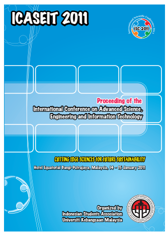
Proceeding of the International Conference on Advanced Science, Engineering and Information Technology 2011

Hotel Equatorial Bangi-Putrajaya, Malaysia, 14 - 15 January 2011

ISBN 978-983-42366-4-9



An Experimental Study into Behaviour of Circular Footing on Reinforced Soil

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***Abstract*— The experimental investigations are reported on the study of load-deformation behavior of a model circular footing on reinforced soil in respect of two-layered system comprising clay as sub-grade and mine waste as backfill material. The footing was subjected to axial load. Two different types of reinforcing materials such as Kolon Geo-grid (KGR-40) and rubber grids derived out of waste tyres were used in the study. The study revealed appreciable increase in ultimate bearing pressure and decrease in settlement with the provision of a single layer reinforcement. Further, rubber grid performed better than the Geo-grid in respect to BCR and SRF. The study indicates significance of solid waste materials such as mine wastes and discarded tyres as effective civil engineering construction materials.**

***Keywords*— Bearing Pressure, Bearing Capacity Ratio (BCR), Settlement Reduction Factor (SRF), Tyre Wastes**

I. INTRODUCTION

Founding of structure on a ground with adequate bearing capacity is one of the basic requirements for the stability of a structure. However, in some situations, structures are required to be built on weak or difficult soils. Under such circumstances, improvement of bearing capacity of such a soil is of great importance for the safety and long term stability of the structures. Inclusion of reinforcing layers within the sub-soil is an effective and economical method amongst many others.

Soil reinforcing technique has emerged as one of the promising fields in civil engineering, especially for a foundation engineer to improve certain characteristics of soils. Many waste materials such as rubber shreds, high density polyethylene (HDPE) strips, polypropylene fibers and jute fibers have been used as a fill along with soil in embankments and retaining walls to improve certain soil characteristics. Some of the prominent investigations reported in the literature dealing with numerical and experimental studies on the behaviour of footings subjected to vertical loads on un- reinforced soil and the reinforced are briefly reviewed in the subsequent section. Further, a few of the investigations pertaining to the use of waste materials in various civil engineering works are also briefly reviewed.

II. LITERATURE REVIEW

Some of the researchers (e.g. [1] - [3]) have reported theoretical studies and model tests to study the behaviour of footings subjected to axial loads on un-reinforced soil. The interfacial friction (skin friction) between the soil and construction materials is one of the aspects of the design of reinforced soil system. This aspect was studied by several researchers (e.g.[4]- [6]) through experimental studies by conducting pull out tests and sliding tests on reinforcing materials.

Several experimental and analytical studies (e.g. [7]- [14]) have been reported on the behavior of footing on reinforced soil. There have been several studies (e.g. [15]- [18])conducted to study the effect of waste materials on the performance of sub-grade soil.

III. Objective And Scope Of The Work

The above-mentioned review of available literature cites works related to the mobilization of internal friction, reinforced soil bed on soft clay and sand, footings subjected to axial loads in respect of reinforced and un-reinforced soil beds. Most problems of soft clays under imposed loads can be identified to be associated with low shear strength and high compressibility. The review, further, highlights scanty work on reinforced soil technique using rubber grids as a reinforcing material in solving engineering problems associated with foundations on soft clays subjected to vertical, centric loads. In view of the need to understand the behavior of a rubber reinforced system, an experimental investigation was conducted on the soft soil reinforced with rubber grid (Fig.1). Further, the results are compared with the soft soil reinforced with Geogrid (Fig.2)

Fig. 1.Rubbergrid

The results of experimental investigations are reported on the study of load-deformation behavior of a model circular footing under un-reinforced and reinforced conditions in respect of a two-layered system, consisting of clay as sub-grade and mine waste as backfill material, under the application of vertical centric loads. Kolon geo-grid KGR-40 (Fig.2) and rubber grids (Fig.1) derived out of waste tyres were used as single layer reinforcements of soft sub-grade to control settlements. The width and depth of the reinforcing materials were varied to determine their effects on the settlement and bearing capacity ratios.

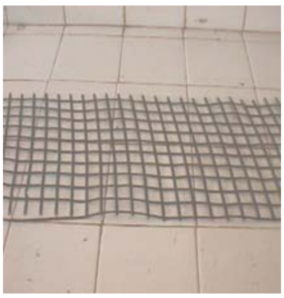

Fig. 2.Geogrid

IV. Experimental Programme

Tests were conducted in a tank (1000 mm × 1000 mm × 1000 mm) fabricated out of 8 mm thick M.S. plates. Load was applied through a load cell of 50 kN capacity, attached to a hydraulic jack and it was operated through a hydraulic power pack of 75 kN capacity. A load and displacement indicator unit facilitated reading the applied load and displacement of footing at any instant of time to an accuracy of 10 N. Three linear variable differential transformers (LVDT) were used to record settlements of the footing (Fig.3).

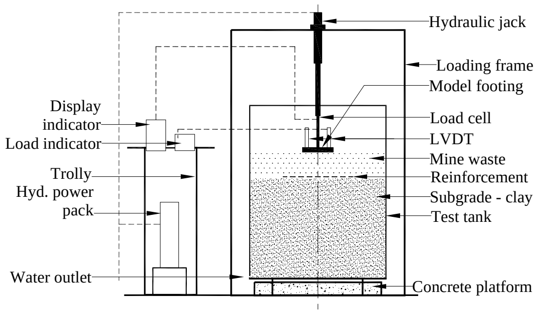

Fig.3. Details of test tank

The footings were placed on air-dried (un-reinforced and reinforced) mine waste, compacted to a relative density of 78.85% on clay sub-grade of wet density 1.768 gm/cc with 88% degree of saturation. Footings were subjected to vertical centric loads. The physical properties of soils are reported in Table I and Table II. The description and properties of the reinforcements are reported in Table III and Table IV.

TABLE I
PROPERTIES OF PROCESSED MINE WASTE

Physical Properties	
Sp. Gravity	2.65
Max. Density (gm/ cc)	1.48
Min. Density (gm/ cc)	1.165
Rel. density achieved in tank (%)	78.85
E	0.892
e_{max}	1.274
e_{min}	0.790
Geotechnical Properties	
Liquid Limit (%)	47.0
Plastic Limit (%)	33.33
Plasticity Index (%)	14.67
Angle of int. friction (degrees)	35.5
Density achieved in tank (gm/cc)	1.4

TABLE III
PROPERTIES OF SILTY CLAY SUBGRADE

Bulk density (gm/ cc)	1.720
Dry density (gm/cc)	1.33
Specific gravity	2.619
Liquid limit (%)	45.75
Plastic limit (%)	33.09
Plasticity index (%)	12.66
OMC (%)	28.9
Un-drained cohesion (kPa)	33.5

TABLE IIIII
PROPERTIES OF GEO GRID KGR-40

Property/ Item	Specification
Material	PET
Weight (gm/ m^2)	280
Aperture size ± 5 %	20/ 22
Tensile Strength (kN/m) @ 5 % Strain @ break	 14/6 40/20
Elongation (%)	<12
Creep (%)	<1
Roll width (m)	2.0
Roll length (m)	50

TABLE IVV
PROPERTIES OF RUBBER GRID

Parameter	**Specification**
Form	Strips
Size (mm)	5
Thickness (mm)	5
Color	Blackish white
Weight (gm/m)	50
Tyre type	Nylon reinforced, Bias
Corrosion resistant	Yes
Light weight	Yes
Non biodegradable	Yes
Material	SBR
Tensile strength at break (kN)	0.11*
Elongation at break (%)	45
*Applied strain rate 6 mm/ min	

V. RESULTS AND DISCUSSION

Pressure- settlement characteristics were obtained from various tests. The tests were conducted till failure and corresponding load and settlement were recorded. The terms Bearing Capacity Ratio (BCR) and Settlement Reduction Factor (SRF) are used for convenience to interpret the test data. The tests were conducted for three different values of H/B ratios such as 0.25, 0.375 and 0.5 .

$$BCR = q/q_o \text{ and } SRF = (S/B)_r / (S/B)_o$$

Where

- q_o = Average contact pressure of footing for unreinforced soil at failure
- q = Average contact pressure for reinforced soil at failure
- $(S/B)_r$ = Settlement ratio for reinforced soil and at failure
- $(S/B)_o$ = Settlement ratio for unreinforced soil and at failure
- H = Thickness of mine waste layer
- B = Footing width
- B' = Reinforcement width

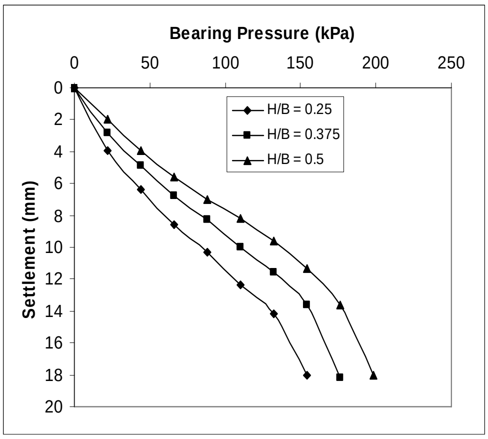

Fig 4. Pressure- settlement curves for un-reinforced case

A typical pressure -settlement characteristics for three different values of H/B ratios in respect of un-reinforced case is shown in Fig. 4. It is observed that initially the settlement is proportional to increase in bearing pressure for settlement up to about 4 % of footing width. However, it increases thereafter at a decreasing rate with increase in pressure. Further, increments in pressure result in continued settlements thereby indicating failure. It is further seen that maximum ultimate bearing pressure is obtained in case of H/B= 0.375. This is considered as the critical H/B ratio. Ultimate bearing pressure corresponding to critical value of H/B ratio is considered in calculating BCR.

In respect of tests under reinforced condition, pressure settlement characteristics were obtained to optimize the thickness of backfill material required on clay sub-grade and width of reinforcement. Performance of various reinforcements was also evaluated.

A. Effect of reinforcement width

The effect of width of reinforcement was studied for various H/B ratios and the ultimate bearing pressures were calculated for various values of B'/B such as 2, 4 and 6. Typical pressure settlement relationship for H/B = 0.25 and B'/B =2 is shown in Fig. 5.

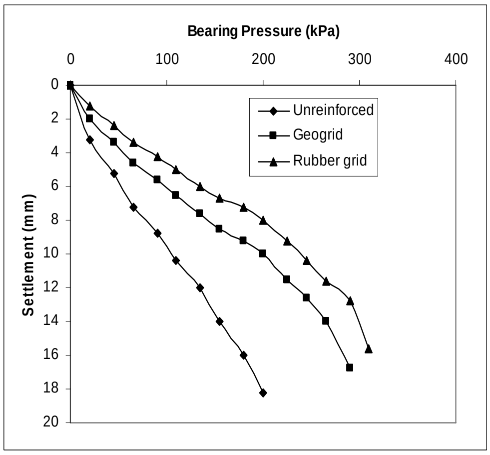

Fig. 5. Pressure- settlement curves [H/B =0.25 and B'/B = 2]

The variation of BCR with H/B for various reinforcements with their widths ranging from 2B to 6B was also studied as shown in Figure 6. BCR is observed to be maximum at B'/B

=4 in respect of all the reinforcements used in the present study. The results further indicate that the combination of B’/B =4 and H/B= 0.375 yields maximum value of BCR.

B. Effect on Bearing Capacity Ratio(BCR)

The effect of reinforcement type (such as geo-grid and rubber-grid) was studied on the performance of reinforced soil beds. The variation of BCR with H/B ratios in respect of the above reinforcements reveal maximum values of BCR to be 3.4 and 3.05, respectively with rubber grid and geo-grid at B’/B= 4 and H/B= 0.375 (Fig.6).

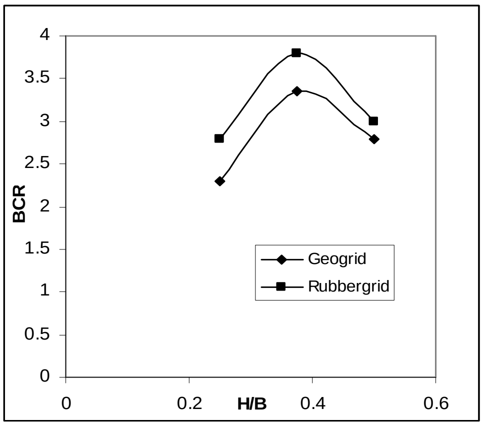

Fig. 6. Variation of BCR with H/B on reinforced soil at B’/B=4 [Critical case]

It is further observed that at B’/B =4 and H/B = 0.375, rubber grid yields an ultimate bearing pressure of 680 kPa whereas geo-grid yields an ultimate bearing pressure of 610 kPa. This is 11.48 % higher than that for geo-grid. The above results clearly show that rubber grid is more effective in terms of improvement in bearing pressure. The superior performance of the rubber grid may be attributed to better frictional adherence between the longitudinal members of the grid and soil which is influenced by the surface properties and coefficient of friction between them. The nylon belt provided within the tread and sidewalls of the tyre remains protruded even after stripping. This helps in creating the desired roughness in the rubber grid and in turn develops greater frictional resistance, although its tensile strength is less than that of geo grid. Semi- elastic properties of rubber grid develop better pseudo- cohesion owing to the temporary deformation of rubber grid. However, this mechanism is not present in case of other conventional grids.

C. Effect of reinforcement on settlement

The effect of reinforcement was also studied on settlement. It is seen that at B’/B =2, SRF decreases with increase in H/B values for all the reinforcements. However, at B’/B = 6, SRF values increase with increase in H/B. It is further seen that at critical values of B’/B and H/B ratios, SRF values are minimum for all the reinforcements. Figure 7 shows the variation of SRF with H/B values at (B’/B)cr. It is further seen from the variation of SRF with H/ B values at (B’/B)cr that SRF of 0.87 is recorded in respect of rubber grid which is 1.14% less than that for geo-grid.

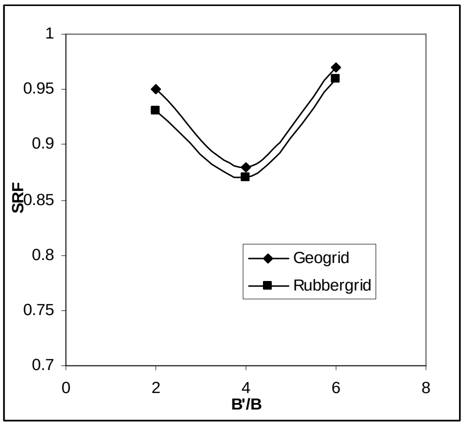

Fig. 7. Variation of SRF with different reinforcement widths at (H/B) = 0.375

VI. CONCLUSION

The experimental investigations reported herein demonstrate the use of mine waste and reinforcing materials towards the improved performance of a soft clay sub-grade in respect to bearing capacity and settlements. The better performance of rubber grid could be a cheaper and viable alternative for effective ground improvement.

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