Bearing Capacity of Square Footing on Soft Soil Stabilized with Rice Husk Ash—An Experimental Study

Dr. R.K. Tripathi, and Laxmikant Yadu

Abstract—Laboratory model study of load settlement behavior was undertaken to evaluate the effectiveness of rice husk ash (RHA) as soil stabilizers. Soft soil having low unconfined compressive strength (UCS) have been collected from the site and improvement in UCS and load settlement behavior have been obtained by mixing RHA as soil stabilizers. Load settlement behavior and UCS of unstabilized and stabilized soil have been determined by mixing the RHA in different percentage i.e. 3%, 6%, 9%, 12% and 15%. Bearing capacity ratio (BCR) at ultimate load and settlement reduction ratio (SRR) two terms have been used to evaluate the effectiveness of rice husk ash. From the laboratory test considerable increase in UCS, BCR and reduction in settlements have been observed. 12 % rice husk ash has been observed as optimum dose for stabilizing the soft soil.

Keywords—Bearing capacity; Model test; Soft soil; Rice usk ash; Unconfined compressive strength.

I. INTRODUCTION

Soft soil creates problem in civil construction works due to its high compressibility and low bearing capacity. Low bearing capacity and high settlement behavior of soft soils is the challenge for the engineers to work on it. Various works have been reported in the literature to reinforce the low strength soil to increase its bearing capacity. Various materials used by researchers to reinforce the soil are metal strips [2 and 14], metal bars [2], rope fibres [6] and geotextiles/geogrid/geocells [7, 15, 16, 17, 19 and 20]. Apart from the reinforcing materials some soil stabilizers (i.e., fly ash, cement kiln dust, lime) and locally available materials (i.e., slate dust, rice husk ash) can be used for stabilization of soil. Some studies reported in the literature have used RHA to evaluate the index properties i.e specific gravity, atterberg’s limit, compaction and strength properties i.e. California and bearing ratio and unconfined compressive strength of soil [1, 4, 8, 10, 11, 12 and 18]. They have observed considerable improvement in index properties and strength properties of stabilized soil with RHA as compared to virgin soil. From the literature review, it has been observed that much attention has not been given to get the load settlement behavior of rice husk ash stabilized soil with locally available material RHA. With this consideration, present study has been undertaken to evaluate the effectiveness of rice husk ash as an admixture for improving the bearing capacity and reduction of settlement of soft soil.

II. MATERIAL PROPERTIES

A. Soft Soil

Soil having 70% fraction finer than 75 micron has been used in this study. Index properties of the soil have been found in the laboratory and tabulated in Table I. Soil has been classified as low compressible soil with letter symbol ‘CL’ as per unified soil classification system (USCS). Amount of water content present in the soil defines its state of consistency. Soft state of the soil has been used for evaluating the load settlement behavior of the soil. For evaluating soft state of the soil mass a parametric study has been performed by adding various percentage of water in soil. Cylindrical sample of length to diameter ratio 2:1 have been prepared and unconfined compressive strength (UCS) obtained in the laboratory. Fig. 1 shows the variation of UCS with water content. From the Fig. 1, it can be observed that water content corresponding to 30 % gives minimum value of UCS. Hence, 30 % water content has been chosen as critical water content to obtain the soft state of soil. Same amount of water content (i.e. 30%) has been used for preparing the soil bed in the model test to get the load settlement behavior of virgin as well as stabilized soil with RHA. Unit weight of soil at 30 % of water content has been found in the laboratory. Soil bed of same unit weight has been prepared in the test tank by adding 30% of water content and imparting proper compaction energy to maintain the uniformity of the test condition throughout the test series.

B. Rice Husk Ash

RHA was identified as Non-Plastic (NP) material with 94% liquid limit and having low specific gravity 2.039 as compared to virgin soil. Maximum dry density and optimum moisture content has been found 6.97 kN/m³ and 45.5 % respectively.
TABLE I
PROPERTIES OF SOIL

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Field moisture content (%)</td>
<td>3.26</td>
</tr>
<tr>
<td>2</td>
<td>Maximum dry density (kN/m^3)</td>
<td>19.84</td>
</tr>
<tr>
<td>3</td>
<td>Optimum moisture content (%)</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Liquid limit (%)</td>
<td>52</td>
</tr>
<tr>
<td>5</td>
<td>Plastic limit (%)</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>Plasticity index (%)</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>Specific gravity</td>
<td>2.63</td>
</tr>
</tbody>
</table>

III. MODEL TEST SETUP AND PROCEDURE

A. Model Test Setup

Load settlement behavior of un-stabilized soil and stabilized soil with RHA has been found on a square test tank of dimension 0.3 m X 0.3 m and depth 0.33 m. A square plate of dimension 0.06 m X 0.06 m and thickness 0.0124 m has been used as a square footing. Dimension of the test tank has been kept 5 times of the dimension of the footing plate, to minimize the boundary effect. A gravity loading arrangement as shown in the Fig. 2, with tripod stand, a plunger at center and a loading platform on top has been used to load the footing plate. A number of constant weights have been kept one by one in the loading platform to load the footing plate. Corresponding settlement has been measured with vernier caliper attached with loading arrangement and kept on the footing plate as shown in Fig. 2.

B. Preparation of Soil Bed

To prepare the soil bed in the test tank, oven dried soil sample has been taken and broken the lumps of the soil sample with wooden mallet. As per the height and unit weight of the soil bed, to be maintained in the test tank, amount of soil sample has been calculated and properly mixed with 30 % of water content. To compact the soil bed in the test tank with specific unit weight and height, required amount of compaction energy has been determined by various trials in prior. The same compaction energy has been given by the wooden board placed at the top of the filled soil and hammering the board with a drop hammer of base diameter 10 cm with weight 14 kg by certain number of blows. The soil has been compacted in the test tank in 4 equal layers each of 50 mm height. RHA mixed soils have also been compacted in the test tank in the similar way. After the preparation of soil bed, square footing placed at the center of the top surface of the leveled soil bed. After each load test, undisturbed cylindrical samples have been extracted from the soil bed to find the unit weight and UCS. Average unit weight of different test series of soil bed shows less than 2 % variation as compared to unit weight previously obtained for soil sample with 30 % water content. Test having higher variation in unit weights have been discarded and repeated the same.

C. Test Procedure

Load tests in the laboratory have been performed as per Indian standards [5]. Square footing placed at top of prepared leveled surface of soil bed in the test tank and loaded with gravity loading as shown in Fig. 2. Load in terms of constant weights have been placed on the loading platform and maintained for a sufficient time. Settlement has been recorded at different time interval after loading say 0.5, 1, 2, 4, 8, 15, 30, 60 minutes and each 60 minutes interval until settlement of footing becomes less than 0.02 mm. Afterwards next increment of load applied. The test has been continued upto the total footing settlement of 20 % of the footing width.

Fig. 1 Variation of UCS with water content of un-stabilized soil.

Fig. 2 Pictorial view of the model test setup

IV. RESULTS AND DISCUSSION

This section shows the results of the load settlement behavior and discussion in the various aspects i.e. increase in load bearing capacity and decrease in footing settlement. To show the increase in bearing capacity of various cases a term bearing capacity ratio at ultimate load has been used [7]. Ultimate Bearing capacity ratio (BCR_u) defines as ratio of ultimate bearing capacity of stabilized soil with different percentage of RHA to the ultimate bearing capacity of unstabilized soil. Decrease in footing settlement of stabilized soil as compared to un-stabilized soil has been represented by a
term settlement reduction ratio (SRR). SRR defines as ratio of difference between settlement of un-stabilized and stabilized soil to settlement of un-stabilized soil at constant load. These two terms have been used throughout in this paper to discuss the results.

A. Load Settlement Curve

Fig. 3 show the load settlement curve of the unstabilized and stabilized soil with different percentage of rice husk ash i.e. 3%, 6%, 9%, 12% and 15%. From the Fig. 3 it can be noticed that curves do not show the marked sign of failure hence to evaluate the ultimate bearing capacity of various cases log-log curve of difference cases has been plotted and approximate value of ultimate bearing capacity has been found as per IS 1888:1982. Typical log-log curve of the un-stabilized case (i.e. 0 % RHA) is shown in Fig.4.

B. Effect on BCR of different % of RHA

Variation of ultimate bearing capacity with various percentages of RHA stabilized soil is shown in Fig. 5. Initially ultimate bearing capacity increases with increase of RHA amount. After certain value of RHA, further increases of RHA do not cause significant increase in ultimate bearing capacity and becomes almost constant. From Fig. 5, it can be noticed that ultimate bearing capacity value increases initially and reaches maximum 69 kN/m² at 12 % RHA as compared to 52 kN/m² of un-stabilized soil. Further increase of RHA amount causes slight decrease in ultimate bearing capacity. The initial increase in the bearing capacity with addition of RHA is attributed to the formation of cementitious compounds between the CaOH present in the soil and the pozzolana present in the RHA. The decrease in the ultimate bearing capacity values after addition of 12% RHA may be due to formation of weak bonds between the soil and the cementitious compounds formed [13]. Bearing capacity ratio at ultimate load has been calculated and variation of the BCR with % of RHA is shown in Fig. 6. Maximum value of BCR obtained from the graph as 1.33 at 12 % RHA, there after slight decrease has been observed. 33 % increase in ultimate bearing capacity has been observed at 12 % RHA.

C. Effect on settlement reduction ratio of different % of RHA

Sometimes shallow foundations are designed for limited settlement. Differential settlements in the foundations also causes serviceability problem in various structures. To reduce this problem, it is essential to reduce the individual settlement as well as differential settlement of the foundation. With these considerations settlement reduction ratios have been obtained of the square foundation at various loads. Three loads namely ultimate loads and about twice & thrice of the ultimate load have been considered to show the settlement reduction of the square foundation. Variations of the SRR with % of RHA for three loads i.e. 52, 105 and 150 kPa is shown in Fig. 7. From the Fig. 7, it can be noticed that at the ultimate load rate of reduction in settlement is more as compared to loads higher than the ultimate load. At the ultimate load, initial reduction in settlement is more by addition of the RHA. It reaches to maximum and becomes constant thereafter. Maximum SRR observed as 0.24 corresponding to 6% of RHA at ultimate load and further increase of RHA it become almost constant. Maximum reduction in settlement has been observed as 24 % at ultimate load. Load higher than ultimate loads do not show much reduction in settlement, however trend of reduction in settlement by addition of various percentage of RHA is similar to the variation at ultimate load.

D. Effect on unconfined compressive strength of different % of RHA

Formation of cementitious compounds between pozzolanic materials present in the RHA and CaOH present in the soil strengthen the stabilized soil and increases the load carrying capacity. Along with load test for finding the ultimate bearing capacity of the stabilized soil, unconfined compressive strength is also evaluated by taking out the cylindrical sample of length to diameter ratio 2.0 from the soil bed after each model load test. Variation of UCS with various percentage of RHA is shown in Fig. 8. From the Fig. 8, it can be inferred that there is considerable increase in UCS at various percentage of RHA. Initially UCS value increases as increases the RHA amount, reaches at maximum value 202 kN/m² at 12 % RHA as compared to 33 kN/m² of un-stabilized soil. Thereafter there is slight decrease in UCS by further increase of RHA amount. Hence, about 500 % increase in UCS value have been observed by addition of 12 % RHA.
V. CONCLUSIONS

Model tests have been performed to evaluate the effect of bearing capacity of square footing of soft soil stabilized with various percentages of RHA i.e. 3, 6, 9, 12, 15%. Settlement reduction ratio and unconfined compressive strength of stabilized soil has also been evaluated to obtain the effect of stabilization. Based on the model test results following conclusions can be drawn.

1. Substantial increase in bearing capacity and reduction in settlement has been observed by addition of RHA with soil.
2. Maximum 33% increase in ultimate bearing capacity and 24% reduction in settlement has been observed by addition of 12% RHA.
3. Reduction in settlement has been observed as more at ultimate load as compared to higher load than ultimate load.
4. Significant increase in unconfined compressive strength has been observed. 500% increase in UCS has been observed at 12% RHA.
5. Based on the ultimate compressive strength and UCS, 12% of RHA amount has been considered as optimum amount as stabilizer for soft soil.
6. RHA is a potential waste product for stabilization of soft soil prone sites for the construction of relatively lighter civil structures.

However, above findings are based on the model test performed in the laboratory. It depends upon the various factors like chemical composition of soil and rice husk ash, type of footing and shape of footing. More tests have to perform to generalize the conclusions.

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REFERENCES