MONOTONIC AND CYCLIC RESPONSE OF POND ASH REINFORCED WITH COIR GEOTEXTILE – A COMPARATIVE STUDY

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ABSTRACT

India is one of the largest producers of Coir and its related products in the world. There is a tremendous scope for utilization of coir geotextiles in ground modification. At the same time, the need for increasing the utilization of pond ash is ever increasing due to the constant growth in thermal power sector. In view of this efforts were made in the present study to investigate the effectiveness of pond ash reinforced with coir geotextile under monotonic as well as cyclic loading by conducting a series of load tests. Efforts were made to compare the response of pond ash reinforced with coir geotextile with that of more popular polymeric woven geotextile. The monotonic load test results indicated that, for a given improvement in bearing capacity, the coir reinforced pond ash has undergone greater settlement than that of woven geotextile reinforced pond ash, underlining the fact that the modulus of former is lesser than that of the later. Similar behavior was observed in cyclic load tests. The resilient modulus of the coir reinforced pond ash was found to be smaller than that of woven geotextile reinforced pond ash. The study indicated that, there is need for improvement of modulus of the coir geotextile for its use as reinforcement.

Keywords: Pond ash, coir geotextile, monotonic and cyclic load tests, comparison with polymeric geotextile

INTRODUCTION

Over the past few years, the need for application of ecofriendly limited life geosynthetics in ground improvement is increasing steadily. Coir geotextiles are one of the versatile products under this category. India, being the largest producer of coconuts, is also the major producer of coir geotextiles. In view of the cost effectiveness of these products, there is great necessity for exploring the prospects of their usage in geotechnical engineering applications.

In addition, in India, there is a constant need for increasing the utilization of pond ash. In the present study, both the necessities were combined in the form of pond ash reinforced with coir geotextile and its prospects as a fill materials for construction of embankments, retaining walls, bridge approaches etc., is investigated. Accordingly, the primary objective of this study is to understand the monotonic and cyclic response of pond ash reinforced with coir geotextile. Further, the objectives include, comparison of the response of coir geotextile reinforced pond ash with that of polymeric woven geotextile reinforced pond ash.

REVIEW OF LITERATURE

Beginning with the classical work of Binquet and Lee (1975a,b), several researchers have studied the monotonic response of geosynthetic reinforced soil through model load tests. Adams et al. (1997a.b) have conducted large sized model load tests and reported that, the reinforcement effect is comparable to that of embedment depth of the footing.

Venkatappa Rao et al. (2000) and (2005), have broadly indicated that the biodegradability of coir can be used to advantage and the coir based geotextiles have potential for use in specific geotechnical applications.

Leflaive (1985), performed repeated load triaxial tests and observed “additional compaction under cyclic loading”. Barksdale et al. (1982), Sheo Gopal (1993), Dixit (1994), Das et al. (1998), Datta et al. (2002), Nazzal et al.(2007), Yu Qian et al. (2010), observed a definite reduction in cyclic deformation and an increase in apparent resilient modulus when soil is reinforced. The observation is also similar to the outcome of full scale cyclic load tests performed by Kharchafi and Dysli (1994) and the field studies made by Indrarathna et al. (2010). McGown et al. (1990), identified a dynamic interlock mechanism responsible for this improvement in the cyclic response of geogrid reinforced aggregate.

Only a few studies have been carried out on the monotonic response of reinforced pond ash (Ghosh et al. (2005), Pothal (2007) and Bera et al. (2008)) from which, it was concluded that, the response of reinforced pond ash is similar to that of reinforced soils. However, neither the mechanisms were fully understood nor the relative influence of different types of geosynthetics was studied. In addition, there appears to be no literature traceable on the cyclic load test response of reinforced pond ash pertaining to geotechnical and transportation engineering applications.

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 ρ_d = 70% of MDD	
c (kPa)	0
Φ	31º48′
At ρ_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)	1.47×10^{-3}
Differential free swell index (%)	Nil

Characterization of geosynthetics

The woven geotextile (WGT) and the Coir Geotextile (CGT) used in this study are shown in Figs. 1 and 2.

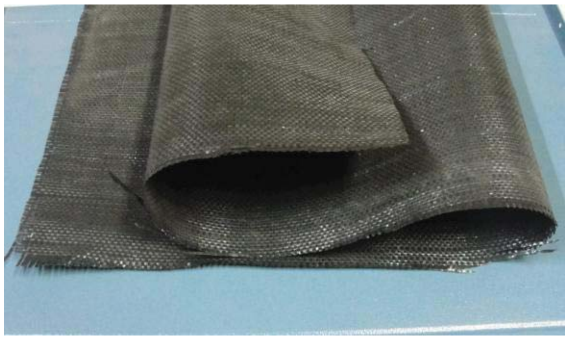

Fig. 1 A view of the woven geotextile (WGT)

Fig. 2 A view of the coir geotextile (CGT)

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

Table 2 Characteristics of the geosynthetics

Product name	Make	Offset modulus (kN/m)	Inter-face friction factor
Woven geotextile (WGT)	SKAPS W-250	52.17	0.94
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.

Load Test Facility

The test set up used in this study is show in Fig.3. 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.

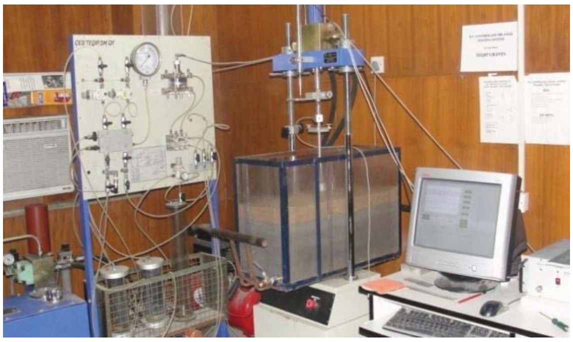

Fig. 3 The test set up

MONOTONIC LOAD TESTS

In monotonic load tests, 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. 4.

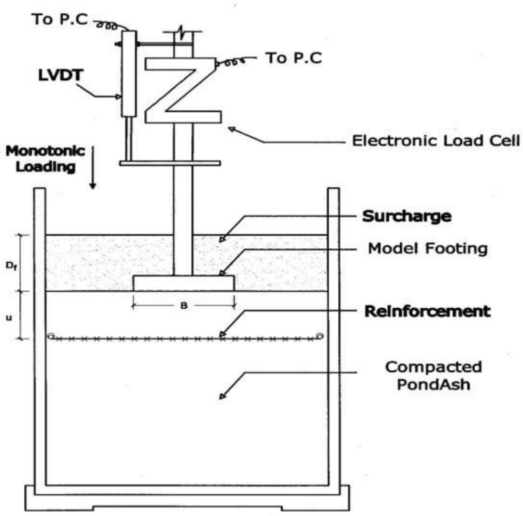

Fig. 4 Definition sketch of the test procedure

The basic "Bearing pressure versus settlement" plots for pond ash reinforced with WGT are presented with and without surcharge separately in Figs. 5 and 6, respectively. Similar plots for CGT are presented in Figs. 7 and 8, respectively.

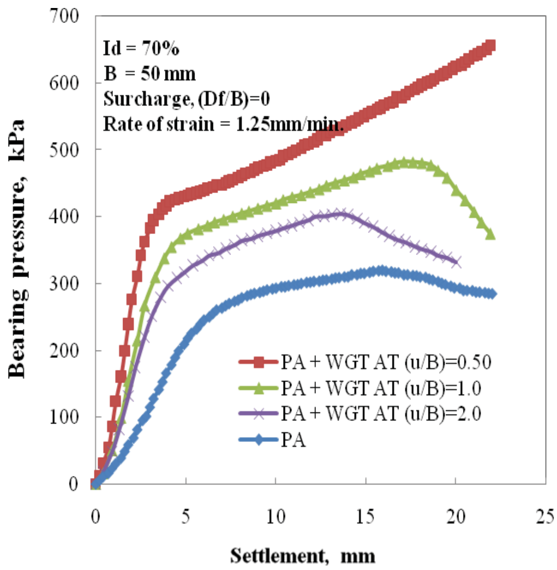

Fig. 5 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with woven geotextile (WGT) without surcharge

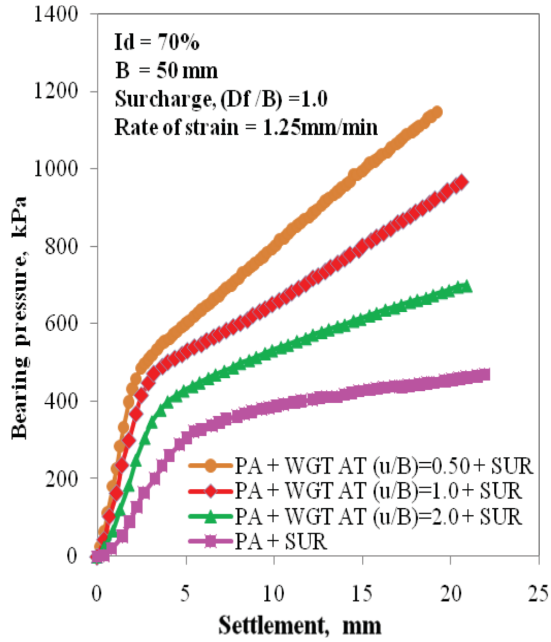

Fig. 6 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with woven geotextile (WGT) with surcharge of (D_f/B)=1.0

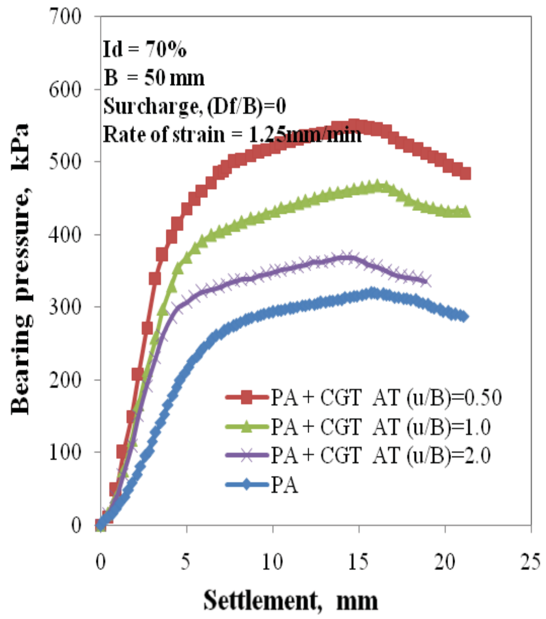

Fig. 7 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with coir geotextile (CGT) without surcharge.

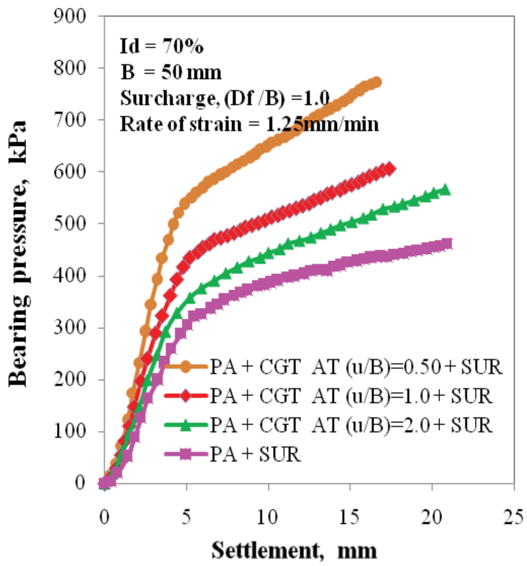

Fig. 8 Variation of bearing pressure with settlement for different (u/B) ratios for pond ash reinforced with coir geotextile (CGT) with surcharge of (D_f/B)=1.0

GENERAL COMPARISION

The test results are compared and analysed in terms of BCR_u, $BCR_{5\%}$, apparent axial strain at failure (ε_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. 9. It can be seen that, the hierarchy of improvement is expressed as CGT > WGT.

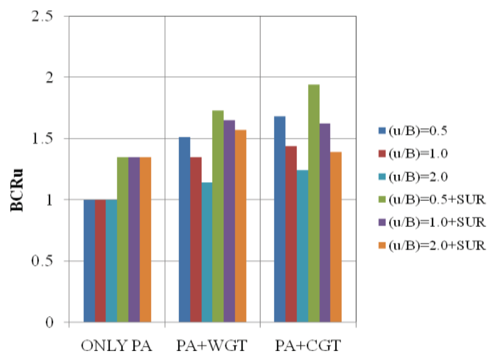

Fig. 9 Variation of BCR_u for the test conditions

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. 10. It can be seen that, the hierarchy of improvement is found as WGT > CGT, which is different from that of BCR_u.

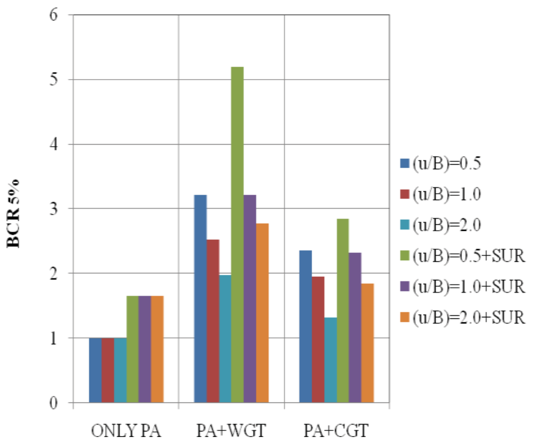

Fig. 10 Variation of $BCR_{5\%}$ for the test conditions

Apparent Axial Strain at Failure (ε_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. 11. It can be seen that, the hierarchy of improvement in terms of reduction in settlement at failure, is expressed as WGT > CGT. Interestingly, it is coinciding with that of $BCR_{5\%}$.

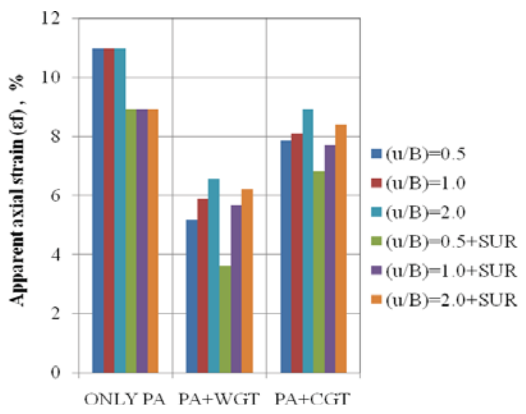

Fig. 11 Variation of (ε_f) for the test conditions

Apparent Initial Tangent Modulus (E_i)

The variation of (E_i) with (u/B) ratio for all the test conditions is presented in Fig. 12. As it can be seen, the hierarchy of improvement is found as WGT > CGT, which is coinciding with that of $BCR_{5\%}$ and (ε_f).

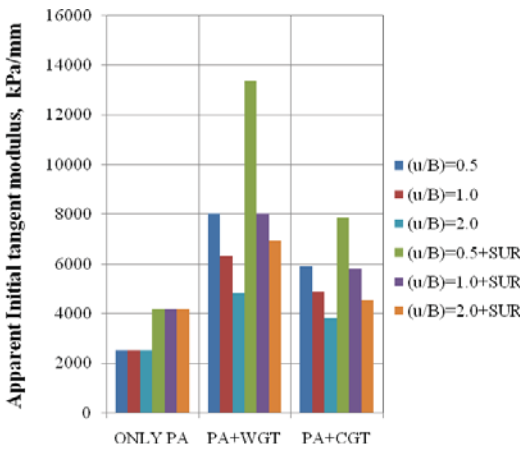

Fig. 12 Variation of (E_i) for all the test conditions

OBSERVATIONS

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

1. As it can be seen from Fig.9, the BCR_u was found to be higher for CGT reinforced pond ash than that due to WGT reinforced pond ash. It is important to note here that, the BCR_u is essentially dependent on strength and is independent of the settlement at failure. Interestingly, the 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 followed by tensile strength of the reinforcing element. It may be inferred that, though the in-isolation tensile modulus of the WGT is higher, the failure in WGT reinforced pond ash may have taken place due to relatively lower interface friction.
2. The Figs. 10 to 12, clearly indicate that, the modulus dependent properties viz., the bearing capacity ratio corresponding to (s/B) of 5%, $BCR_{5\%}$, the apparent axial strain at failure (ε_f) and the apparent initial tangent modulus (E_i) are all found to be higher for WGT reinforced pond ash than that of CGT reinforced pond ash.

CYCLIC LOAD TESTS

A series of stress controlled cyclic load tests were performed on the similar reinforced pond ash test beds. The cyclic stress in the range of 0 to 400 kPa was applied at a frequency of 1 Hz, up to 1000 cycles. A view of the online monitoring of application of cyclic loading is shown in Fig. 13.

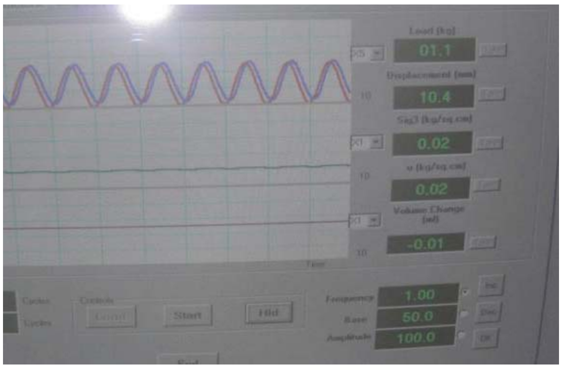

Fig. 13 A view of the application of cyclic load

The PC controlled facility logs 32 data points per cycle. The typical total cyclic deformation versus the number of cycles is as shown in the Fig. 14.

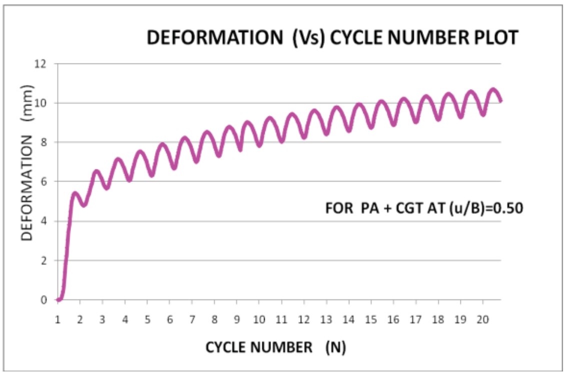

Fig. 14 Variation of total cyclic deformation with cycle number

CYCLIC LOAD TEST RESULTS

The cyclic load test results pertaining to the WGT reinforced pond ash for different (u/B) ratios in the absence and presence of surcharge are shown in Fig. 15 and those for CGT reinforced pond ash are shown in Fig. 16.

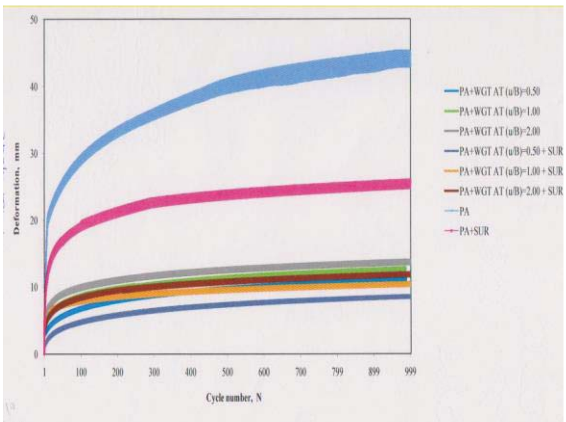

Fig. 15 Cyclic deformation versus cycle number plot for WGT reinforced pond ash

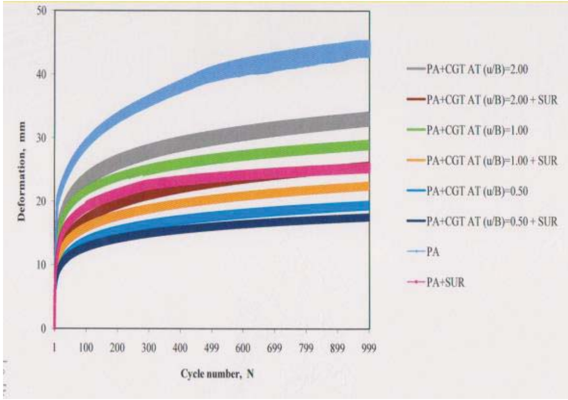

Fig. 16 Cyclic deformation versus cycle number plot for CGT reinforced pond ash

Analysis of the Cyclic Load Test Results

The results of the cyclic load tests are analysed in terms of the Apparent resilient modulus (ARM) as defined below:

$$ARM = \frac{\text{Magnitude of peak cyclic stress applied (kPa)}}{\text{Elastic or recoverable component of the cyclic deformation (mm)}}$$

The variation of ARM with cycle number for the pond ash reinforced with WGT and CGT, for different (u/B) ratios in the absence and presence of surcharge are depicted in Figs. 17 and 18, respectively.

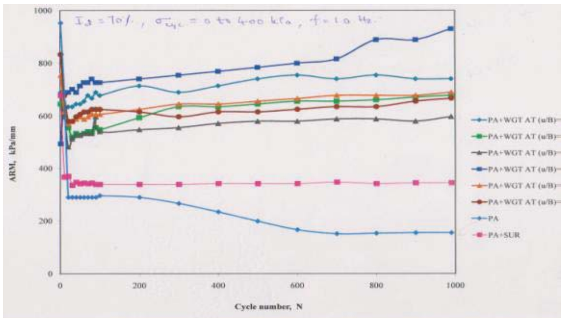

Fig. 17 Variation of ARM with cycle number for pond ash reinforced with WGT

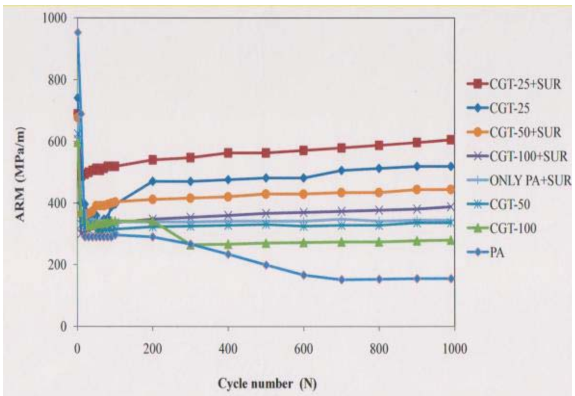

Fig. 18 Variation of ARM with cycle number for

pond ash reinforced with CGT

GENERAL COMPARISON

The cyclic load test results of the pond ash reinforced with WGT and CGT are compared in terms of variation in total cyclic deformation and in apparent resilient modulus (ARM), for different (u/B) ratios in the presence and absence of surcharge, as presented in Figs. 19 and 20. The data pertains to the status at 1000th cycle.

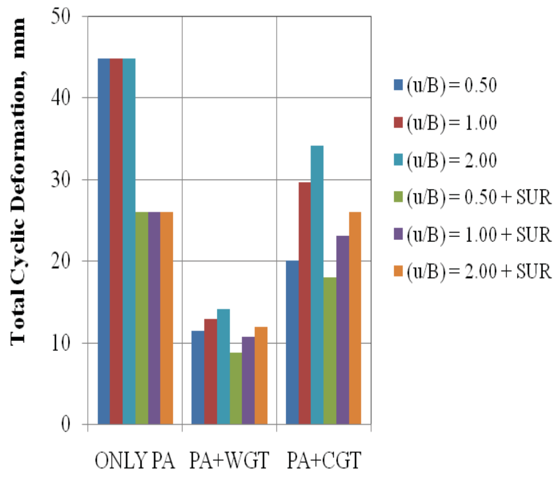

Fig. 19 Comparison of variation in total cyclic deformation at 1000th cycle

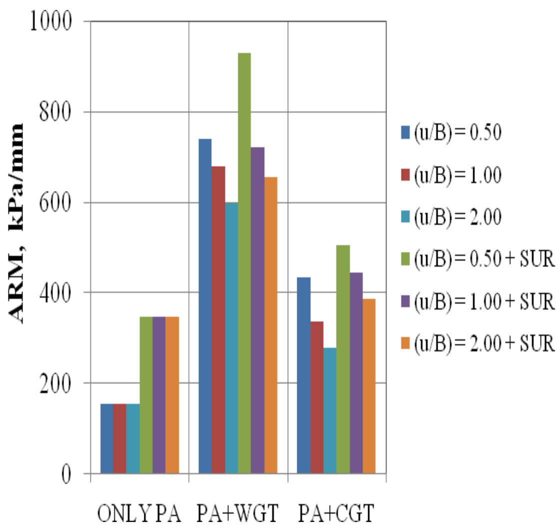

Fig. 20 Comparison of variation in apparent resilient modulus (ARM) at 1000th cycle

OBSERVATIONS

Based on the analysis of the cyclic load test results, the following observations are made :

1. As it can be seen from Figs. 14 to 16, the total cyclic deformation versus cycle number plot is typically showing large deformations in the first few cycles up to a distinct point of inflection followed by a gentle slope. The point of inflection may be indicative of completion of additional fill compaction that is exclusive under cyclic loading conditions. It is indicative of improvement in elastic modulus of the medium. Under the application of a given cyclic stress, the number of cycles required to reach the point of inflection is dependent on the initial elastic modulus of the medium. The pond ash reinforced with low modulus CGT required more number of cycles to reach point of inflection and in the process has undergone more total and recoverable deformation than that of pond ash reinforced with higher modulus WGT.
2. It is interesting to note that, beyond the point of inflection, up to 1000 cycles, complete failure was not observed in pond ash reinforced with WGT in friction, as observed in monotonic load tests. This may be due to the fact that, the interface friction may have been enhanced due to additional fill compaction.
3. As it can be seen from Figs. 17 and 18, the apparent resilient modulus of the pond ash reinforced with WGT as well as CGT, is found to be increasing as the number of cycles are increasing. This encouraging sign is indicative of effectiveness of reinforced pond ash in resisting the cyclic stresses.
4. As it can be seen from Fig. 19, the apparent resilient modulus for the pond ash reinforced with higher modulus WGT is found to be greater than that of pond ash reinforced with lower modulus CGT.
5. Figure 20, clearly indicates the effectiveness of the pond ash reinforced with higher modulus WGT in containing the total and recoverable deformation is found to be greater than that of pond ash reinforced with lower modulus CGT.

CONCLUSIONS

Based on the monotonic and cyclic load tests performed in the present study, the following conclusions can be drawn:

1. The monotonic and cyclic response of geosynthetic reinforced pond ash in general is found to be similar to that of cohesionless soils such as sands. The present study demonstrated the potential of reinforced pond ash as a fill material in transportation engineering applications wherein traffic induced cyclic loads govern the load bearing mechanism.
2. The monotonic load tests showed that, 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. The cyclic load tests indicated the additional fill compaction and the associated improvement in density and the interface friction. It was demonstrated again that, in the absence of failure in friction, the in-isolation modulus of the reinforcement appears to have governed the cyclic response. The pond ash reinforced with higher in-isolation modulus WGT showed better cyclic response than that with CGT.
4. This study clearly indicated the need for enhancement of in-isolation tensile modulus of the CGT, for its use as an effective reinforcement element on par with the conventional polymeric geosynthetics.

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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