International Journal of Advanced Technology in Civil Engineering

Volume 1 | Issue 1 Article 3

January 2012

Behaviour of a Strip Footing on Compacted Pond Ash Reinforced with Coir Geotextiles

Goutam Kumar Pothal
Indira Gandhi Institute of Technology, Sarang, gkpothal@gmail.com

G. Venkatappa Rao
Indian Institute of Technology Delhi, gvrao.19@gmail.com

Behaviour of a Strip Footing on Compacted Pond Ash Reinforced with Coir Geotextiles

Dr. Goutam Kumar Pothal, Dr. G. Venkatappa Rao[2]
Assistant Professor, Department of Civil Engineering
Indira Gandhi Institute of Technology, Sarang, Indian Institute of Technology Delhi[2]
Odisha, India, New Delhi, India[2]
e-mail: gkpothal@gmail.com, gvrao.19@gmail.com [2]

Abstract— Pond ash, produced in huge quantities by thermal power plants, require large land area for disposal and causes environmental hazards. The pond ash can be effectively used as a fill material for low lying areas as site reclamations and in embankments. The low bearing capacity of pond ash fills can be improved by using coir geotextiles, as reinforcement which will be an eco-friendly approach. The effectiveness of horizontally placed coir geotextiles, as reinforcement in single and multiple layers, on the bearing capacity of compacted pond ash is investigated. In the present study, the bearing capacity behaviour of a strip footing on two pond ash samples reinforced with two types of woven coir geotextiles has been studied by load bearing tests in model tanks in the laboratory. The parameters varied during the tests were width of reinforcement, depth of the top reinforcement layer below the base of the footing and the number of geotextile layer. The improvement of ultimate bearing capacity was studied. The ultimate bearing capacity ratios were evaluated. A mathematical model based on the geometric parameters of the reinforcement, tensile properties of reinforcement and shear parameter of pond ash has been developed.

Keywords- Pond ash; coir geotextiles; reinforcement; ultimate bearing capacity; bearing capacity ratio

I. Introduction

Pond ash, the by-product of thermal power plants is considered as solid waste and its disposal is a major problem from environmental point of view and also it requires large disposal areas. Utilization of pond ash to the maximum possible extent is a worldwide problem. To solve the problem, pond ash can be used as a structural fill for developing low-lying areas to construct civil engineering structures on it. The decreasing availability of good construction sites has led to the increased use of filling low lying areas with pond ash, whose bearing capacity is low. In order to improve their bearing capacity with reinforcements is a good alternative to other methods of stabilization. Improvement of load bearing capacity of shallow foundation on pond ash is possible by introducing geosynthetic reinforcement. Majority of geosynthetics used in civil engineering application are polymeric in composition. These products generally have a long life and do not undergo biological degradation, but are liable to create environmental problem from its manufacture till the end use. In view of this, the use of biodegradable natural fibers geotextiles is gaining popularity. Previous studies by Singh and Rao [8] clearly indicated that the coir hardly degrades in one year and the life expectancy can be upto a decade. Hence, the potential of coir geotextile, if not same, is comparable to the polymeric materials.

In the present study, the effects of the above parameters on ultimate bearing capacity of strip footing have been made. Bearing capacity ratio is used to compare the performance of reinforced and un-reinforced pond ash.

The purpose of the paper is to present some recent laboratory model test results conducted to evaluate the bearing capacity improvement of a strip footing on pond ash reinforced with two types of coir woven geotextiles. Finally a mathematical model developed by multiple regression analysis has been presented.

II. Review of Litrature

Numerous studies on the bearing capacity of shallow foundation on reinforced soils have been reported by different researchers by taking different types of foundation material and reinforcements. Binquet and Lee [2, 3], Fragaszy and Lawton [4], Omar et al. [6] and Shin et al. [9] studied the bearing capacity shallow strip footing on geogrid reinforced sand. Vinod et al. [11] studied the behavior of a square footing on loose sand reinforced with braided ropes. Tafreshi, S. N. M. and Dawson, A. R., [10] compared the bearing capacity of a strip footing on sand with geocell and planar forms of geotextile reinforcements. Ghosh et al. [5] worked on the study of the bearing capacity of shallow square foundation on reinforced pond ash. Pothal et al. [7] studied the bearing capacity of two pond ash samples reinforced with a polymeric biaxial geogrids. It is revealed that the previous researchers have studied the effects of various parameters on the bearing capacity ratio (the ratio between bearing capacity of reinforced soil and bearing capacity of un-reinforced soil) both with respect to ultimate load (BCR_u), the parameters being the number of layers (N) of reinforcement, the depth of the upper most layer of reinforcement from base of the footing (u) and width of the reinforcement layer (b).

III. Present Study

A review of literature clearly depicted that a lots of experimental research has been carried out on sand and clay with different forms polymeric geogrids. Very few studies have been done on compacted pond ash reinforced with natural fibre geotextiles. Hence, an attempt has been made to study the behavior of a strip footing on compacted pond ash reinforced with coir geotextiles.

A. Geometric Parameter

A strip footing of width ‘B’ being supported on pond ash reinforced with ‘N’ number of reinforcement layers as shown in Fig. 1. The vertical height between the consecutive reinforcement layers is ‘h’ and the top layer of the reinforcement layer is located at a depth of ‘u’ from the base of the footing. The width of the reinforcement under the footing is ‘b’. The depth of the reinforcement, ‘d’, below the bottom of the footing can be expressed as:

$$d = u + (N-1)\, h \tag{1}$$

B. Material

In the present study two pond ash samples were selected as the foundation medium. Two woven coir geotextiles are selected as the reinforcement material.

1) Pond Ash

Pond ash was procured from the ash pond of the Captive Power Plant (CPP) of National Aluminum Company Ltd. (NALCO), Angul, Odisha, India. From the ash pond two samples of pond ashes were collected. First one from near the slurry disposal point which is coarser in nature and second one far away from the slurry disposal point which is finer in nature. These two samples of pond ash are designated as ‘NC’ and ‘NF’ for the study. The detailed properties are detailed in Table 1.

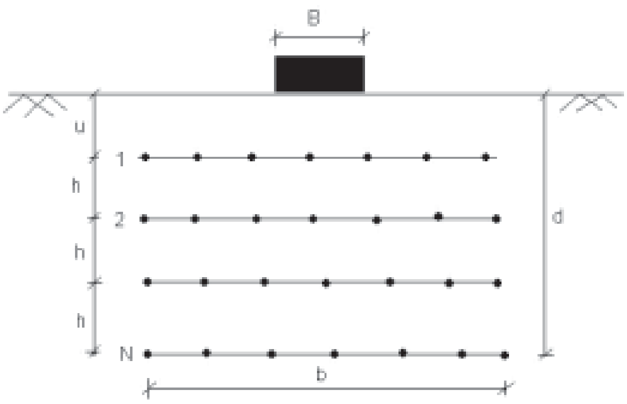
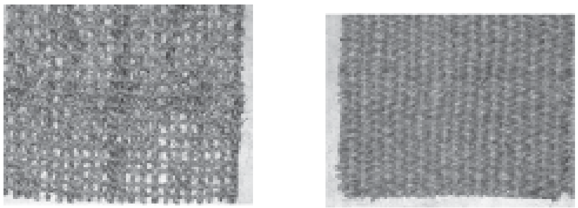


Figure 1. Schematic diagram of strip footing on compacted pond ash reinforced with multilayer of coir geotextiles

Grain size distribution	> 4.75mm (%)	0	0
	4.75- 0.475mm (%)	2	4
	0.475- 0.075mm (%)	40	76
	0.075-0.002mm (%)	56	19
	< 0.002mm (%)	2	1
Specific gravity		2.02	2.48
Liquid limit (%)		48	33
Plastic limit (%)		Non-plastic	Non-plastic
Maximum dry density (kN/m^3)		10.7	13.6
Optimum moisture content (%)		34.5	25.2
Angle of internal friction (Degrees) at MDD		28	35

The woven coir geotextiles used for the study are shown in Fig. 2. They were designated as ‘Type A’ and ‘Type B’ respectively. The detailed physical and mechanical properties are given in Table 2. The tensile strength of these reinforcement materials was determined by the wide strip tensile test as per ASTM D 4595 [1]. The results are presented in Fig. 3.



Type A Type B

Figure 2.Coir woven geotextiles

Parameter	Coir woven geotextile	
	Type A	Type B
Roll width (m)	1	1
Roll length (m)	50	24
Aperture size (mm × mm)	10 × 12	7 × 4
Thickness (mm)	8.1	9.6
Mass per unit area (gsm)	610	1335
Ultimate tensile strength (kN/m)	19.1	38.1
Strain at ultimate strength (%)	22.6	37.3

TABLE II. Properties of Coir Woven Geotextiles

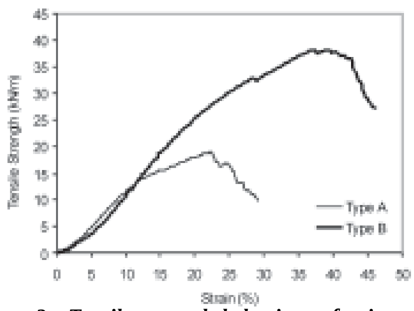


Figure 3. Tensile strength behaviour of coir geotextiles

IV. EXPERIMENTAL ARRANGEMENT

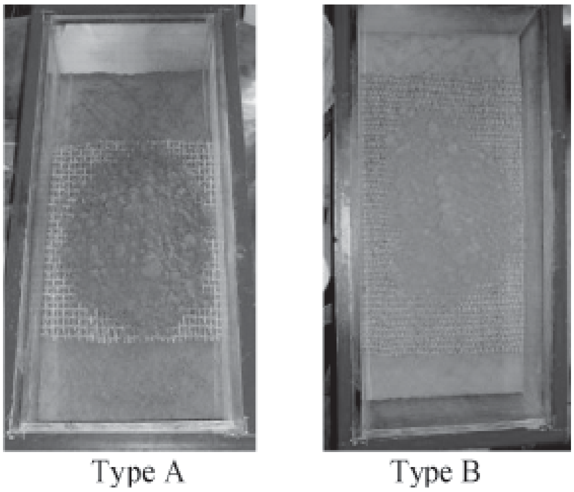
The bearing capacity tests were conducted in a rectangular box measuring 750 mm (length) × 300 mm (width) × 400 mm (depth). The tank was made up of 12 mm perspex sheet and was reinforced with a frame made up of mild steel angles sections so that there will be no lateral yielding of the box during compaction and loading. The inside walls of the box were polished and a thin coating of grease were applied to reduce friction as much as possible. The model footing used for the study was made of wood of size 75 mm (width) ×296 mm (length) ×50 mm (height). On the top of the wooden block a ribbed steel plate was placed during loading such that there is no bending of the footing during loading process.

The two pond ash samples collected were pulverized in the laboratory and mixed with predetermined amount of water. For uniform moisture distribution the moist pond ash was placed in several plastic bags and put in airtight containers during the test periods. The moisture content was checked in regular intervals and the corrections were made if found required.

Before the actual loading test, trial compactions were carried out in layers of 50 mm and densities were found out by core cutter method at different depths of the tank. The compaction of different layers was done by using a heavy proctor hammer. A wooden plank of the size of the tank was used above the fill and the hammer was dropped on it for predetermined number of blows for a specific layer. A plastic sheet was placed between the soil and the wooden plank so that it will act as a moisture barrier, to prevent the moisture from the soil to get absorbed by the wood while compaction. The number of blows was changed for different layers. After conducting a number of trials for both the type of pond ashes it was found that the density of all the layers remains about the same as the numbers of blows are increased from 60 to 80. It was decided to start the bottom most layers with 60 numbers of blows distributed over the whole area of the tank and the number of blows increased to 80 numbers as the top most layers is placed. After the trial tests it was found that the pond ash type NC was compacted to a dry density of 12.7 kN/m^3 i.e. 93.5 % of MDD. Similarly for pond ash type NF the dry density achieved was 9.8 kN/m^3 i.e. 91.6% of MDD.

The coir geotextile layer was placed in the desired depths for different values of u/B, h/B and N as shown in Fig. 4. The model footing was centrally placed on the top finished pond ash surface. The ribbed steel plate was placed on the wooden model footing and the load was applied on it.

For loading the footing an automatic Universal Testing Machine (UTM) used. The UTM was a constant strain rate machine and was capable of constant strain rates in the range of 0.01 mm/min to 500 mm/min and a 50 kN load cell. The machine was connected to a computer where the load and settlement was recorded. The load applied to the footing at a constant strain rate of 1.0 mm/min and the settlement and corresponding increase in load was recorded at a settlement interval of 0.1 mm. The setup is shown in Fig. 5.



Type A Type B

Figure 4.Coir Geotextiles being placed on compacted pond ash

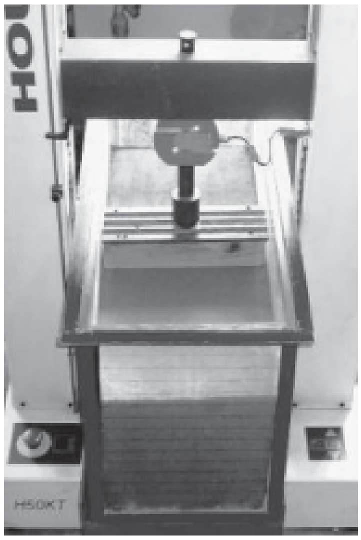


Figure 5. The load test on progress

Several series of tests were conducted, as listed in Table 3. Test series A was conducted with unreinforced pond ash. Test series B, C and D were conducted with varying b/B, u/B and N respectively.

TABLE III. PLAN FOR MODEL TEST

Test series	Detail parameters
A	Tests on unreinforced pond ash
B	Constant: u/B = 0.66, N =1 Variable: b/B = 3, 5, 7, 9
C	Constant: b/B = 5, N =1 Variable: u/B = 0.26, 0.4, 0.53, 0.66
D	Constant: u/B=0.4, b/B=5, h/B = 0.33 Variable: N = 1, 2, 3

V. MODEL TEST RESULTS

The results of the model load tests are being presented, and discussed in this section.

A. Bearing capacity of un-reinforced pond ash (test series A)

These tests were conducted on un-reinforced pond ashes. The ultimate bearing capacity (q_u) of unreinforced pond ash type NC was found to be 283.6 kPa at a settlement (s_u) of 6.7 mm and similarly for pond ash type NF these values were found to be 247.1 kPa and 6.1 mm.

B. Effect of b/B on bearing capacity of pond ash (test series B)

These tests were conducted with varying the width of the reinforcement by changing the b/B at 3, 5, 7 and 9 while keeping the values of N equal to 1 and u/B equal to 0.67. The values of ultimate bearing capacity (q_u) were observed to be 363.5 kPa, 374.9 kPa, 394.7 kPa and 424.3 kPa at settlements (s_u) of 8.7 mm, 9.2 mm, 9.6 mm and 10.1 mm respectively for b/B ratios of 3, 5, 7 and 9 for pond ash type NC with coir geotextile Type A. Similarly the values of q_u for similar changes in the parameters were found to be 334.0 kPa, 357.9 kPa, 384.2 kPa and 390.5 kPa respectively at values of s_u being 8.6 mm, 10.3 mm, 9.8 mm and 10.7 mm respectively for pond ash type NC with coir geotextile Type B.

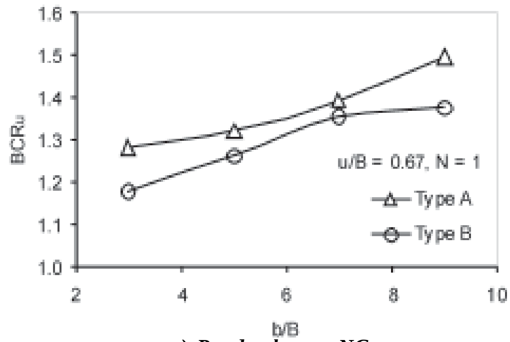
The values of q_u and su for pond ash type NF with coir geotextile Type A, for values of b/B equal to 3, 5. 7 and 9 and value of N equal to 1 and value of u/B equal to 0.67 were found to be 368.4 kPa, 382.0 kPa, 401.8 kPa and 393.1 kPa respectively at 9.2 mm, 9.6 mm, 10.7 mm and 9.8 mm settlement respectively. These values of q_u and s_u for pond ash type NF with coir geotextile Type B were observed to be 349.6 kPa, 361.8 kPa, 379.5 kPa and 377.8 kPa respectively and 10.8 mm, 11.2 mm, 11.3 mm and 10.2 mm respectively.

The value of ultimate bearing capacity ratio (BCR_u) for pond ash type NC with coir geotextile Type A increased from 1.28 to 1.50 as the b/B ratio was increased from 3 to 9. Similarly for pond ash type NC with coir geotextile Type B, the values of BCR_u increased from 1.18 to 1.36 as the b/B ratio increased from 3 to 7 and then marginally increased to 1.38 as the b/B ratio is further increased to 9 as shown in Fig. 6(a).

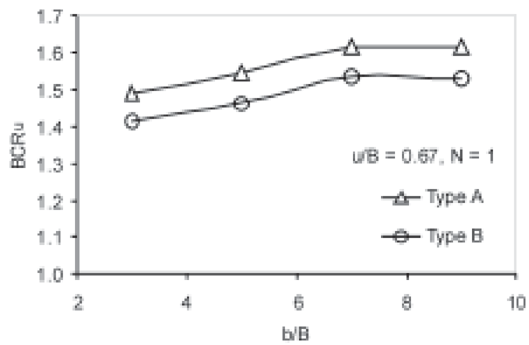
Similarly, for pond ash type NF, with coir geotextile Type A, the value of BCR_u increased from 1.49 to 1.63 with increase in the value of b/B from 3 to 7 and further increase in the value of b/B to 9 the value of BCR_u decreased marginally to 1.59. It was also observed that the value of BCR_u of pond ash type NF with coir geotextile Type B also increased from 1.42 to 1.54, with increase in the b/B value from 3 to 7 and then decreased marginally to 1.53 with further increase in the b/B value to 9 as shown in Fig. 6(b).

A. Effect of u/B on bearing capacity of pond ash (test series C)

These tests were conducted with varying the depth of the reinforcement layer from the base of the footing (u) by changing the value of u/B at 0.27, 0.4, 0.53 and 0.67 while keeping the value of N equal to 1 and the value of b/B equal to 5. The values of ultimate bearing capacity (q_u) were observed to be 384.8 kPa, 406.1 kPa, 416.6 kPa and 374.9 kPa at settlements (s_u) of 8.7 mm, 9.0 mm, 9.2 mm and 9.2 mm respectively for u/B ratios of 0.26, 0.40, 0.53 and 0.67 for pond ash type NC with coir geotextile Type A. Similarly the values of q_u with similar changes in the parameters were found to be 378.6 kPa, 390.2 kPa, 387.6 kPa and 357.9 kPa respectively at values of s_u being 8.1 mm, 8.4 mm, 8.7 mm and 10.3 mm respectively for pond ash type NC with coir geotextile Type B.



a) Pond ash type NC



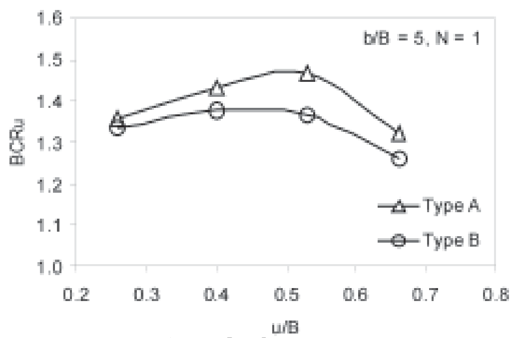
b) Pond ash type NF

Figure 6. Variation of BCR_u with b/B

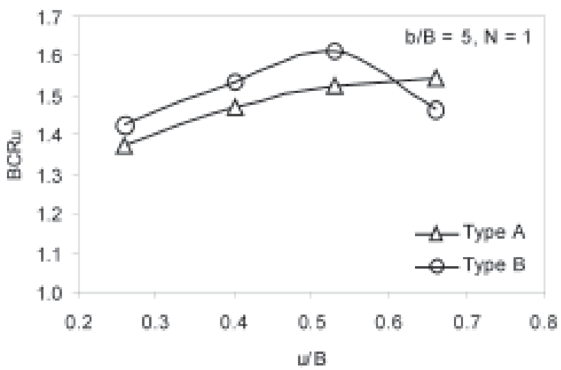
The values of q_u and s_u for pond ash type NF with coir geotextile Type A, for values of u/B equal to 0.26, 0.40, 0.53 and 0.67 and value of N equal to 1 and value of b/B equal to 5 were found to be 339.3 kPa, 363.7 kPa, 376.8 kPa and 382.0 kPa respectively at 7.8 mm, 8.1 mm, 8.3 mm and 9.6 mm settlement respectively. The values of q_u and s_u for pond ash type NF with coir geotextile Type B were observed to be 351.6 kPa, 379.3 kPa, 398.3 kPa and 361.8 kPa respectively and 10.6 mm, 11.1 mm, 11.3 mm and 11.2 mm respectively.

The value of ultimate bearing capacity ratio (BCR_u) for pond ash type NC with coir geotextile Type A increased from 1.36 to 1.47 as the u/B ratio was increased from 0.26 to 0.53. Similarly for pond ash type NC with coir geotextile Type B, the values of BCR_u increased from 1.34 to 1.38 as the u/B ratio increased from 0.26 to 0.40 and then marginally decreased to 1.37 as the u/B ratio is further increased to 0.53 and on further increasing the value of u/B to 0.66 the value of BCR_u sharply decreased to 1.26 as shown in Fig. 7(a).

Similarly, for pond ash type NF, with coir geotextile Type A, the value of BCR_u increased from 1.37 to 1.53 with increase in the value of u/B from 0.26 to 0.53 and further increase in the value of u/B to 0.67 the value of BCR_u increased marginally to 1.55. It was also observed that the value of BCR_u of pond ash type NF with coir geotextile Type B also increased from 1.42 to 1.61, with increase in the u/B value from 0.26 to 0.53 and then decreased to 1.46 with further increase in the u/B value to 0.67 as shown in Fig. 7(b).



a) Pond ash type NC



b) Pond ash type NF

Figure 7. Variation of BCRu with u/B

D. Effect of N on bearing capacity of pond ash (test series D)

These tests were conducted with varying the number of the reinforcement layers (N) by changing the value of N at 1, 2 and 3 while keeping the u/B, h/B and b/B equal to 0.40, 0.33 and 5 respectively. The values of ultimate bearing capacity (q_u) were observed to be 406.1 kPa, 511.8 kPa and 746.6 kPa at settlements (s_u) of 9.0 mm, 10.7 mm and 13.3 mm respectively for values of N equal to 1, 2 and 3 for pond ash type NC with coir geotextile Type A. Similarly the values of q_u with similar changes in the parameter N were found to be 390.2 kPa, 487.5 kPa and 672.9 kPa respectively at values of s_u being 8.4 mm, 10.6 mm and 12.9 mm respectively for pond ash type NC with coir geotextile Type B.

Similarly, the values of q_u and s_u for pond ash type NF with coir geotextile Type A, for values of N equal to 1, 2 and 3 were found to be 363.7 kPa, 451.9 kPa and 598.5 kPa respectively at settlements (s_u) of 8.1 mm, 10.3 mm and 12.4 mm respectively. The values of q_u and s_u for pond ash type NF with coir geotextile Type B were observed to be 379.3 kPa, 484.8 kPa and 643.9 kPa respectively and 11.1 mm, 13.0 mm and 15.2 mm respectively.

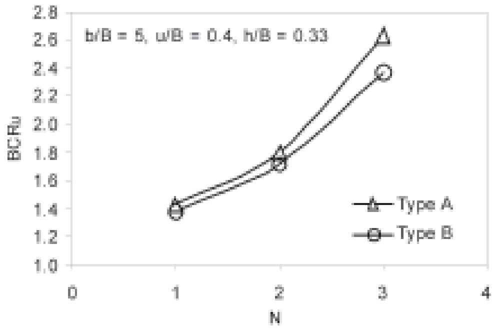
The value of ultimate bearing capacity ratio (BCR_u) for pond ash type NC with coir geotextile Type A increased from 1.43 to 2.53 as the value of N was increased from 1 to 3. Similarly for pond ash type NC with coir geotextile Type B, the values of BCR_u increased from 1.38 to 2.37 for similar increase in the value of N, as shown in Fig. 8 (a).

Similarly, for pond ash type NF with coir geotextile Type A, the value of BCR_u increased from 1.47 to 2.42 with increase in the value of N from 1 to. It was observed that the value of BCR_u of pond ash type NF with coir geotextile Type B also increased from 1.54 to 2.61, with increase in the value of N from 1 to 3, as shown in Fig. 8 (b).

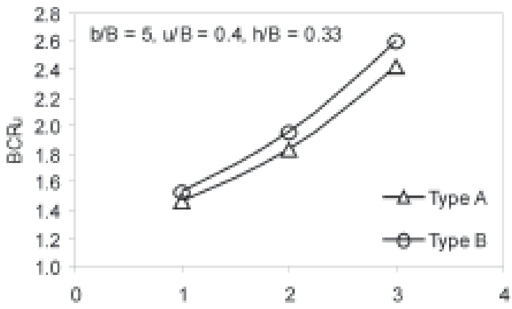
VI. Mathematical Model

The mathematical model developed by multiple regression analysis for any type of pond ash is given in "(2)". For developing a model for any type of pond ash, the tangent of the angle of internal friction (ϕ) of the pond ash has been considered. For incorporating the tensile property of the reinforcements into consideration, the ratio between tensile strengths at 5 % and 10 % strain obtained from the tensile stress vs. strain curve of the reinforcements has been considered. All the parameters in the mathematical model are dimensionless.

$$BCR_u = A_0 + A_1\,(b/B) + A_2\,(u/B) + A_3\,(d/B) + A_4\,(t) + A_5\,(\tan\phi) \quad (2)$$



a) Pond ash type NC



b) Pond ash type NF

Figure 8. Variation of BCRu with u/B

Where,

b/B = ratio between the width of the reinforcement to the width of the footing,

u/B = ratio between the depth of the top reinforcement from the base of the footing to the width of the footing,

d/B = ratio between the vertical distance between the reinforcement layers for multilayer reinforcement system or the depth of the bottom most reinforcement from the base of the footing to the width of the footing,

t = ratio between tensile strength at 5 % and 10 % strain obtained from the tensile stress vs. strain curve of the reinforcements,

tan ϕ = the tangent of the friction angle of the pond ash found from direct shear test.

All of the above are input or the independent variables and BCR_u is the dependent variable.

A0………A5 are the coefficient of the regression equation for each input or independent variables.

Data regression has been done for all test results investigated in the study of reinforced pond ash. Two different models were first developed for both types of pond ash by multiple regression analysis. In each of the models the data obtained from the 36 numbers of the model tests and 180 test data were used.

The mathematical model proposed is as follows,

$$BCR_u = 1.81 + 0.025\,(b/B) - 1.542\,(u/B) + 1.593\,(d/B) + 0.436\,(t) - 1.076\,(\tan\phi) \quad (3)$$

The above model “(3)” developed has coefficient of determination (R^2) = 0.9496 and the adjusted coefficient of determination ($R^2_{adjusted}$) = 0.9412.

The comparision of the experimental results and predicted values by using the above model are shown in a combined form in Fig. 9.

I. Conclusion

On the basis of the model test results and results obtained from the developed mathematical model, the following conclusions have been drawn.

1. The provision of coir geotextiles greatly improves the ultimate bearing capacity of the model footing at all the levels of settlement considered during the study.
2. From overall performance point of view of the model footing, the optimum width of the coir geotextile reinforcement is about 7 times the width of the strip model footing.
3. The finer pond ash showed greater BCR_u value than the coarser pond ash with both the types of geotextiles, reaching values of more than 1.6 in single layer reinforcement.
4. Coir geotextile Type A showed better results with coarse pond ash NC and the coir geotextile Type B with fine pond ash type NF, which may be due to better gripping of the geotextile inside the pond ash due to its larger aperture size.
5. Multiple layers of coir geotextile can be used effectively for improving the bearing capacity of pond ash fills. The BCR_u values reaching upto 2.6 with triple layers of reinforcement for both types of pond ash.
6. The model obtained through regression analysis of model test results may be used to predict the BCR_u as all the parameters viz. the shear parameter of pond ash samples, the tensile parameter of the reinforcements and the placement parameters of reinforcements like u, b and N has been considered.
7. The experimental results can be substantiated by conducting a 3D FEM analysis to enable extension to a prototype scale footing.

The primary aim of the research work reported in this paper was to ascertain whether coir geotextile reinforcement would result in significant improvement in bearing capacity. Though care has been taken during fabrication of set up and experimental procedure, all the results presented may have scale effect and hence can be considered to be only quantitative in nature. A large scale field test to study the long term suitability of the coir geotextile reinforcements and the possibility of reinforced pond ash getting stabilized before the biodegradability of coir geotextiles is worth to be studied.

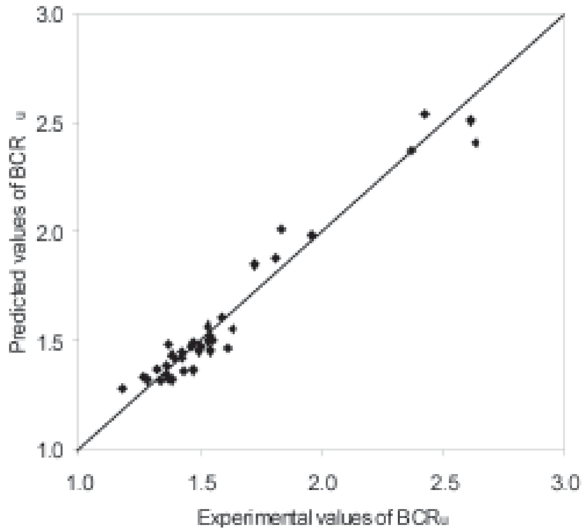


Figure 9. Variation in experimental and predicted values of BCRu

Acknowledgements

The authors are very grateful to the General Manager, Captive Power Plant (CPP), National Aluminum Company Ltd. (NALCO), Angul, Odisha, India for making arrangements for pond ash required for carrying out the study. The authors also express their thanks to the Kerala state Coir Corporation, Alappuzha, Kerala, India for supplying the coir woven geotextiles for the current research work.

References

[1] ASTM D 4595, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method, American Society for Testing and Materials, West Conshohocken, Pennsylvania, USA.

[2] Binquet, J. and Lee, K.M., Bearing Capacity Test on Reinforced Earth Slabs, Journal of Geotechnical Engineering, ASCE, 1975, 101(12), pp. 1241-1255.

[3] Binquet, J. and Lee, K.M., Bearing Capacity Test on Reinforced Earth Slabs, Journal of Geotechnical Engineering, ASCE, 1975, 101(12), pp. 1257-1276.

[4] Fragaszy, J.R. and Lawton, E., Bearing Capacity of Reinforced Sand Subgrades, Journal of Geotechnical Engineering, ASCE, 1984, 110(10), pp. 1500-1507.

[5] Ghosh Amalendu, Ghosh Ambarish and Bera, A.K., Bearing Capacity of Square Footing on Pond Ash Reinforced with Jute Geotextile, Geotextiles and Geomembranes, 2005, 23(2), pp. 144-173.

[6] Omar, M.T., Das, B.M., Puri, V.K. and Yen S.C., Ultimate Bearing Capacity of Shallow Foundation on Sand with Geogrid Reinforcement, Canadian Geotechnical Journal, 1993, 30, pp. 545-549.

[7] Pothal, G. K. and Venkatappa Rao, G., Pond Ash Bearing Capacity Improvement with Geogrids, Proceedings in International Seminar on Geosynthetics in India – Present and Future, New Delhi, Nov.-2006, pp. 57–67.

[8] Singh, R.M. and Venkatappa Rao G., Sustainable Development: - Durability of Natural Geotextiles as Erosion Control Product, 5th ICEG Environmental Geotechnics, Thomas Telford, London, 2006, pp. 1060–1067.

[9] Shin, E.C., Das, B.M., Puri, V.K., Yen, S.C. and Cook, E.E., Bearing Capacity of Strip Foundation on Geogrid Reinforced Clay, Geotechnical Testing Journal, ASTM, 1993, 17(4), pp. 534-541.

[10] Tafreshi, S. N. M. and Dawson, A. R., Comparison of Bearing Capacity of a Strip Footing on Sand with Geocell and with Planar Forms of Geotextile Reinforcement, 2010, 28, pp. 72-84.

[11] Vinod, P., Bhaskar, A. B. and Shreehari, S., Behaviour of A Square Model Footing on Loose Sand Reinforced with Braided Coir Rope, Geotextiles and Geomembranes, 2009, 27, pp. 464-474.