>
<th>Symbol</th>
<th>Range of % by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silica</td>
<td>SiO(_2)</td>
<td>61 to 64.29</td>
</tr>
<tr>
<td>2</td>
<td>Alumina</td>
<td>Al(_2)O(_3)</td>
<td>21.6 to 27.04</td>
</tr>
<tr>
<td>3</td>
<td>Ferric oxide</td>
<td>Fe(_2)O(_3)</td>
<td>3.09 to 3.86</td>
</tr>
<tr>
<td>4</td>
<td>Titanium dioxide</td>
<td>TiO(_2)</td>
<td>1.25 to 1.69</td>
</tr>
<tr>
<td>5</td>
<td>Manganese oxide</td>
<td>MnO</td>
<td>Up to 0.05</td>
</tr>
<tr>
<td>6</td>
<td>Calcium oxide</td>
<td>CaO</td>
<td>1.02 to 3.39</td>
</tr>
<tr>
<td>7</td>
<td>Magnesium oxide</td>
<td>MgO</td>
<td>0.5 to 1.58</td>
</tr>
<tr>
<td>8</td>
<td>Phosphorous</td>
<td>P</td>
<td>0.02 to 0.14</td>
</tr>
<tr>
<td>9</td>
<td>Sulphur trioxide</td>
<td>SO(_3)</td>
<td>Up to 0.07</td>
</tr>
<tr>
<td>10</td>
<td>Potassium oxide</td>
<td>K(_2)O</td>
<td>0.08 to 1.83</td>
</tr>
<tr>
<td>11</td>
<td>Sodium oxide</td>
<td>Na(_2)O</td>
<td>0.26 to 0.48</td>
</tr>
<tr>
<td>12</td>
<td>Loss of ignition</td>
<td></td>
<td>0.20 to 0.85</td>
</tr>
</tbody>
</table>
Lime
Commercial grade lime mainly consisting of 58.67% of CaO and 7.4% silica was used in the study.

Cement
Ordinary Portland cement with Raasi brand 43 grade was used in the investigation. The properties of Portland cement as supplied by the manufacturer are given below.
- Normal consistency: 30% by weight of cement
- Percentage fineness: 8%
- Initial setting time: 30 min
- Final setting time: 130 min
- Specific gravity: 3.15

Experimental Procedure
Laboratory California Bearing Ratio (CBR) tests
CBR tests are conducted in the laboratory as per IS specifications (IS: 2720) (part16). Different percentages of lime/cement is mixed with the fly ash separately and compacted at OMC of untreated fly ash. Soaked CBR tests are conducted for different mixes, i.e., fly ash + lime + cement in the laboratory as per IS specifications. It has been found from the laboratory results that fly ash with 2% lime + 0.5% cement are giving a CBR value of 20%.

Construction of model flexible pavements
In this investigation four model flexible pavements were prepared in the laboratory by using 60 cm diameter mild steel tank with different alternatives as given in Table 3. Expansive soil and sand soil were used as subgrade soils for all the tests. Out of the four model flexible pavements two with expansive soil subgrade and other two with sand subgrade were considered in this study. Above all the four alternative subbases, WBM-III base course was laid uniformly.

Sand Subgrade
Preparation of subgrade — The sand used for subgrade was collected at a depth of 30 cm below the ground level from JNTU Engineering College Campus, Kakinada. The sand was compacted to 2 cm thickness in 10 layers to a total thickness of 20 cm to its optimum moisture content and maximum dry density in the mild steel tank.

Preparation of subbase — On the prepared sand subgrade, fly ash mixed with water at OMC was laid in layers of 2.5 cm compacted thickness to a total thickness of 5.0 cm. The subbase layer was compacted corresponding to MDD and OMC of untreated fly ash. For lime-cement stabilized fly ash subbase the desired contents of 2% lime + 0.5% cement (obtained from laboratory CBR test results) were added to the fly ash and compacted corresponding to the maximum dry density at optimum water content of fly ash. All these layers were compacted to optimum moisture content and maximum dry density.

Base course — On the prepared subbase, two layers of WBM-III each of 2.5 cm compacted thickness, was laid to a total thickness of 5.0 cm.

Expansive Soil Subgrade
Preparation of subgrade — Sand bed of 1.0 cm thickness was placed before laying the subgrade soil in the tank. The expansive soil brought from Godilanka, near Amalapuram was allowed to dry and then pulverized with wooden rammers and sieved through 4.75 mm sieve. Sand drains were provided by means of 3 vertical sand columns of 4.0 cm diameter from bottom to top of the subgrade soil for saturation. Then it was compacted to 2.0 cm thickness in 10 layers to a total thickness of 20 cm to its optimum moisture content and maximum dry density in mild steel test tank.

Preparation of subbase — On the prepared subgrade, fly ash mixed with water at OMC was laid in two layers each of 2.5 cm compacted thickness to a total thickness of 5.0 cm. The subbase layer was compacted corresponding to MDD and OMC. The lime-cement stabilized fly ash subbase was prepared similar to cement stabilized fly ash subbase except in place of cement, 2% lime + 0.5% cement (obtained from laboratory CBR test results) were added to fly ash and compacted corresponding to maximum dry density at optimum moisture content of fly ash. All these layers were compacted to optimum moisture content and maximum dry density.

Base course — On the prepared subbase two layers of WBM-III each of 2.5 cm compacted thickness, were laid to a total thickness of 5.0 cm.

Table 3 — Details of the model flexible pavements in the laboratory

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Sub-grade</th>
<th>Sub-base</th>
<th>Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Expansive soil</td>
<td>Fly ash</td>
<td>WBM - III</td>
</tr>
<tr>
<td>2</td>
<td>Expansive soil</td>
<td>Fly ash + 2% lime + 0.5% cement</td>
<td>WBM - III</td>
</tr>
<tr>
<td>3</td>
<td>Sand</td>
<td>Fly ash</td>
<td>WBM - III</td>
</tr>
<tr>
<td>4</td>
<td>Sand</td>
<td>Fly ash + 2% lime + 0.5% cement</td>
<td>WBM - III</td>
</tr>
</tbody>
</table>
Heave measurements in the laboratory

The model flexible pavement system was saturated completely by pouring water above the base course. Heave readings were taken with the help of dial gauges at regular intervals, for the expansive soil subgrade pavements. These readings were measured until there was no significant change between consecutive readings observed.

Cyclic load test in the laboratory

These tests were carried out on flexible pavements systems in a circular steel tank of diameter 60 cm as shown in Figs 1 and 2. The loading was done through a circular metal plate of 10 cm diameter laid on the model pavement system. The steel tank was placed on the pedestal of the compression testing machine. A 50 kN capacity proving ring was connected to the loading frame and the extension rod welded to the circular plate was brought in contact with proving ring. Two dial gauges of least count 0.01 mm were placed on the metal flats welded to the vertical rod to measure the vertical displacements of the loading plate. The load was applied in increments corresponding to type pressures of 500, 560, 630, 700 and 1000 kPa and so on and for each pressure increment was applied, cyclically, until there was insignificant increase in the settlement of the plate between successive cycles. The testing was further continued till the occurrences of failure to record the ultimate loads.

For tests in saturated condition, the soil was allowed to absorb water by providing a thin sand layer (10 mm thick) at the bottom and also through vertical sand drains. Two inlet valves are welded on opposite sides of the tank through which water was supplied. The dial gauge readings were recorded until maximum heave was obtained and during this process, proving ring was disconnected. Cyclic load tests were also carried out in saturated state exactly in the same manner as for those at OMC. These tests were carried out at OMC and in saturated states for all the model flexible pavements.

Field Experimentation

In this investigation four test tracks of 3 m long and 1.5 m wide are laid on expansive soil subgrade and on sand subgrade as shown in the Fig. 3 in the campus of JNTU Engineering College. Out of the four test tracks, the two test tracks with expansive soil subgrade and other two test tracks with sand subgrade are considered. The two alternative subbases, viz., alternative-1: fly ash subbase and alternative-2: lime-cement stabilized fly ash subbase is constructed on expansive soil subgrade and also on sand subgrade. Above all the subbase courses, WBM base course II is laid uniformly.

Construction procedure of test track on expansive soil subgrade

Two alternative test tracks are prepared on expansive soil subgrade, with different subbases the details of which are presented below.

Fly ash subbase (alternative – 1)

Excavation of test pit — A trench of size 3 m long and 1.5 m wide is excavated to an average depth of
0.8 m. Out of which 0.5 m is for laying subgrade, 0.15 m is for laying subbase and 0.15 m for laying base course.

Preparation of subgrade material — In this stretch, the expansive soil brought from ‘Godilanka’ is spread in the field, allowed to dry sufficiently and then pulverized to small pieces with wooden rammers.

Laying of subgrade material — In the prepared trench, the pulverized expansive soil mixed with water at OMC is laid in layers of 5 cm compacted thickness, to a total thickness of 50 cm. The compaction corresponding to MDD is done using hand-operated roller.

Subbase — On the prepared subgrade, fly ash mixed with water at OMC is laid, in three layers, each of 5 cm compacted thickness to a total thickness of 15 cm. Each layer is compacted to MDD using hand-operated roller.

Base course — Over the prepared subbase, a layer of WBM-II of 7.5 cm compacted thickness was laid, over which another layer of WBM-III of 7.5 cm compacted thickness was laid.

Lime–cement stabilized fly ash subbase (alternative- 2)

This stretch is also constructed similar to alternative-1, but instead of fly ash, lime-cement stabilized fly ash is used as subbase material. Based on the laboratory soaked CBR tests 2% lime + 0.5% cement, giving 20% CBR is used for preparation of lime-cement stabilized fly ash layer. Accordingly, 2 % of lime + 0.5 % cement is mixed separately with fly ash in dry state and then water is added to the mix corresponding to OMC and the mix is laid in three layers of 5 cm compacted thickness to a total thickness of 15 cm. Each layer is compacted to MDD using hand operator roller. After sufficient curing of the subbase, 15 cm thick compacted base course is laid.

Construction procedure of test tracks on sand subgrade

Two test tracks are prepared on sand soil subgrade, with different subbases.

Fly ash subbase (alternative- 3)

Excavation of test pit — A trench of size 3 m long and 1.5 m wide is excavated to an average depth of 0.8 m. Out of which 0.5 m for laying subgrade, 0.15 m is for laying subbase and 0.15 m for laying base course.

Laying of subgrade material — In the prepared trench, sand was mixed with water at OMC and was laid in layers of 5 cm compacted thickness to a total thickness of 50 cm. The compaction corresponding to MDD was done using hand operated roller.

Subbase — On the prepared subgrade, 15 cm thick fly ash subbase consisting of 3 layers each of 5 cm compacted thickness was laid.

Base course — Over the prepared subbase, a layer of WBM-II of 7.5 cm compacted thickness was laid, over which another layer of WBM-III of 7.5 cm compacted thickness was laid.

Lime–cement stabilized fly ash subbase (alternative- 4)

This stretch was also constructed similar to alternative-3, but instead of fly ash, lime-cement stabilized fly ash was used as a subbase material.

In-situ tests on pavement systems

Expansive soils behave critically in both dry and wet seasons because of the presence of montmorillonite mineral. Hence, various field studies were carried out in both dry and wet seasons with a view to study the relative performance of the adopted stabilizing agents.

Heave measurements

Cement concrete panels of size 0.3 m × 0.3 m × 0.05 m were placed centrally in all the stretches for heave measurements. The reduced levels of the top of panels were fixed using leveling instrument with 5 mm accuracy and heave measurements were taken during wet and dry seasons for all the stretches laid on expansive soil subgrades.

Cyclic plate load test

Cyclic plate load tests were carried out for all the two test stretches with the adopted stabilizing technique under normal tyre pressures using circular
steel plate of diameter 0.3 m. A loading frame was loaded with the help of sand bags as shown in Fig. 4. The loading frame was arranged centrally over the test track. A steel base plate of 0.3 m diameter was placed centrally over the test pit. Hydraulic jack of capacity 500 kN was placed over the plate attached to the loading frame with a loading cylinder. Three dial gauges with a least count of 0.01 mm were placed on the metal flats to measure the settlements. A load of 5 kPa was applied as a seating load with the help of hydraulic jack and released. The load was applied in increments corresponding to tyre pressures of 500, 560, 630, 700 and 1000 kPa and each pressure increment was applied cyclically until there was insignificant increase in the settlement of the plate. These tests were carried out on all the prepared stretches in both dry and wet seasons. The process of loading and unloading for each pressure intensity was continued in a cyclic manner until difference in deformation level between successive cycles was negligibly small.

**Results and Discussion**

**Laboratory test results**

Soaked CBR tests for lime-cement-fly ash mixes are conducted in the laboratory. Based on the results, it is observed that mix having 2% lime + 0.5% cement in fly ash is giving a soaked CBR value of 20%, which is desirable for subbase material as per IRC 37-2001.

**Heave-time studies**

Figure 5 depicts the influence of different treatment alternatives laid on expansive subgrade in respect of heave. It is observed that there is a maximum reduction in heave for lime-cement stabilized subbase model flexible pavement system compared to fly ash model flexible pavement.

**Load test results**

It can be observed from Fig. 6 that load carrying capacity is significantly increased for lime cement stabilized fly ash alternative in comparison with fly ash alternative for both subgrades. The improvement in the load carrying capacity could be attributed to the improved load dispersion through stabilized subbase on to the subgrade.

**Results of field studies**

**In-situ heave-time studies**

The influence of different alternatives laid on expansive subgrade in respect of heave is shown in Fig. 7. From Fig. 7, it is observed that the maximum heave values are 5.96 mm and 2.42 mm for the test track stretches with fly ash and lime-cement fly ash subbase respectively. It can be seen that there is a maximum reduction in heave values for lime-cement stabilized fly ash subbase with respect to fly ash subbase.
These results are in conformity with the previous works carried out with stabilized fly ash as cohesive material in arresting heave\textsuperscript{22-24}. Cyclic load test results for different alternative test stretches Cyclic plate load tests are carried out on all the test stretches laid on sand sub-grade and clay subgrades for the two different subbases, viz., fly ash and lime-cement stabilized fly ash. All the tests are carried out for different tyre pressures during wet season. It can be seen from Fig. 8 that lime-cement stabilized fly ash stretch has shown improvement in load carrying capacity. The improvement in load carrying capacity is more prominent in the test stretch laid on sand soil subgrade compared to expansive soil subgrade. Further, it can be seen that heaving of the expansive soil considerably decreases the load carrying capacity of the pavement system. The improvement in the load carrying capacity could be attributed to the improved load dispersion through stabilized subbase on to the subgrade. This in turn results in lesser intensity of stresses getting transferred on to subgrade, thus leading to lesser subgrade distress.

Conclusions The following conclusions are drawn based on the experimental studies carried out in this investigation.

(i) The load carrying capacity of the flexible pavement system is significantly increased for lime-cement stabilized fly ash subbase stretch with respect to the fly ash subbase stretch, on sand subgrade and on expansive subgrade. The total deformation values of the flexible pavement system are decreased considerably for the lime-cement stabilized fly ash subbase stretch, when compared with fly ash subbase stretch both on sand subgrade and expansive subgrade respectively.

(ii) From Fig. 8, it is observed that the total deformation at 500 kPa is decreased by 52.73\% for treated lime-cement fly ash subbase when compared to untreated fly ash subbase laid on sand subgrade. For expansive soil subgrade the total deformation at 500 kPa is decreased by 65.07\% for treated lime-cement fly ash subbase as compared to untreated fly ash subbase stretch in the laboratory.

(iii) In case of field stretches, the total deformation at 500 kPa is decreased by 52.68 \% for treated lime-cement fly ash subbase when compared to untreated fly ash subbase laid on sand subgrade. For expansive soil subgrade, the total deformation is decreased by 72.86\% for treated lime-cement fly ash subbase as compared to untreated fly ash subbase stretch.

(iv) Maximum reduction in heave values are obtained for the lime-cement stabilized fly ash subbase stretch compared to other stretches on expansive soil subgrade. Heaving of the expansive soil has considerably decreased the load carrying capacity of flexible pavement system.

References