LOAD BEARING CAPACITY OF FOOTING RESTING ON A MULTILAYER REINFORCED FLY ASH SLOPE

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ABSTRACT: In several parts of the world, disposal of waste materials like fly ash is a great problem. Applications of some waste materials as structural fills in foundations is one of the best solutions to disposal problems, because wastes can be used in large volumes. There may be difficulty due to poor load-bearing capacity of fly ash, especially when footings are rested on the top of the fly ash fill slope; but inclusion of polymeric reinforcements as horizontal sheets within the fill may be one of the most viable solutions to improving the load-bearing capacity of reinforced fly ash slope. The aim of present investigation is to find out the efficacy of more than one layer of reinforcement in improving the load-bearing capacity when it gets incorporated within the body of a model fly ash embankment slope. An increase in load bearing capacity due to the incorporation of reinforcement in the model slope was found by conducting laboratory tests. Experimental results were compared by numerical findings obtained using commercial software PLAXIS.

INTRODUCTION
Use of geosynthetic reinforcements for improving load-bearing capacity of foundation has been extensively reported by researchers by using different foundation materials. These investigations have demonstrated that ultimate bearing capacity and settlement characteristics of the foundation can be improved by the inclusion of reinforcements within the fill. In reality, there are many situations where foundations need to be located either on the top of a slope or on the slope itself, for examples foundation of a bridge abutment, foundations constructed on hill slopes, etc. When a footing is constructed on a sloping ground, the bearing capacity of the footing may be significantly reduced depending upon the location of the footing with respect to slope. The improvement of load-carrying capacity of such loaded slopes is therefore one of the important aspects of geotechnical engineering practice because structures are liable to be unsafe due to slope failure. One of the possible solutions to improve the bearing capacity would be reinforcing the sloped fill with the layers of geogrid. To design a footing on a reinforced sloped fill requires a thorough understanding of both the bearing capacity behaviour of the footing and mechanical behaviour of the reinforced slope. Limited studies on bearing capacity behaviour of strip footings on reinforced slopes have been reported in the literature [1-7]. For the first time a comprehensive overview of geosynthetic-reinforced slopes were presented by Shukla et al. [8], including the suitability of geosynthetics, modes of failure, methods of slope stability analysis and design, model studies, and typical slope stabilization methods and some specific recommendations. The decreasing availability of good construction sites has led to the increased use of low-lying areas filled up with industrial wastes whose bearing capacity is low. Many times the industrial wastes (fly ash, blast furnace slag, etc.) often termed as man-made soils, if available locally and found suitable can reduce the construction cost significantly apart from encouraging the sustainable development and reducing the environmental problems. In several parts of the world, disposal of waste materials like fly ash is a great problem and requires a large land area. Acquiring open lands for disposal in developing countries like India is difficult due to small land-to-population ratio. In the areas of thermal power plants as well as in near-by areas, fly ash fill can be used to elevate the foundation level of footings in low-lying areas. Fly ash when used as structural fills or as embankments offers several advantages over borrow soils. It is light in weight, exerts low pressure on subgrade as a fill material, and a well compacted embankment made of fly ash would exert only 50% of the pressure on a soft subgrade as a fill of equivalent height using coarse granular material. Additionally, the compaction curve of fly ash is relatively flat, thus implying that construction is less sensitive to compaction-moisture content than that of the fine grained soils commonly used as structural fill [9]. Fly ash being non-plastic will also solve the problem of dimensional instability as exhibited by plastic soils. Further properties of fly ash from a given source are likely to be more consistent as compared to the soil from natural borrow areas. There may be difficulty due to poor load-bearing capacity of fly ash, especially when footings are rested on the top of the fly ash fill slope. Inclusion of polymeric reinforcements as horizontal sheets within the fill may be one of the most viable solutions for improving the load-bearing capacity of reinforced fly ash slope. Studies on bearing capacity of shallow foundations on a level and plain fly ash ground have been reported in literature by several authors but very limited studies on load carrying capacity behavior of footing resting on a reinforced fly ash slopes are available.
in the literature [9-11]. The bearing capacity determination technique is an important part for correct design of footings on reinforced slope. In recent years, numerical analyses such as finite difference and finite element analyses have become popular in design practices. However, despite many attempts, no obvious method for determination of ultimate bearing capacity of strip footing resting on reinforced slope is available and therefore much investigation still remains to be carried out. In view of limited information available on this aspect in the literature, the aim of present investigation is to find out the efficacy of multilayer reinforcement in improving the load-bearing capacity when it gets incorporated within the body of a fly ash embankment slope. An increase in load bearing capacity due to the incorporation of reinforcement in the model slope was found by conducting laboratory tests. These experimental results were compared by load bearing capacity values obtained numerically using PLAXIS software. In the experimental investigations, the reinforcement was provided in the form of multilayer reinforcement, and the number of layers was varied as well. The results showed an increase in load bearing capacity due to the incorporation of reinforcement in the model slope. 

Table 1. Variables of the investigation

<table>
<thead>
<tr>
<th>Variables (Laboratory test and numerical analysis)</th>
<th>Fly ash model test results. PLAXIS software (version 8.0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of test</td>
<td>Constant parameter</td>
</tr>
<tr>
<td>Reinforced slope</td>
<td>B = 100 mm</td>
</tr>
<tr>
<td></td>
<td>D&lt;sub&gt;r&lt;/sub&gt;/B = 1.0</td>
</tr>
<tr>
<td></td>
<td>z&lt;sub&gt;j&lt;/sub&gt;/B = 0.25, 0.50, 1.0, 1.5, 2.0, 2.50, 3.0</td>
</tr>
<tr>
<td></td>
<td>β = 45°</td>
</tr>
<tr>
<td></td>
<td>N = 1, 2, 3, 4, 5, 6, 7</td>
</tr>
<tr>
<td></td>
<td>L&lt;sub&gt;r&lt;/sub&gt; = 7B</td>
</tr>
</tbody>
</table>

LABORATORY MODEL TEST

Fly ash procured from electrostatic precipitators of TISCO (Tata Iron and Steel Company Limited), Jamshedpur, India was used throughout the investigation. As per the particle size distribution, fly ash consists of 68% silt and 28% sand. Using standard proctor test, the maximum dry unit weight and the corresponding optimum moisture content (OMC) were found to be 9.34 kN/m³ and 48% respectively. The value of apparent cohesion (c) and angle of internal friction (φ) were 20 kPa and 14°, respectively. Commercially available polypropylene model geogrids (0.27 mm thick and 300 mm wide) having an average tensile strength (EA) of 4.0 kN/m and tie-soil friction angle (φ<sub>t</sub>) equal to 35° were used as reinforcing elements. A series of plain strain model tests were conducted on unreinforced and reinforced fly ash slope models by loading it with a strip footing resting on the crest of slope to failure. The experimental setup and test procedure is available in detail in literature [9]. The geometry of the test configuration has been shown in Fig. 1.

NUMERICAL APPROACH

A series of two dimensional finite element analysis (FEA) using PLAXIS software (version 8.0) were performed for numerical analysis on reinforced fly ash slope assuming Mohr-Coulomb model theory in order to verify the
RESULTS AND DISCUSSION

The comparison of experimental and numerical results has been shown through Figs. 7 - 9. A typical variation of pressure and settlement ratio with and without soil reinforcement for different layer of reinforcement (N = 1-7) is presented in Fig. 6. In this series, all the tests were performed on a 100 mm wide footing placed at an edge distance; \( D_e = 1.0B \) from the slope crest at slope angle, \( \beta = 45^\circ \). It can be seen from Fig. 6 that the ultimate bearing pressure of the footing increases with an increase in number of reinforcement layers up to certain value and thereafter any further increase in number of reinforcement layers (N) does not enhance the ultimate bearing capacity of the footing. The experimental results are in good agreement with findings of numerical analysis. Maximum improvement in ultimate bearing capacity occurs when number of reinforcement is four or more, which is highly consistent with the results reported in literature [1, 3, 4, 6] for reinforced sand slope though the fill material used in the present investigation is different. In order to study the effect of number of reinforcing layers (N) on the footing slope performance, studies were carried out in which all other parameters were kept constant except the number of
reinforcement layers (N). The embedment ratio (z/B) for multilayer reinforcement were varied from 0.25 to 3.0 \([z_j / B] = 1 to 7 = 0.25, 0.50, 1.0, 1.50, 2.0, 2.50, 3.0]\) depending on number of geogrid reinforcement layers (N = 1–7) used. Typical comparison for experimental and numerical results of ultimate bearing capacity with number of reinforcing layers (N) for a 100 mm wide footing located at edge distance equal to footing width (B) is shown in Fig. 8. It is observed that for a given edge distance, BCR, in general, increases with the increasing number of geogrid layers (N) within the fill; however, the rate of increase in BCR becomes less significant once the number of geogrid layers incorporated in the fly ash fill are four or more. This is consistent with the previous studies of strip or square footing over dry sand on level grounds, which demonstrates that there exists an optimum number of geogrid layers after that the BCR almost remains constant. The increase in footing ultimate load with increasing number of reinforcing layers can be attributed to reinforcement mechanism derived from the passive resistance, interlocking of the transverse member and adhesion between the longitudinal/transverse geogrid members and the fly ash. When restraining force exerted by reinforcement is imposed on soil elements, the reorientation of strain characteristics associated with the constraint of the minor principal strain of the soil elements occurs in the vicinity of the reinforcement. A part of the reinforced zone where relatively large reinforcement force has developed, behaves like a part of the rigid footing and transfers a major part of the footing load into a deeper zone. This mechanism has been described as deep footing effect. The mobilized passive earth resistance of soil column confined in the geogrid apertures along with the interlocking limits the spreading of slope and lateral deformations of soil particles. The mobilized tension in the reinforcement enables the geogrid to resist the imposed horizontal shear stresses built up in the soil mass beneath the loaded area and transfer them to adjacent stable layers of soil leading to a wider and deeper failure zone. Therefore soil–geogrid interaction not only results in increasing the bearing capacity due to developed longer failure surface but also results in broadening the contact area between soil and rigid bottom surface of the footing. The results shown in Fig. 8 have also been presented in terms of a non-dimensional parameter as bearing capacity ratio (BCR), which is shown in Fig. 9. Bearing capacity ratio (BCR) is defined as a ratio of the load carrying capacity of a footing resting on the reinforced slope to that of the footing resting on the unreinforced slope. In Fig. 9, it is noticed that the experimental bearing capacity ratio coincides closely with the numerical bearing capacity ratio, thus confirming the validity of numerical analysis.

**CONCLUSIONS**

The bearing capacity behaviour of a strip footing resting on the top of a reinforced fly ash slope was investigated experimentally and numerically. The following conclusions may be drawn from the present study.

1. Fly ash can be used successfully as an embankment fill material.
2. Insertion of a geogrid reinforcement layer at a suitable location within the slope fill considerably improves the load carrying capacity of footings located on such slopes.
3. The load carrying capacity increases with an increase in number of reinforcement layers within the slope.
4. The maximum improvement occurs when the number of reinforcement layers is four or more. Any increase in reinforcement layers thereafter does not affect the result significantly. This particular result is valid only within the limit of parameters considered for the test or numerical study.
5. Experimental observations are found to be in good agreement with numerical results.

**REFERENCES**