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# MONOTONIC LOAD TESTS ON GEOSYNTHETIC REINFROCED POND ASH

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## ABSTRACT

The rapid expansion of thermal power sector in India, posed one of the biggest technological challenges of increasing the utilization of coal ashes generated in huge quantities, as a byproduct. Efforts were made in the present study to investigate the prospects of improvement of pond ash when reinforced with geosynthetics. Monotonic load tests were performed on a compacted pond ash reinforced with four chosen geosynthetics. The results indicated a considerable improvement in bearing capacity of pond ash, when reinforced. The present study provided an insight in to the mechanism and clearly brought out the relative roles of interface friction and the tensile modulus of the geosynthetics on the reinforcement function. The most beneficial effect was observed when the reinforcement was placed at a depth equal to half the width of the model footing. The surcharge was found to enhance the monotonic response of the reinforced pond ash.

*Keywords: Pond ash, reinforced, geosynthetics, surcharge, bearing capacity*

## INTRODUCTION

The electric power and the transportation are two key sectors of infrastructure development in India. The coal based thermal power generation is undergoing rapid expansion, leading to the generation of coal ashes, safe disposal of which has become a serious concern. The thermal power stations are facing stiff resistance in finding ash disposal sites. Therefore, it has become necessary to increase the utilization levels.

On the other hand, the transportation sector, is in need of fill materials for construction of embankments, retaining walls, bridge approaches etc. In view of this, efforts were made to study the feasibility of utilization of pond ash duly reinforcing it with the geosynthetics, in these applications. The primary objective of this study is to understand the monotonic response of pond ash reinforced with geosynthetics. The objectives include, investigating the effect of depth of placement of the reinforcement and the effect of overburden in the form of surcharge.

## REVIEW OF LITERATURE

The behavior of reinforced soils is well understood (Binquet and Lee, 1975a,b), (Adams et al., 1997a,b), (Das et al.,1998), (Venkatappa Rao et al. 2005). However, only a limited research is published on the behavior of reinforced pond ash. Ghosh et al. (2005), studied the bearing capacity of square footing on pond ash reinforced with jute textile. Pothal (2007) studied the monotonic response of two types of pond ash reinforced with polymeric geogrids and coir geotextiles. Bera et al. (2008) conducted model load tests on pond ash compacted at three different densities, reinforced with one jute geotextile and three polymeric geotextiles. They related the reinforcement effect to the “friction ratio”. All these studies indicated the response of reinforced pond ash similar to that of soils. However, the effect of in-isolation characteristics of the materials and the interaction parameters were not well explained. Efforts were made in the present study in this direction.

## METHODOLOGY

The experimental methodology includes characterization of the materials used, description of the test setup, test procedure and the analysis of the test results.

### Characterization of Pond Ash

The pond ash was collected from the ash pond of National Thermal Power Corporation (NTPC), Ramagundam plant in Andhra Pradesh, India. The properties of the pond ash are presented in Table 1.

Table 1 Engineering characteristics of pond ash

| Parameter | Value |
|---|---|
| Specific gravity of solids | 1.93 |
| Percentage of | |
| Gravel size particles | 4.00 |
| Sand size particles | 87.30 |
| Silt size particles | 8.70 |
| Plasticity characteristics | NP |
| Classification as per IS:1498 | SP |
| IS Heavy compaction test results | |
| MDD (kN/cum) | 11.70 |
| OMC (%) | 29.20 |
| Triaxial UU Test results | |
| At $\rho_d$ = 70% of MDD | |
| c (kPa) | 0 |
| Φ | 31º48′ |
| At $\rho_d$ = 90% of MDD | |
| c (kPa) | 0 |
| Φ | 39º09′ |
| CBR value at 90% of MDD | |
| Unsoaked (%) | 19.60 |
| Soaked for four days (%) | 9.90 |
| Coefficient of permeability (cm/s) | $1.47 \times 10^{-3}$ |
| Differential free swell index (%) | Nil |

## Characterization of Geosynthetics

The primary characteristics of the four geosynthetics used in this study are summarized in Table 2.

Table 2 Characteristics of the geosynthetics

| Product name | Make | Offset modulus (kN/m) | Interface friction factor |
|---|---|---|---|
| Woven geotextile (WGT) | SKAPS W-250 | 52.17 | 0.94 |
| Non-woven Geotextile (NWGT) | Polyfelt TS-30 | 35.82 | 1.09 |
| Flexible geogrid (FGG) | TENCATE Miragrid 40 x 40 | 26.60 | 1.05 |
| Coir woven geotextile (CGT) | CCM, Kerala, India | 16.00 | 1.07 |

The modulus of the geosynthetics was obtained from the wide width tensile strength tests and the interface friction was obtained from the laboratory pull out tests, as the present tests pertains to bearing capacity of pond ash in medium dense to dense state.

## Test Procedure

The test set up used in this study is show in Fig. 1. A test tank of 750 mm x 310 mm x 600 mm is used. The pond ash test bed of 250 mm thickness is prepared at 70% of its maximum dry density corresponding to IS Heavy compaction test, in five layers of 50 mm thickness each. The pre-test quality was controlled by depth measurements and the density of the test bed is verified through the pre-placed cups, collected in the post test stage. The load is measured by a load cell of 1 N sensitivity and the settlement by a LVDT of 0.1 mm sensitivity. The PC controlled test facility allows feeding the input test conditions, executes, displays on line progress, logs data at specified interval of 20 seconds and stores.

Fig. 1 The test set up

The load was applied through a model square footing of 50 mm size(B) with rough base, made of rigid Aluminium plate of 25 mm thickness. The rate of deformation was at 1.25 mm/min.

## Analysis of the Test Results

The basic load versus settlement data has been plotted in terms of "Bearing pressure versus settlement" curves. The point of inflection of the curve is obtained as the point of intersection of the two tangents drawn. The bearing pressure and settlement corresponding to this point are considered as the ultimate bearing pressure and the ultimate settlement. The ratio of ultimate bearing pressure of reinforced pond ash up on that of un-reinforced pond ash is defined as "Ultimate bearing capacity ratio, ($BCR_u$). A similar ratio corresponding to a permissible settlement (s) expressed as (s/B) of 5% is considered as ($BCR_{5\%}$). The slope of the initial tangent is considered as apparent initial tangent modulus (ITM).

## MONOTONIC LOAD TEST RESULTS

A series of monotonic load tests were performed with depth of placement (u) of the reinforcement beneath the base of the footing expressed as (u/B) ratio and application of surcharge expressed in terms of ($D_f$/B) ratio wherein $D_f$ is the thickness of the dry sand placed at a density of 16.40 kN/cum, as shown in Fig. 2.

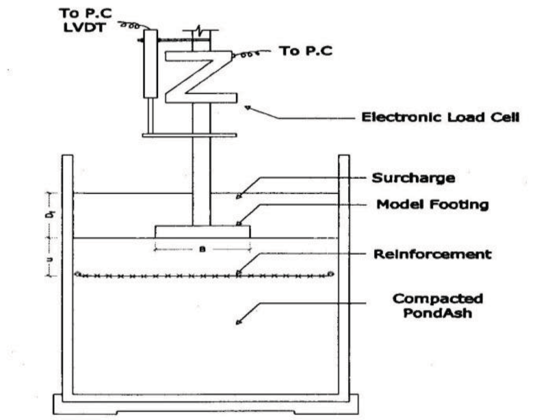


Fig. 2 Definition sketch of the test procedure

The basic "Bearing pressure versus settlement" plots for each geosynthetic product are presented with and without surcharge separately in Figs. 3 to 10.

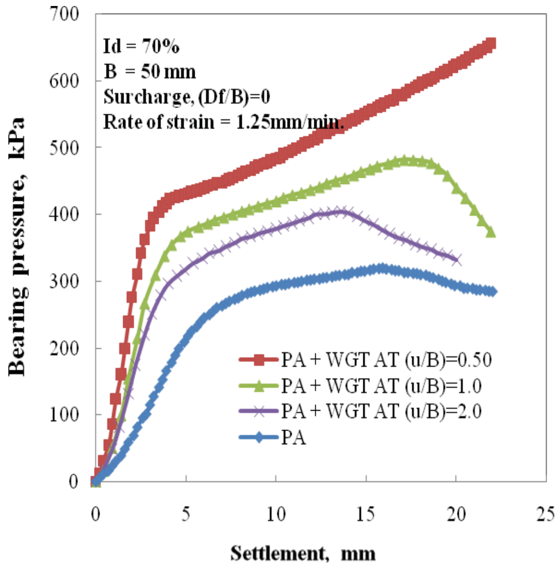


Fig. 3 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with woven geotextile (WGT) without surcharge

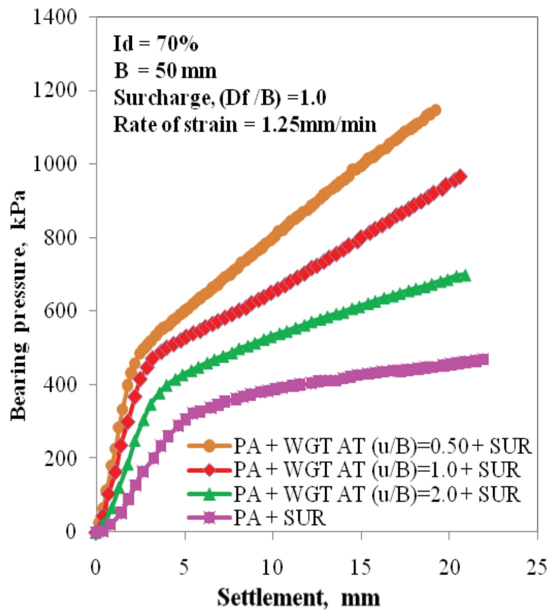


Fig. 4 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with woven geotextile (WGT) with surcharge of ($D_f$/B)=1.0

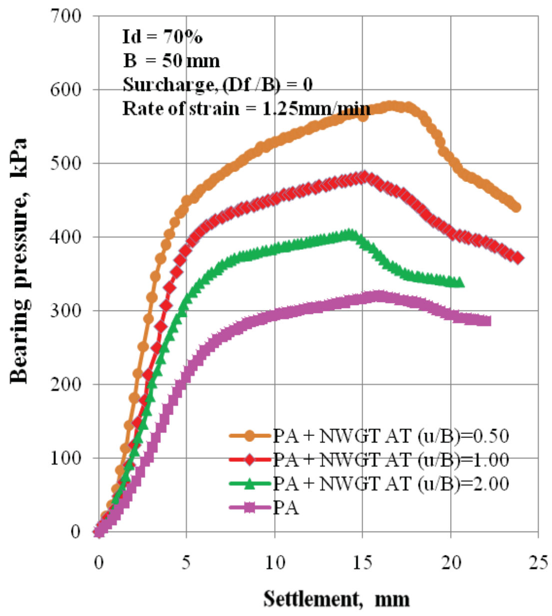


Fig. 5 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with non woven geotextile (NWGT) without surcharge

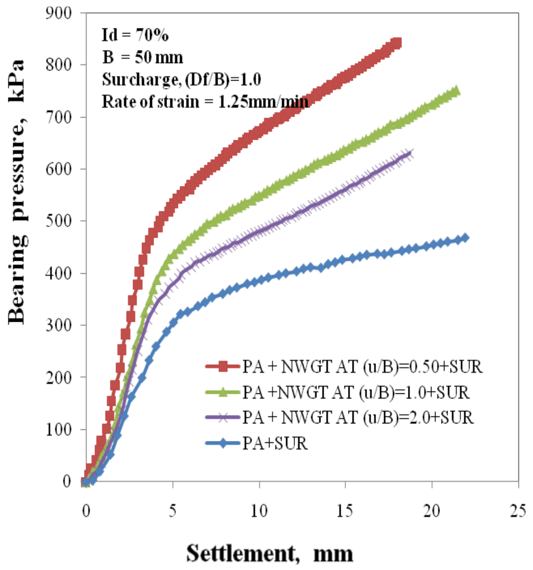


Fig. 6 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with non woven geotextile (NWGT) with surcharge of $(D_f/B)=1.0$

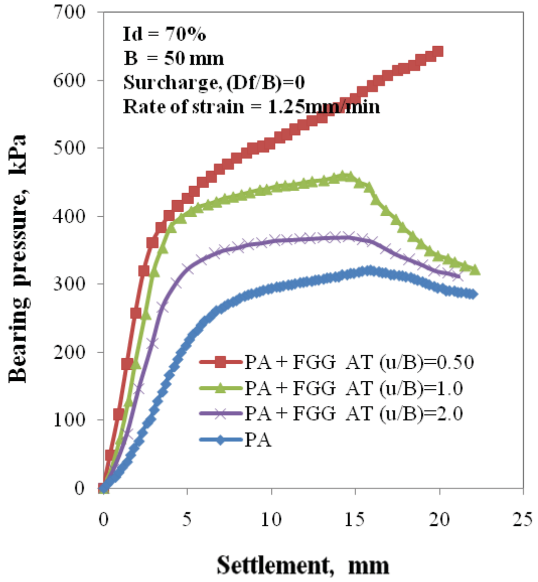


Fig. 7 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with flexible geogrid (FGG) without surcharge

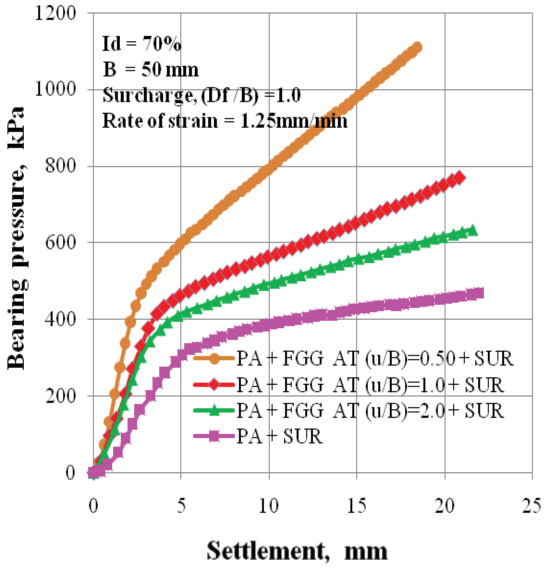


Fig. 8 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with flexible geogrid (FGG) with surcharge of $(D_f/B)=1.0$

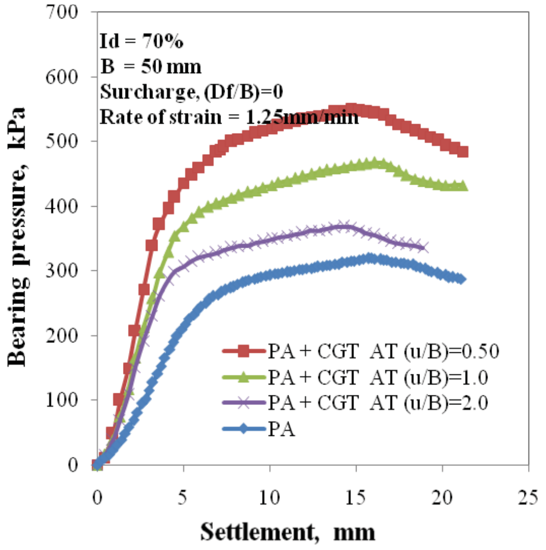


Fig. 9 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with coir geotextile (CGT) without surcharge.

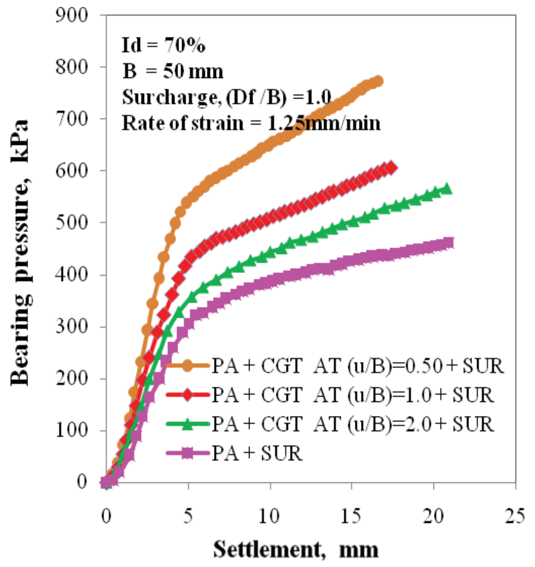


Fig. 10 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with coir geotextile (CGT) with surcharge of $(D_f/B)=1.0$

## GENERAL COMPARISION

The test results are compared and analysed in terms of $BCR_u$, $BCR_{5\%}$, apparent axial strain at failure ($\varepsilon_f$) and the apparent initial tangent modulus ($E_i$), as described in the following subsections.

### Ultimate Bearing Capacity Ratio ($BCR_u$)

The variation of $BCR_u$ with (u/B) ratio are depicted in Fig. 11. It can be seen that, the hierarchy of improvement is expressed as NWGT > CGT > FGG > WGT.

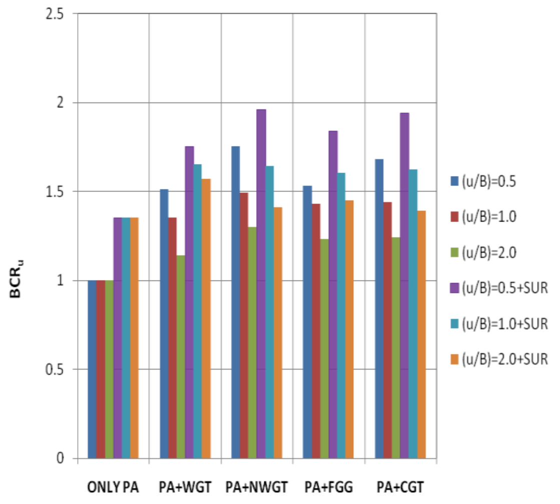
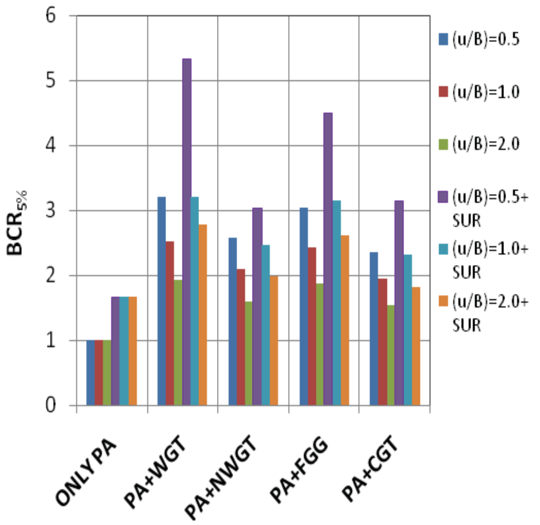


Fig. 11 Variation of $BCR_u$ for all the test conditions

### Bearing Capacity Ratio for (s/B) of 5% ($BCR_{5\%}$)

The variation of $BCR_{5\%}$ with (u/B) ratio for all the test conditions are depicted in Fig. 12. It can be seen that, the hierarchy of improvement is found as WGT > FGG > NWGT > CGT, which is different from that of $BCR_u$.



### Apparent Axial Strain at Failure ($\varepsilon_f$)

The apparent axial strain at failure is defined as the ratio of settlement at failure up on the width of model footing expressed as a percentage. Its variation with (u/B) ratio for all the test conditions is shown in Fig. 13. It can be seen that, the hierarchy of improvement in terms of reduction in settlement at failure, is expressed as WGT > FGG > NWGT > CGT. Interestingly, it is coinciding with that of $BCR_{5\%}$.

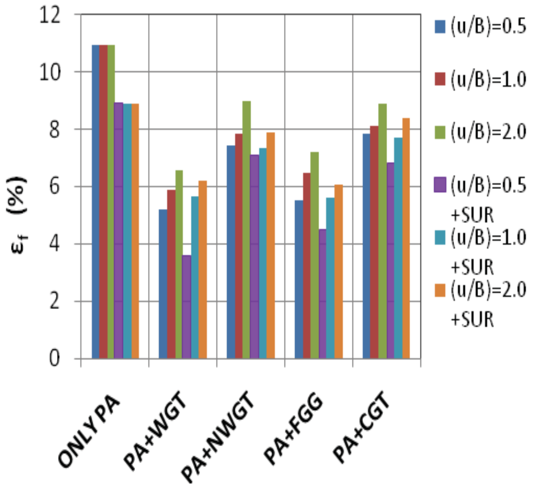


Fig. 13 Variation of ($\varepsilon_f$) for all the test conditions

### Apparent Initial Tangent Modulus ($E_i$)

The variation of ($E_i$) with (u/B) ratio for all the test conditions is presented in Fig. 14. As it can be seen, the hierarchy of improvement is found as WGT > FGG > NWGT > CGT, which is coinciding with that of $BCR_{5\%}$ and ($\varepsilon_f$).

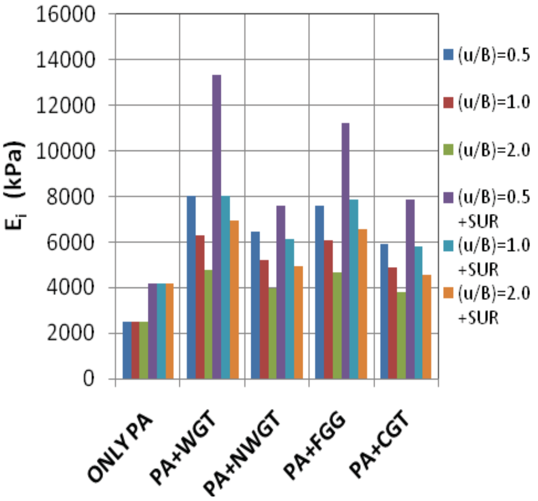


Fig. 14 Variation of ($E_i$) for all the test conditions

## OBSERVATIONS

Based on the monotonic load tests, the following observations are made :

1. As it can be seen from Fig.11, the maximum $BCR_u$ was found to be 1.75 for without surcharge case and 1.96 for with surcharge case, both obtained when the NWGT was placed at a (u/B) ratio of 0.50. It is important to note here that, the $BCR_u$ is independent of the settlement at failure. A careful examination indicate that, though the NWGT is having lower tensile modulus than WGT, FGG; the $BCR_u$ was found to be higher. Interestingly, coincidence of hierarchy of $BCR_u$ with that of hierarchy of friction factor earlier referred in Table 2, suggests that, the ultimate bearing pressure is primarily governed by the interface friction. Further, it may be inferred that, the higher modulus products viz., WGT and FGG, may have failed earlier than NWGT due to low interface friction. This was substantiated by the lower ($\varepsilon_f$) values recorded in respect of WGT and FGG.
2. Noting the fact that, in geotechnical engineering practice, the settlements are kept within permissible limits, the $BCR_{5\%}$ is a more appropriate design parameter than $BCR_u$, As it can be seen from Fig. 12, the maximum $BCR_{5\%}$ was found to be 3.21 and 5.19 respectively for without and with surcharge. In almost all cases, the (s/B) of 5% , lies in the elastic part of load bearing mechanism, without the eventuality of failure in friction. Hence, the hierarchy of $BCR_{5\%}$ is coincided with that of tensile modulus of the geosynthetics.
3. As seen in Fig. 13, the ($\varepsilon_f$) of 10.97% for the unreinforced pond ash has been reduced to 5.12% and 3.66% respectively for without and with surcharge cases. The hierarchy is coinciding with that of tensile modulus of the geosynthetics, suggesting that, the deformation of reinforced pond ash is very much a function of the elastic modulus of the geosynthetics.
4. The variation in apparent initial tangent modulus, shown in Fig.14, indicate improvement from 5.89 MPa for unreinforced pond ash to 8.01 MPa and 13.01 MPa for without and with surcharge cases respectively. The hierarchy of improvement is very much dependent on the tensile modulus of the geosynthetics, as expected.
5. As it can be seen from Figs. 11 to 14, irrespective of the type of geosynthetics, presence or absence of surcharge, the most beneficial effect was always obtained at a (u/B) ratio of 0.50, which happens to be the closest possible depth from the base of model footing adopted in this study. This reconfirms the established fact that, straining of the reinforcement element is necessary to derive the reinforcement function effectively.
6. Interestingly, the pond ash due to its "fly by air" nature is always provided with a soil cover, which has been modeled in this study as a surcharge. The Figs. 11 to 14, clearly indicate that, the application of surcharge has a definite improvement in the bearing capacity of reinforced pond ash.

## CONCLUSIONS

Based on the analysis of the monotonic load test results, the following conclusions are made :

1. The pond ash has potential for improvement when reinforced with geosynthetics. This enhances its scope for greater utilization in geotechnical engineering applications.
2. The interface friction is a pre-requisite for deriving the reinforcement function. However, when adequate frictional bond exists between the pond ash and the geosynthetics, the level of improvement is dependent on the tensile modulus of the geosynthetic reinforcement.
3. This study clearly brought out the difference between $BCR_u$ and $BCR_{5\%}$, on the lines of conceptual difference between the safe bearing capacity and allowable bearing capacity and emphasized that $BCR_{5\%}$ is a more appropriate design parameter than $BCR_u$.

4. The overburden in the form of surcharge has beneficial effect on the bearing capacity of reinforced pond ash.

## EXPERIMENTAL LIMITATIONS

The limitations of the present laboratory model load tests that were beyond the scope of this study are mentioned below:

1. The size effect between the present model tests and the full scale foundation. The smaller size of the model footing may not have provided adequate confinement to the medium, as that in full scale foundation. This may result in comparatively lower bearing pressure and higher settlement at every stage of the load bearing mechanism. To overcome this limitation, efforts are made in this study to find the size effect by modeling of models.
2. The scale effect between the foundation model and the reinforcement element. This is primarily due to the inability to model the reinforcement element to the same scale of the model footing. This does introduce a mismatch of geometry, strength and more importantly stiffness between the model behaviour and prototype response. To overcome this limitation, efforts were made to use the weakest available geosynthetic products against the relatively stronger products used in the field
3. The time effect in terms of the long term consolidation settlement and creep effect, if any, are not part of the present study. However, pond ash being a non-plastic cohesionless medium, the consolidation settlement may not be a serious concern.

It is important to note here that, these limitations are not just specific to the present study but they are generally applicable to most of the previously published model studies, as well. Nevertheless, the present study effectively brought out the relative response, which may be useful in the selection of materials and in the design of systems.

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