IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 52-58
www.iosrjournals.org

Behaviour of Eccentrically Loaded Model Square Footing on Reinforced Soil: An Experimental Investigation

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ABSTRACT: *The experimental investigations are reported on the study of load-deformation behavior of model square 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 eccentric loads. Three different types of reinforcing materials such as Geotextiles, Kolon Geo-grid (KGR-40) and Rubber grids derived out of waste tyres were used in the study. The study revealed that the performance of an eccentrically loaded model square footing improves with the presence of reinforcing element in the soil system. This is reflected in terms of the values of BCR, SRF and tilt of footing. The beneficial effect of reinforcement is particularly observed at higher load eccentricities. Further, rubber grid performed better than the geo-grid and geotextiles in respect of BCR, SRF and tilt of footings. The study indicates significance of solid waste materials such as mine wastes and discarded tyres as effective civil engineering construction materials.*
Keywords – *Geo-grid, Geo-textile, Rubber-grid, Settlement reduction factor, Bearing Capacity ratio.*

I. INTRODUCTION

Footings serving as foundations for retaining walls, abutments, stanchions and portal framed buildings may be subjected to moments and shears in addition to vertical loads. An eccentric load or an eccentric-inclined load may replace these forces and moments. Further, 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 even on weak or difficult soils. Under such circumstances, improvement of bearing capacity of such 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 field in civil engineering, especially for a foundation engineer to improve certain characteristics of soils. Many waste materials such as rubber shreds, high density poly ethylene (HDPE) strips, polypropylene fibers and jute fibers have been used as fill along 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 and inclined loads on un- reinforced soil and the reinforced are briefly reviewed in the subsequent paragraph. Further, few of the investigations pertaining to the use of waste materials in various civil engineering works are also briefly reviewed.

Meyerhof [1], Siddiquee *et.al*. [2] and others have reported theoretical studies and model tests to study the behavior footing 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. Ingold [3] and Kate *et al.* [4] through experimental studies by conducting pull out tests and sliding tests on reinforcing materials. Several experimental and analytical studies are reported on the behavior of footing on reinforced soil. Some of the prominent investigations reported on this aspect include those by Binquet and Lee [5], Akinmusru and Akinbolade [6], Ohri and Choudhary [7], Manjunath [8], Dash *et al.* [9], Kumar and Saran [10] and Basudhar *et al.* [11]. Several studies are reported on the effect of waste materials on the performance of subgrade soil. Some of the prominent works include those by Benson and Khire [12], Garga and O'Shaughnessy [13] and Praveen Kumar *et al.* [14].

II. SIGNIFICANCE AND SCOPE OF WORK

The afore- mentioned review of literature cites many work related to mobilization of internal friction, reinforced soil bed on soft clay and sand, isolated footing as well as strip footings, subjected to axial and eccentric loads in respect of reinforced soil and un-reinforced soil bed. Several researchers reported model tests on soft soils reinforced with waste inclusions to improve the strength and bearing capacity of such soils. There could be a number of situations in which soft soils are to be used as a foundation material. 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 relatively lesser work on reinforced soil technique using rubbergrids as reinforcing material in solving engineering problems associated with foundations on soft clays subjected to vertical centric and eccentric loads. On the backdrop of the need to understand the behaviour of rubber reinforced system, an experimental investigation was conducted on the model footings reinforced with rubbergrid, Dewaikar *et al.* [15] reported the study of load deflection behaviour of model square and circular footings, 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 geogrid KGR-40, non woven geotextile GPB-203 (Sri Dinesh Mills, Vadodara) and rubbergrids derived out of waste tyres (Fig. 1) were used as single layer reinforcements soft sub-grade to control settlement were investigated in the studies. The width and depth of the reinforcing materials were varied to determine their effects on the settlement and bearing capacity ratios. The results on rubber grids showed that, there is significant difference in the contribution of increase in bearing capacity ratios and settlement reduction factors as compared to the other reinforcing elements.

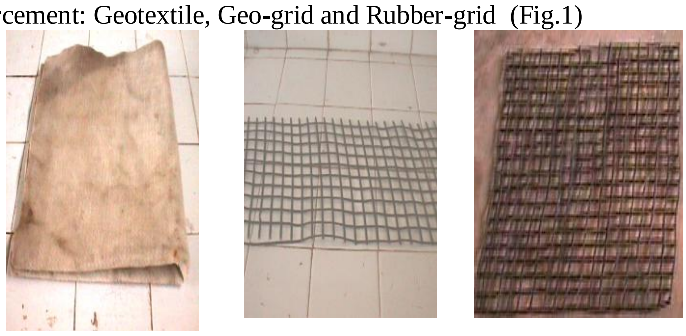
Along similar lines, The load-deformation behavior of a model square footing under un-reinforced and reinforced conditions in respect of a two-layered system, consisting of clay as sub-grade and mine waste as backfill material, under the application of eccentric loads along one axis of the footing is reported in this paper. In view of this, an experimental investigation was conducted on the soft soil reinforced with geotextiles, geo-grid and rubber grid.

III. MATERIALS AND METHODOLOGY OF INVESTIGATION

Experimental Programme

The experimental programme included a series of model footing tests on two layered soil system. Model mild steel plates of square and circular shapes with thickness 20 mm were used and following aspects were studied.

- Shape of footing: Square (120 mm × 120 mm)
- Eccentricity of the applied load (e): 0.00B, 0.1 B, 0.2 B and 0.3 B (B being the width / diameter of model footing)
- Thickness of the granular layer (H): 0.25 B, 0.375 B and 0.5 B
- Width of the reinforcement (B'): 2 B, 4 B and 6B
- Type of reinforcement: Geotextile, Geo-grid and Rubber-grid (Fig.1)



Geotextile Geogrid Rubbergrid

Fig. 1: Different reinforcement used in the study

Test Tank Details

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.2). The model footings (120×120×20 mm) 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 eccentric loads.

The schematic of the model footings (cross-section and plan) is shown in Fig.2. The physical properties of soils are reported in Table 1 and 2. The description and properties of the reinforcements are reported in Table 3 -5.

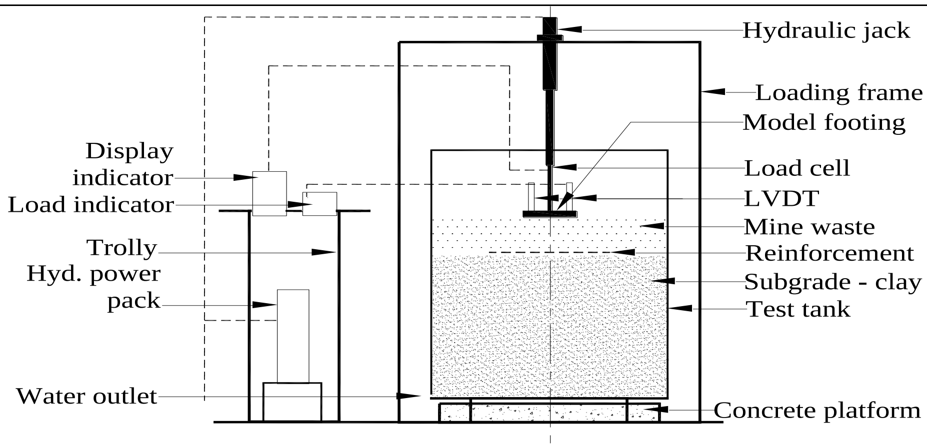


Fig.2 Details of test tank

Table 1: Properties of processed mine waste

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
Angle of int. friction (degrees)	35.5
Density achieved in tank (gm/cc)	1.4

Table 2: 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
Un-drained cohesion (kPa)	33.5

Table 3: 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 4: Properties of Rubber grid

Form	Strips
Size (mm)	5
Thickness (mm)	5
Color	Blackish white
Weight (gm/m^2)	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	

Table 5: Properties of Geotextile

MAKE: Non- woven needle punched geotextile, Manufactured by: Shri Dinesh Mills, Vadodara, Gujrat (India)	
Type	GPB 203
Material Composition	Polypropylene
Weight (g/m^2)	225
Thickness (mm)	2
Breaking Strength (kg) Warp away Weft away	 30 60
Breaking elongation (%)	80-110
Water Permeability (wt/m^2/sec at lower head)	140
Micron Size (wet sieving method)	30
Mullen Bursting Strength (kg/cm^2)	15

IV. 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 un-reinforced 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 un-reinforced soil and at failure
H = thickness of mine waste layer
B = footing width
B' = reinforcement width

It is observed that the maximum ultimate bearing pressure is obtained in case of H/B = 0.375. This is considered as the critical H/B ratio. Tests were conducted for eccentric loads along one axis of the footing in respect of un-reinforced and reinforced cases with e/B ratios such as 0.1, 0.2 and 0.3. The thickness of mine waste layer corresponded to (H/B)cr, for both reinforced and un-reinforced systems and the width of reinforcement corresponded to the optimum value B/B'. For the determination of ultimate bearing pressure (UBP) of an eccentrically loaded footing, the concept of useful width has been considered. As per this concept, portion of the footing which is symmetrical about the load is considered useful and other portion is simply assumed superfluous for the convenience of computations. Settlement under the load is computed by the method of interpolation, knowing the settlements at the centre and at known distances from the edges of the footing.

Un-reinforced Case

The pressure- settlement characteristics as obtained for various load eccentricities are shown in Table 6. The characteristics show a gradual increase in settlement till failure, which is indicated by suddenly increased settlements with further incremental loading. A bulge formation was noticed on the side of the eccentricity and volume of this bulge increased with increasing eccentricity.

Table 6: Comparison of ultimate bearing pressure (UBP) and settlements

Eccentricity (e/B)	UBP (kPa)	Settlement (mm)
0.0B	190	17.8
0.01B	164	18
0.02B	105	18.4
0.03B	85	18.8

Similarly, the values of the angle of tilt at failure for various load eccentricities in respect of a model square are shown in Table 7. The pressure- tilt relationships for various eccentricities of applied loads indicates that, with increase in load eccentricity, angle of tilt increases, ultimate bearing pressure decreases and also, pressure- tilt curve turns linear.

Table 7: Variation of angle of tilt at failure

Eccentricity (e/B)	Angle of tilt
0.0B	0.0
0.01B	7.5
0.02B	11
0.03B	14

Reinforced Case

In respect of the 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. The performance of various reinforcements was also evaluated.

Effect of reinforcement on BCR

A typical pressure-settlement relationships for a load eccentricity (e/B= 0.1) and corresponding to a critical case are shown in Figure 3, respectively for all the reinforcements. Similarly, the UBP, BCR and SRF values for various eccentricities at critical value of H/B ratio is shown in Table 8.

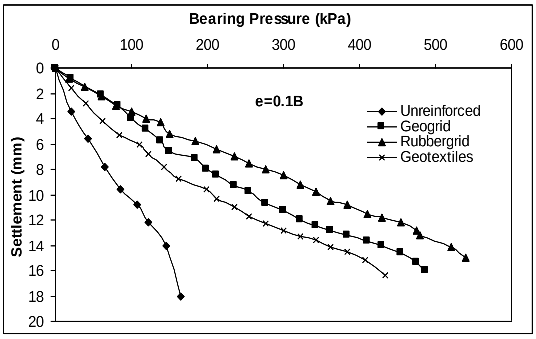


Fig.3: Pressure – settlement relationships for e/B =0.1

Table 8: UBP, BCR and SRF values for a reinforced case

e/B	UBP (kPa)				% increase in UBP			BCR			SRF		
	UR	GT	GG	RG	GT	GG	RG	GT	GG	RG	GT	GG	RG
0.0	190	480	520	570	152	173	200	2.52	2.73	3.00	0.92	0.89	0.83
0.1	164	434	487	540	164	195	229	2.65	2.96	3.29	0.971	0.942	0.859
0.2	105	311	386	405	196	268	286	2.96	3.68	3.86	0.988	0.946	0.886
0.3	85	290	340	380	241	300	347	3.41	4.00	4.47	0.991	0.949	0.892

All the tests were conducted with the centroid of reinforcing elements in line with the applied load. The ultimate bearing pressure is found to reduce with the increase in the eccentricity of load in all the cases. At the same time, the settlement of footing is observed to increase with increase in eccentricity for a given pressure. However, for any specified load eccentricity and for a given load, the settlement in case of a reinforced system is considerably less than that in case of un-reinforced system.

The results indicate that, the provision of a reinforcement layer at the interface of the mine waste and clay, results in an increase in the ultimate bearing pressure by 164%, 196%, and 241%, respectively for e/ B = 0.1, 0.2 and 0.3 in case of geo-textile, 195%, 268% and 300% in case of geo-grid and 29%, 286% and 347% in case of rubber-grid as compared to the un-reinforced cases.

It is further observed that, the rubber grid yields 39.63%, 46.66% and 43.98% more bearing pressure at e/ B = 0.1, 0.2 and 0.3, respectively than geotextiles. The corresponding values in case of geogrid are 17.43%, 6.72% and 15.66%, respectively. This may also be due to the fact that, placement of centriod of reinforcement in line with the applied load, brings a large part of the reinforcement in the zone of soil deformation, thus allowing a better utilization of its tensile strength.

It is further observed that, the BCR improves with increasing load eccentricity. In other words, it means that, provision of reinforcement has more beneficial effect at higher load eccentricities. For both the footings the geo-grid is found to perform better than geotextile and rubber-grid is found to perform better than geo-grid in respect of BCR.

The values of the BCR are observed to be 3.29, 3.86 and 4.47, respectively corresponding to e/ B values of 0.1, 0.2 and 0.3 in case of rubber-grid. These are higher by 24.15%, 30.40% and 31.08% as compared to that in respect of geotextile and by 11.14%, 4.89% and 11.75% as compared to that in respect of geo-grid. It is observed that the rubber-grid proves to be more efficient as compared to other reinforcing elements in respect of BCR.

Effect of reinforcement on settlement

It is observed that, there is a considerable reduction in the settlement in case of reinforced system as compared to the un-reinforced one. The values of the settlement reduction factor (SRF) are observed to increase with the increase in the eccentricity of load in respect of all the reinforcements. The values of the SRF are found to be 0.859, 0.886 and 0.892, respectively corresponding to e/B values of 0.1, 0.2 and 0.3 in case of rubber-grid. These are lower by 13.03%, 11.51% and 11.09% as compared to that in respect of geotextile; and by 9.66%, 6.78% and 6.39% as compared to that in respect of geo-grid. Thus, the results indicate that rubber grid is more effective in terms of improvement in settlement.

Effect of reinforcement on tilt

A typical pressure - tilt relationships for a load eccentricity (e/B =0.1) corresponding to critical case are shown in Fig. 4. Similarly, the values of the angle of tilt and corresponding percentage reduction in tilt for reinforced critical case at different eccentricities are shown in Table 9.

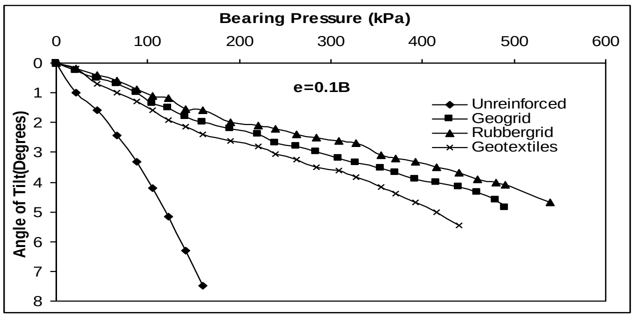


Fig.4: Pressure – tilt relationships (Square footing)

It is observed that, for any specified load eccentricity, there is a considerable reduction in the angle of tilt in case of reinforced system as compared to the un-reinforced one in respect of either footing. A reduction of 36%, 33% and 17% in tilt is observed for eccentricity ratios of 0.1, 0.2 and 0.3, respectively in case of geotextile when compared with the un-reinforced case at failure. The corresponding values in case of geo-grid and rubber-grid are 50%, 57% and 40%; and 56%, 69% and 47%, respectively. This shows that rubber-grid proves to be more efficient in the reduction of tilt of the footing in comparison to the other reinforcing elements.

Table 9: Reduction in tilt for reinforced critical case at failure (Reinforced case)

e/B	Square footing						
	Angle of tilt				% reduction in tilt		
	UR	GT	GG	RG	GT	GG	RG
0.0	0.0	0.0	0.0	0.0	-	-	-
0.1	7.5	5.5	5	4.8	36	50	56
0.2	11	8.25	7	6.5	33	57	69
0.3	14	12	10	9.5	17	40	47

The above results clearly show that, rubber grid is more effective in terms of the improvement in bearing pressure, reduction in settlement and angle of tilt than the other two reinforcements. 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 (Fig.5).

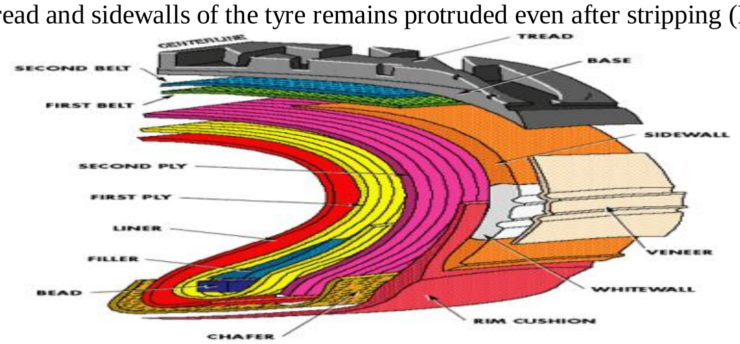


Fig. 5: Typical radial passenger tyre construction

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. Moreover, the apertures present in the grid structure, there are chances for better interlocking of the sub-grade and the reinforcement along with the backfill material. Hence, the performance of grids is better than that of geo-textile.

V. SUMMARY AND CONCLUSIONS

Some of the broad conclusions emerged from the present study are as under:

i. Provision of reinforcement results in enhancement of ultimate bearing pressure and bearing capacity ratio (BCR). This enhancement is more for higher load eccentricities as compared to the lower ones, thus showing beneficial effects of the reinforcement.
ii. Reduction in settlement on provision of reinforcement, shows a decreasing trend, i.e., settlements are more at higher load eccentricities.
iii. Performance of rubber grid is superior to the other two reinforcements, both in terms of bearing capacity ratio (BCR) and settlement reduction, with geotextile being the least effective.
iv. Optimum width of reinforcement (B') for deriving maximum possible BCR is about 4B in case of all the reinforcements and for both the footings.
v. With geo-synthetic reinforcement, the critical value of H/B ratio corresponding to maximum BCR is about 0.375 for all reinforcing elements.
vi. Rubber reinforcement probes to be more economical and effective soil reinforcing elements.

The performance of eccentrically loaded model square footing improves with the presence of reinforcing element in the soil system. This is reflected in terms of the values of BCR, SRF and tilt of footing. The beneficial effect of reinforcement is particularly observed at higher load eccentricities as shown by the increasing values of BCR. The better performance of rubber grid could be a cheaper and viable alternative for effective ground improvement. The study underscores the effective utilization of the solid wastes generated in the process of mining in conjunction with the rubber wastes as civil engineering construction materials.

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