Study on Square Footing Supported on Geocell – Tire Crumb Reinforced Granular Soil

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Abstract— Weak or soft soil is considered unsafe for construction of engineering structures. To bring about improvement in such soil, ground improvement techniques are utilised commonly in these days in which the engineer forces the ground to adopt the project's requirements, by altering natural state of the soil, instead of having to alter the design in response to ground natural limitation. In this present study, tire crumbs from waste have been chosen as the reinforcement material for soil improvement. Another viable alternative to enhance the strength of the soft soils is the adaptation of technique involving the use of geocell mattress which is a three dimensional, polymeric, honeycomb like structure interconnected at joints. The results of the model load tests show that the stiffness and the load carrying capacity of the soil improve substantially with the provision of geocell reinforcement. In addition to it tire crumb's optimum content has also been discussed which gives maximum bearing capacity as compared to unreinforced soil.

Keywords: Design, Development, Low Cost, Orange Sorter

I. INTRODUCTION

A. *Background*

The centuries-old problem of land scarcity in the vicinity of existing urban areas often necessitates the use of sites with soils of marginal quality. Rapid urban and industrial development pose an increasing demand for land reclamation, utilization of unstable and environmentally affected ground and safe disposal of waste. The soil often poses design, construction and maintenance hazards to civil engineering structures founded on them. Problems may arise during construction stage due to inability of the soil to provide adequate support to the construction work. Excessive settlement, insufficient bearing capacity of the subgrade etc. may lead to loss of stability of the overlying structures. If such soil cannot be removed Then its engineering behaviour can often be enhanced by some method of ground improvement techniques also called soil reinforcement techniques.

B. *Ground Improvement*

Ground improvement is the most imaginative field of geotechnical engineering. It is a field in which the engineer forces the ground to adopt the project's requirements, by altering the natural state of the soil, instead of having to alter the design in response to the ground's natural limitations. The results usually include saving in construction cost and reduction of implementation time There are number of techniques available for improving the mechanical and engineering properties of the soil.

C. *Geogrids*

A geogrids is any synthetic planner structure formed by a regular network of tensile elements with apertures of sufficient sizes to allow interlocking with surroundings soil, rock, earth or any other geotechnical material. They are also characterized by high dimensional stability and high tensile modulus at very low elongation. The interlocking effect is determined by the geogrid strength, mesh size and base material. Usually produced with a range of strengths in either a biaxial orientation (meaning strength in both directions), or uniaxial, (meaning strength in one direction only), or tri-axial (with a honeycomb appearance and strength in all directions). The apertures within the grids may therefore be square, rectangular or triangular.

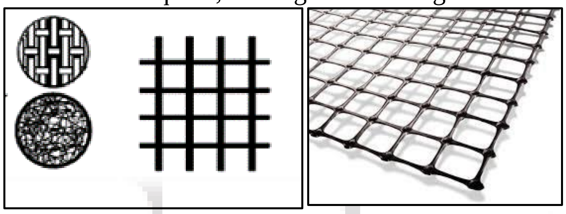


Fig. 1.1: Biaxial geogrid

Geogrids can be used in soil (or rock) retention systems for vertical or near vertical faces possibly in conjunction with soil nails or anchors or tire shreds etc. Geocell are used to construct geocell.

The latest adaptation of this technique involves the use of geocell mattress, which is a three dimensional, polymeric, honeycomb like structure interconnected at joints.

D. *Tyre Crumbs as Reinforcement*

Waste tire are basically tyre product and are used as substitute or replacement for aggregates used in construction structures or as reinforcing material in ground or soil improvement. Tire crumbs are of the form of waste tyres obtained from scrapping waste tire in the form of crumb particle. As with other items made from rubber or plastic, old tires have the potential to be an environmental hazard.

Fig. 1.2: Waste tyres and its shredded form

Reinforcement is an effective and reliable technique for increasing strength and stability of soils. There are many advantages of using scrap tires in civil and geotechnical engineering practice. Their properties such as durability, strength, resiliency, high frictional resistance, light weight, high vibration absorption capacity, high elastic compressibility and high hydraulic conductivity make it capable to be used in geotechnical application.

II. REVIEW OF LITERATURE

A. Studies with Geogrid-Geocell Reinforcement

Sitharam et al. (2007) studied the performance of surface footing on geocell reinforced soft clay beds. For that laboratory model tests were carried out. A test tank of dimension 900x900x600 mm was fabricated. Natural silty clay was used for the study. Geocells of square shaped pockets prepared from biaxial polymer geogrid were used for this study. Five different series of tests were carried out by varying the depth of placements of geocells, width of geocell mattress, height of geocell mattress and influence of additional layer of geogrid at the base of the geocell mattress. The results obtained clearly indicated that geocell reinforcement substantially increases the load carrying capacity of the soil and it reduces the settlement of the footing. This is because the geocell confinement induced stiffening of the soil contained within the pockets of the geocells inhibits the shearing of the soil just below the footing thereby transmitting the footing pressure to a greater depth which gives rise to better load carrying capacity.

B. Studies with Tire Shreds Reinforcement-

N. Hatafet al. (2005) conducted a series of laboratory model tests to investigate the use of shredded waste tires as reinforcement to increase the bearing capacity of soil. Shred content and shreds aspect ratio are the main parameters that affect the bearing capacity. Tire shreds with rectangular shape and widths of 2 and 3 cm with aspect ratios 2, 3, 4 and 5 are mixed with sand. Five shred contents of 10%, 20%, 30%, 40% and 50% by volume were selected. Addition of tire shreds to sand increases BCR (bearing capacity ratio) from 1.17 to 3.9 with respect to shred content and shreds aspect ratio. The maximum BCR is attained at shred content of 40% and dimensions of 3.12 cm. It is shown that increasing of shred content increases the BCR. However, an optimum value for shred contents observed after those increasing shreds led to decrease in BCR. For a given shred width, shred content and soil density it seems that aspect ratio of 4 gives maximum BCR.

C. Studies with Geocell And Tire Shreds Reinforcement

T. Tanchaisawat et al. (2009) studied the effect based on interaction between geogrid reinforcement and tire chip–sand on lightweight backfill. The paper deals with the interaction between the geogrid and the tire chip–sand mixture including the determination of the index properties of the backfill materials, the shear strength parameters, the interaction coefficients, and the efficiency of geogrid reinforcements in tire chip–sand backfills. Numerous experiments including index tests, compaction tests, pullout tests, and large-scale direct shear tests were conducted. The test results revealed that the dry unit weight of tire chip–sand mixtures depended more on the sand content, and less on the water content. The mixture at the mixing ratio of 30:70 by weight or 50:50 by volume was found to be the most suitable fill material compared to other mixing ratios.

D. Conclusion Drawn from Literature Review Geocell

1) Use of geocell enhanced the bearing capacity of weak soil substantially and the differential settlement of the structure was remarkably reduced.
2) Significant improvement in performance could be obtained with increase in height of geocell.
3) Geocell mattress placed at a depth of 0.1 from the footing base gave maximum performance for increasing the bearing capacity.
4) Chevron pattern more effective in increasing the bearing capacity as compared to the Diamond pattern of geocell.
5) Performance improvement of geocell increases with increase in the area of geocell reinforcement.

1) Scrap Tires-

1) Not much work has been done on tire crumb material to efficiently evaluate its optimum performance value.
2) The use of granulated rubber due to its light weight and high capacity are used for seismic force reduction and absorption of earthquake vibration.
3) The use of tire derived aggregate has been concluded as an effective backfill material.
4) Addition of tire shreds (size of tire shreds greater than tire crumb) content to unreinforced sand increases the BCR (bearing capacity ratio) from factor of 1.17 to 3.9. After the optimum value increase in tire shred content decreases the bearing capacity ratio.

III. EXPERIMENTAL INVESTIGATIONS

A. Materials Used in the Study

1) Sand

The sand used in the experimental lab was Pandu river sand obtained at Kanpur, situated in Uttar Pradesh, India. Before test sand was cleaned by removing foreign and vegetative matters. Specific gravity of the sand was obtained 2.65 as per ASTM D. The particle size distribution [ASTM D 6913-04] of the sand is presented in Fig. 3.1. The coefficient of the curvature (CC) and coefficient of uniformity (Cu) was obtained 0.982 and 2.049.

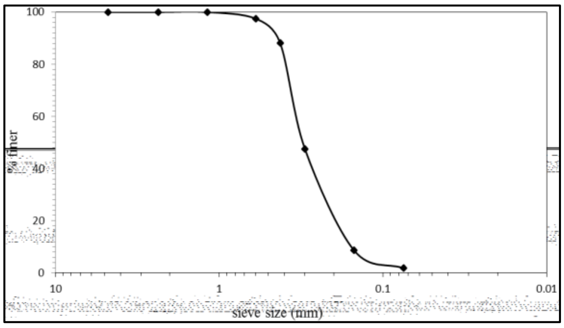


Fig. 3.1: Grain size distribution of sand used in the study

The soil can thus be classified as poorly graded sand, SP, as per Unified Soil Classification System (USCS) [ASTM D 2487-06]. Maximum dry density [ASTM D 4253-00] and minimum dry density [ASTM D 4254-00] of the soil was found to be 17.16 kN/m^3 and 13.84 kN/m^3.

Properties	Values
Specific Gravity, G	2.65

D10 (mm)	0.165
D30 (mm)	0.23
D50 (mm)	0.307
D60 (mm)	0.3381
Coefficient of uniformity, Cu	2.049
Coefficient of curvature, Cc	0.9482
Classification (USCS)	SP
Maximum dry density, γdmax (kN/m3)	17.16
Minimum dry density, γdmin (kN/m3)	13.84
Friction angle (φ) from triaxial test data	
ID 60%	37.98◦
ID 80%	40.25◦
Friction angle (φ) from direct shear test	
ID 60%	40.30◦
ID 80%	42.68◦

Table 3.1: Properties of sand used in the study

Triaxial compression tests were performed on the dry sand samples prepared at relative densities of 60% and 80% as per ASTM D 2850-03.

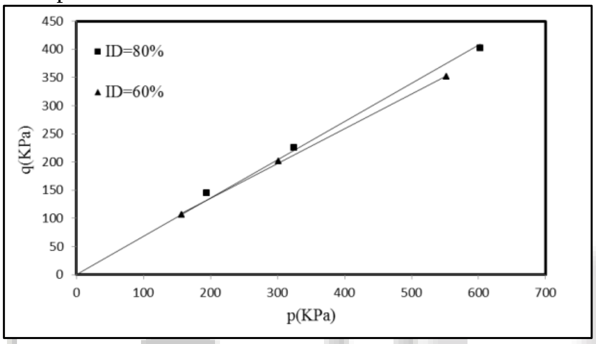


Fig. 3.2: p-q plot for different relative densities of sand under triaxial compression test

Direct shear tests as per ASTM D 6528-07 were performed on samples prepared at relative densities (ID) of 60% and 80% and the corresponding shear stress-shear strain behaviour are shown in Fig. 3.3

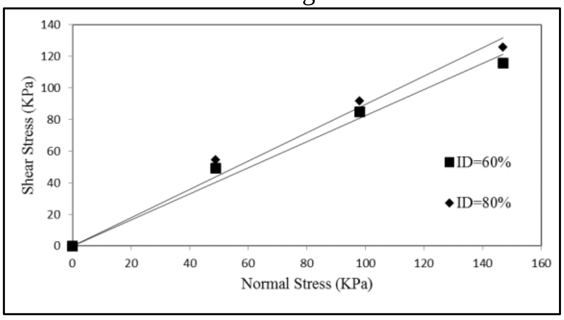


Fig. 3.3 Normal stress-peak shear stress response of sand at different relative densities obtained from direct shear test

B. Tire crumbs:

Crumb Rubber is waste product made by reducing the whole tires through granulators and classifiers obtained from automotive and truck scrap tires. The crumb tires utilized in this experiment was obtained from a tire factory situated in New Delhi. Photo 3.1 shows the tire crumbs used in this study. Crumb rubber usually consists of particles ranging in size from 4.75 mm (No. 4 sieve) to 0.075 mm (No. 200 sieve). Fig. 3.4 represents the distribution of the particles of the tire crumbs used in this study.

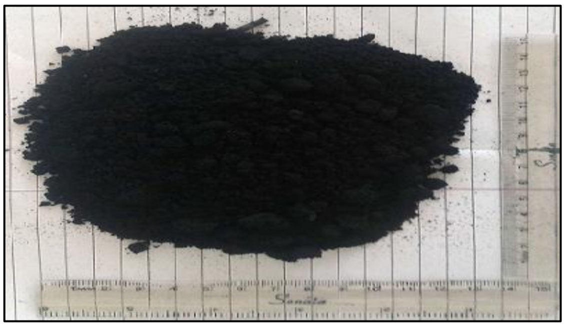


Photo 3.1 Tire Crumbs used in this study

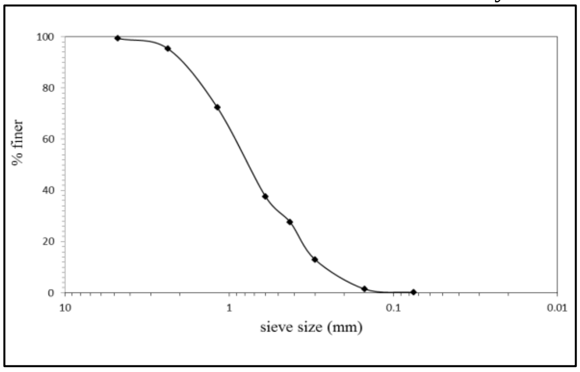


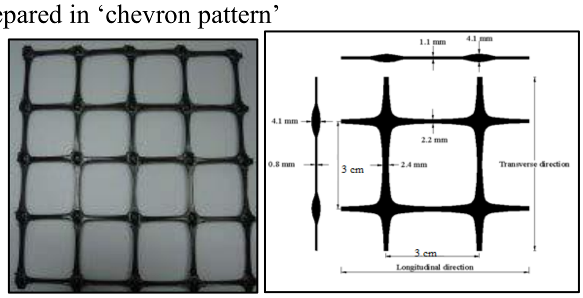
Fig. 3.4: Grain size distribution of tire crumb used in the study

PROPERTIES	VALUES
Specific Gravity, G	0.81
Coefficient of uniformity, Cu	3.73
Coefficient of curvature, Cc	0.85
Classification (USCS)	SP
Maximum dry density, γdmax	6.14
Minimum dry density, γdmin	5.65

Table 3.2: Properties of tire crumb used in the study

C. Geocell

The geocells used in the study were assembled from commercially available biaxial geogrid made from polypropylene. The photograph of the biaxial geogrid and its dimensions are shown in Photos. The properties of the geogrids were determined from standard multi-rib tension test as per ASTM D 6637-01 and are listed in Table 3.3. The joints for the geocells were formed from mild steel wire used to bind the stirrups in the construction work. Three different types of geocell G1, G3 and G5 having different heights were prepared. The pockets of the geocell were prepared in 'chevron pattern'



(a) Biaxial geogrid (b) Geometry of the geogrid

Fig. 3.5: Geogrid used in this study

Property	Values
Ultimate tensile strength (kN/m)	19.3
Failure strain (%)	28

Aperture Size (mm)	30 30
Shape of aperture opening	square

Table 3.3 Properties of the geogrid used in the study

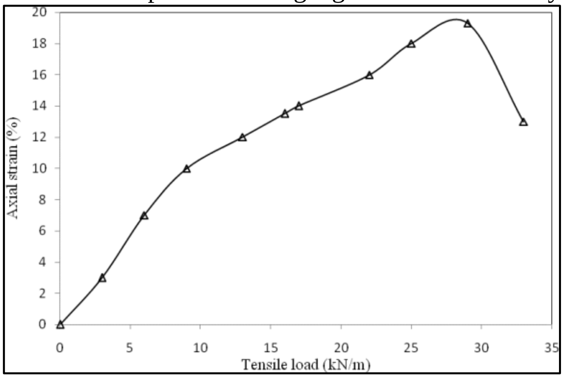


Fig. 3.6: Load-strain behavior of biaxial geogrid used in the study

D. *Planning of experiments*

Schematic diagram of the geometry of the model of the foundation-reinforced bed is presented. The various parameters varied in the experimental program are relative density of infill sand (ID), height of geocell mattress (h) and the provision of various percentages of tire crumbs. The constant parameters include the pocket size of geocell (d), depth of placement of the geocell mattress from base of the footing (u), and the pattern of formation of geocell (chevron pattern of geocell). (Give the value of constant parameters).

Four different series of model tests A, B, C and D were considered in this study. Geometrical parameters like h, u, d and B are taken as h/b, u/b, d/b and B/b respectively which are dimensionless quantity. The pocket size of the geocell (d) is taken as the diameter of the equivalent circular area of the geocell pocket opening. A typical geocell pocket is shown through the hatched area in Fig. 3.11. Here u/B was taken as (mention). d/B was taken as (mention) and other constant parameters. It was found from different literatures that geocell reinforcement performs best on these values.

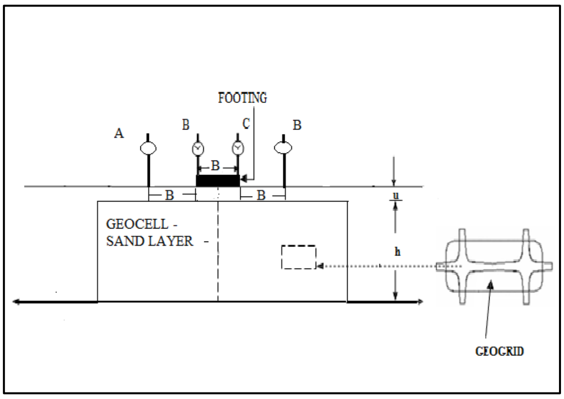


Fig. 3.7: Geometry of the reinforced foundation bed

Photo 3.2: Photographic view of test setup.

E. *Footing*

Model footing made up of mild steel was used. The footing was machined to correct size in square shape. The size of the footing used was 120 mm X 120 mm and 30 mm thick. A semicircle hole was formed at the center of the footing for the inclusion of ball bearing so to reduce the eccentricity as low as possible.

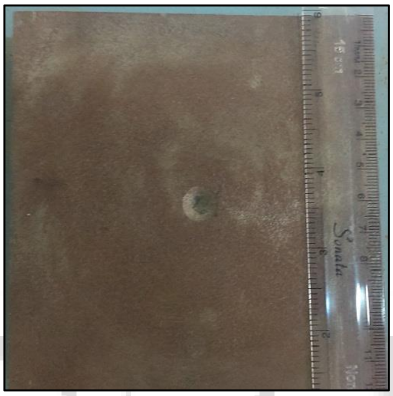


Photo 3.3: Image of the footing

F. *Testing tank*

The size of tank was designed keeping in view the size of footing to be tested and zones of influence. The size of the tank was taken as 5 times the size of plate (IS: 1888-1982). The depth influence zone was designed to affect to a depth of 4B. The dimensions of the tank were fixed as 600 mm X 600 mm and 480 mm.

G. *Proving ring*

The proving ring for measuring the applied load was placed over the footing at lower end and top end was bearing the assembly. The proving ring was properly calibrated. Proving ring of capacities of 50 kN was used. Load was calculated from the standard calibration chart provided by manufacturer.

H. *Dial gauge*

In this study four dial gauges were used. All the dial gauges were from same manufacture and have same specifications.

They can measure deflections up to 50 mm with least count of 0.01 mm.

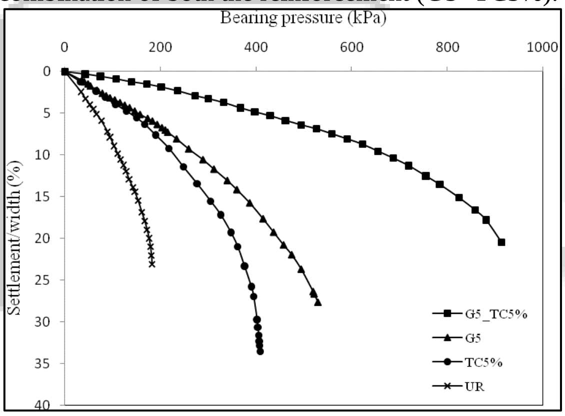
I. EXPERIMENTAL PROCEDURE

After preparation of test bed, square footing was placed over the top of the bed. Then steel ball was placed over the footing and proving ring was attached and connected with reaction frame. Then dial gauges were placed over the surface. Proving ring was used to measure the load and dial gauges were used to measure the surface deformation. Deformation was applied manually and then readings of the dial gauge and proving rings were measured. All readings were taken manually.

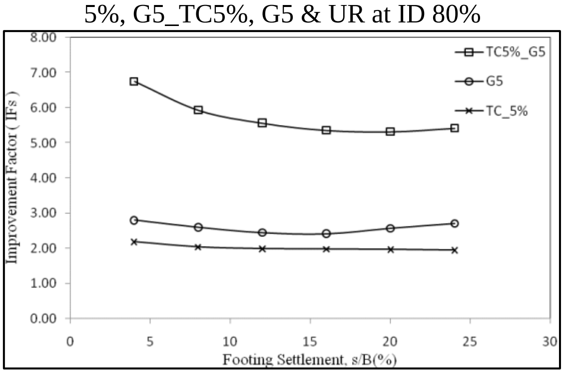
IV. RESULTS AND DISCUSSION

A. Geocell-Tire crumbs Reinforced soil

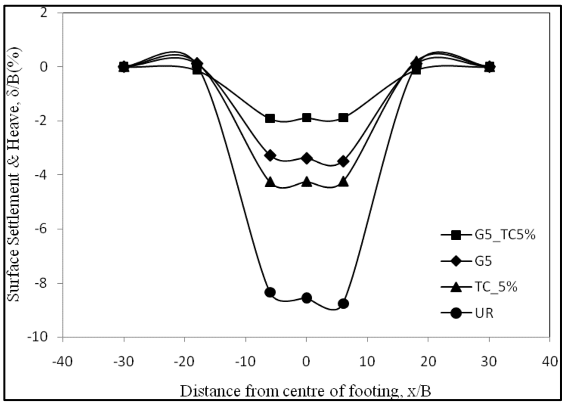
Fig. 4.1 shows typical pressure-settlement responses for all forms of reinforcement. The figure has been established for all forms of reinforcement at relative densities of 80%. Since it has been defined in earlier chapters that of the two densities, better performance has been for 80% ID hence as such for effect of reinforcement higher density has been preferred. The figure shows the pressure – settlement nature for the geocell (G5), tire crumb reinforcement (TC 5%) and the combination of both the reinforcement (G5+TC5%).



Variation of bearing pressure with footing settlement for TC 5%, G5_TC5%, G5 & UR at ID 80%



Variation of improvement factor with footing settlement for TC 5%, G5 & TC5%_G5 at ID 80%



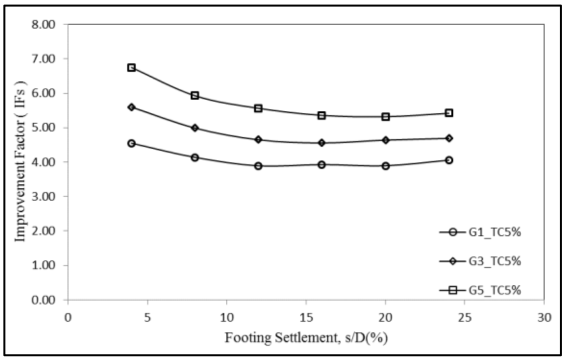
Surface deformation profiles for G5+TC5%, G5, TC5% & UR at bearing stress of 100 kPa, ID 80%

Summary of results in terms of bearing capacity improvement factor (IF) showing the influence of tire crumb-geocell reinforced sand beds (G5_TC5%), geocell reinforced sand bed (G5) and tire crumb reinforced sand bed (TC 5%). Test Series B, C3 and D1

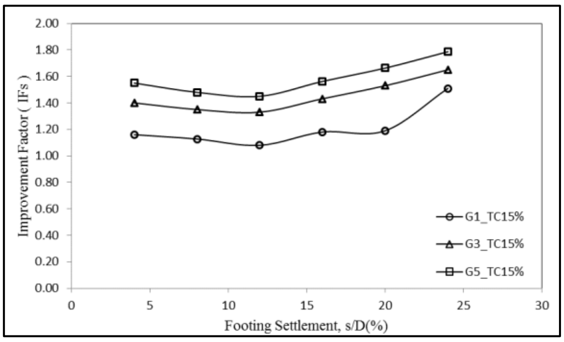
ID = 80%		Bearing capacity improvement factor (IF)				
Variable parameter (h/B)	Constant parameter (u/B)	(s/B) 4%	(s/B) 8%	(s/B) 12%	(s/B) 16%	(s/B) 20%
G5_TC5%	0.1	**6.75**	**5.93**	**5.56**	**5.36**	**5.42**
G5	0.1	2.98	2.82	2.88	2.87	3.31
TC 5%	0.1	2.19	2.04	1.99	1.98	1.95

B. Influence of Height of Geocell Mattress

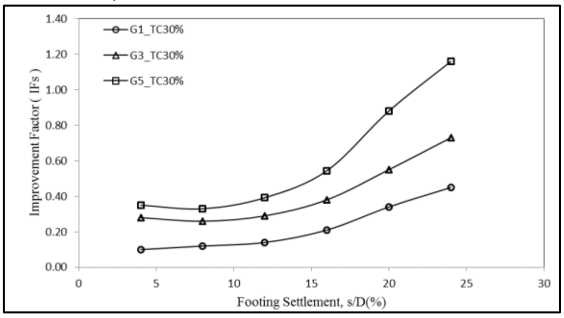
This chapter mainly focuses on the combined reinforcement effect based on the footing load. It must be noted that we have included only for the 80% relative density because in previous chapter we have discussed already about the better performance with higher density. Only 5% and 30% tire crumbs content effect has been discussed as higher crumb content of 30% has no positive effect over the unreinforced sand.



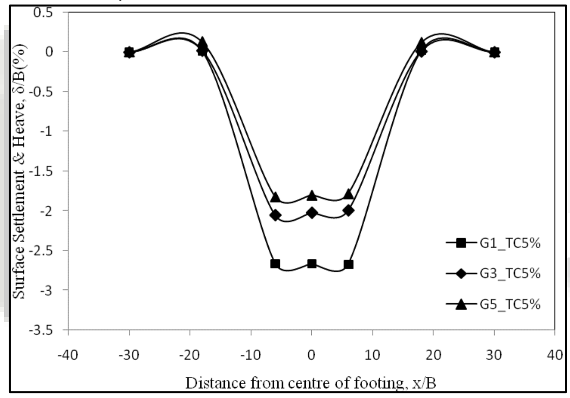
Variation of improvement factor with footing settlement for G1, G3 & G5 with TC5% at ID 80%



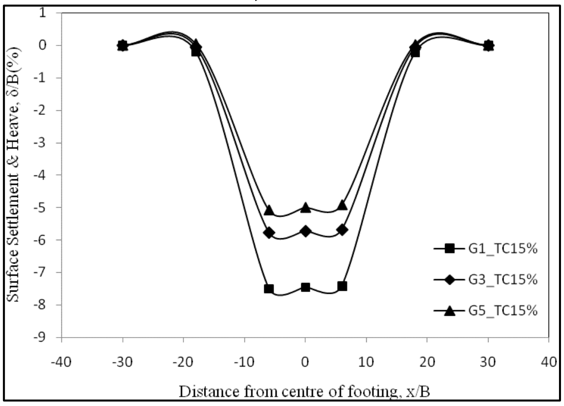
Variation of improvement factor with footing settlement for G1, G3 & G5 with TC15% at ID 80%



Variation of improvement factor with footing settlement for G1, G3 & G5 with TC30% at ID 80%



Surface deformation profiles for G1, G3 & G5 +TC5% at bearing stress of 100 kPa, ID 80%

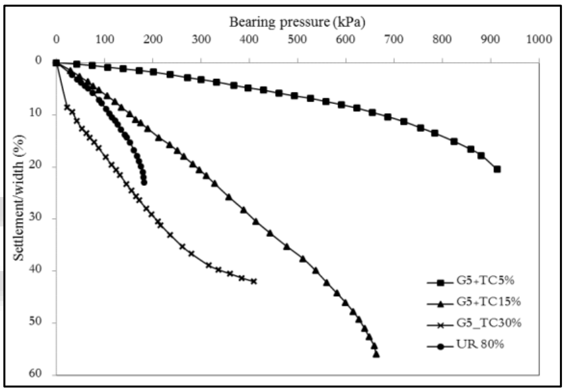


Surface deformation profiles for G1, G3 & G5 +TC15% at bearing stress of 100 kPa, ID 80%

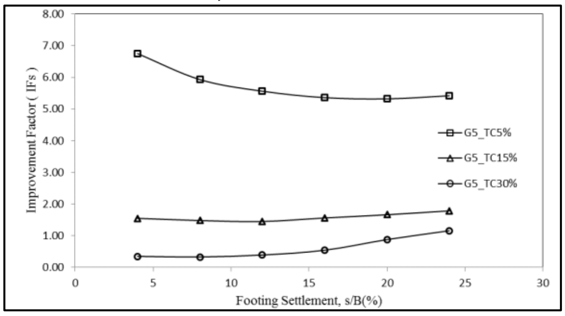
Summary of results in terms of bearing capacity improvement factor (IFgc+tc) showing the influence of tire crumb-geocell reinforced sand beds at different heights of geocell but same tire content (TC = 5%). Test Series D1

	ID = 80%	Bearing capacity improvement factor (IF)				
Variable parameter (h/B)	Constant parameter (u/B)	(s/B) 4%	(s/B) 8%	(s/B) 12%	(s/B) 16%	(s/B) 20%
G5_TC5%	0.1	**6.75**	**5.93**	**5.56**	**5.36**	**5.42**
G3_TC5%	0.1	5.60	4.99	4.65	4.56	4.69
G1_TC5%	0.1	4.55	4.14	3.89	3.93	4.06

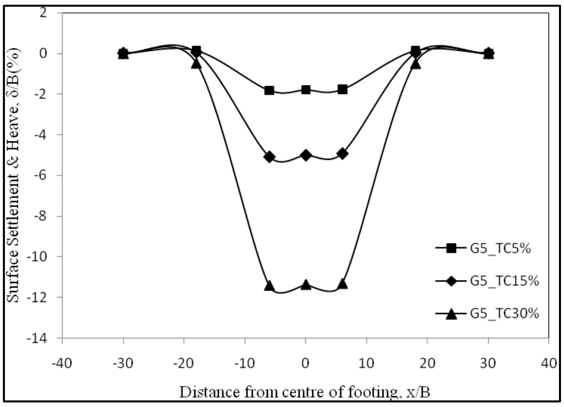
Effect of content of tire crumbs:- It has been observed that with the increase in tire crumb content of soil the bearing capacity of soil decreases and corresponding settlements increases up to 80%. In this case of reinforcement where both tire crumb and geocell provide a combined effect, the optimum result is obtained at less tire crumb content (TC = 5%). This behavior of reinforced soil may be due to the reason that when the tire content is below the optimum value of 5%, the tire particle interacts only with the soil particles helping in improvement of soil characteristics but when the value of tire content is increased from the maximum optimum value the tire particles starts interacting with each other resulting in lower improvement in soil characteristics.



Variation of bearing pressure with footing settlement for G5 with TC 5%, 15% & 30% at ID 80%



Variation of improvement factor with footing settlement for G5 with TC 5, 15 & 30% at ID 80%



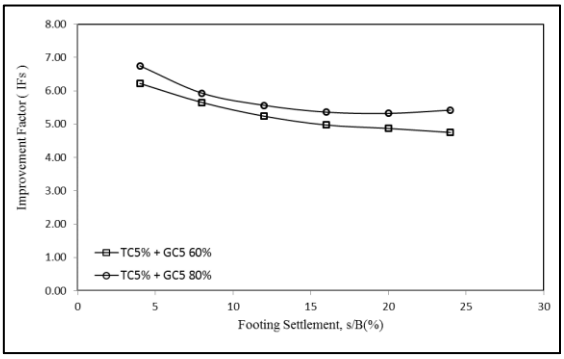
Surface deformation profiles for G5 +TC5, G5+TC15 & G5+TC30% at bearing stress of 100 kPa, ID 80%

Summary of results in terms of bearing capacity improvement factor (IFgc+tc) showing the influence of tire crumb-geocell reinforced sand beds at different content of tire content (TC = 5%, 15% and 30%) (G5). Test Series D1, D2 and D3

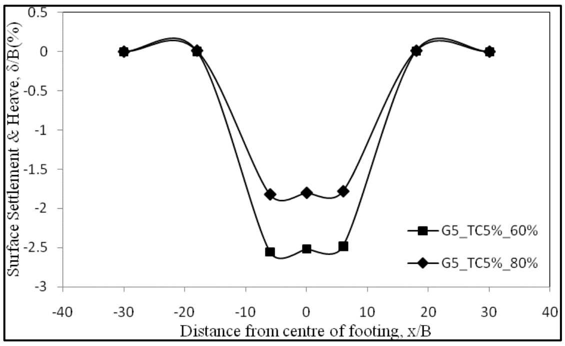
ID = 80%		Bearing capacity improvement factor (IF)				
Variable parameter	Constant parameter	(s/B) 4%	(s/B) 8%	(s/B) 12%	(s/B) 16%	(s/B) 20%
(h/B)	(u/B)					
G5_TC5%	0.1	**6.75**	**5.93**	**5.56**	**5.36**	**5.42**
G5_TC15%	0.1	1.77	1.59	1.52	1.66	1.89
G5_TC30%	0.1	0.35	0.33	0.39	0.54	**1.16**

C. *Influence of Relative Density of Infill Sand :-*

After discussing the result for different parameters in above cases it is concluded that the optimum result was obtained for the combined reinforcement of 5% tire crumb content and geocell G5 (h = 0.8B), hence for this topic we will consider only the mentioned combination of reinforcement. Same as earlier cases the higher relative densities gives us better result in this combination too. Plate load test results were expressed in terms of Bearing Capacity Factor (BCF) for different densities. The bearing capacity for settlement at 20% increases steadily from 755 kPa to 912 kPa for ID of 60% to ID of 80%. Similar is the case for 15% tire crumb content.



Variation of improvement factor with footing settlement for G5 + TC5% at ID 60% &80%



Surface deformation profiles for G5 _TC5% at bearing stress of 100 kPa, ID 60% & 80%

Summary of results in terms of bearing capacity improvement factor (IFgc+tc) showing the influence of tire crumb-geocell reinforced sand beds at different relative densities (ID = 60% and 80%) (TC = 5%) (G5). Test Series D1

		Bearing capacity improvement factor (IF_{gc})				
Variable parameter	Constant parameter	(s/B) 4%	(s/B) 8%	(s/B) 12%	(s/B) 16%	(s/B) 20%
(h/B)	(u/B)					
TC_5%						
60%	0.1	6.22	5.65	5.24	4.97	4.87
80%	**0.1**	**6.75**	**5.93**	**5.56**	**5.36**	**5.32**

This chapter concluded that the effect of combining the reinforcement has much greater improvement as compared to the unreinforced sand and the each reinforcement form acting separately. The combination of geocell reinforcement and randomly mixed tire crumbs with sand subgrade gave us better bearing capacity improvement factor. The higher height of geocell combined with the minimum tire crumbs content provided us with the best optimum result. Even here the higher relative densities gave us the better result.

V. CONCLUSIONS

1) The geocell reinforced foundation bed exhibits a much stronger and stiffer behaviour compared to the unreinforced cases. The pressure-settlement response of the unreinforced sand subgrade shows large settlement due to footing pressure, a typical general failure. But with the provision of geocell-sand mattress the pressure settlement response exhibits a nearly linear trend till large pressure and settlement as high as 20% of footing diameter, indicating that failure hasn't taken place.
2) The critical depth of placement (u) of the geocell mattress was kept constant at 0.01 as per various studies (chapter 2) which gives maximum performance from the base of the footing. The pattern of formation (chevron pattern better than diamond pattern) and pocket size was also kept constant. The variation in the height of geocell described us that the higher height of geocell gave us with optimum result.
3) Three heights of geocell were taken for study in this project. G1 (1-layer geocell, h = 0.24B), G3 (3-layer

geocell, h = 0.5B) and G5 (5-layer geocell, h = 0.8B) are the three types of geocell undertaken described in chapter 3. Irrespective of two relative density, geocell G5 gave us optimum result showing increase in improvement of bearing capacity by factor of 3 as compared to unreinforced sand. Geocell G3 increased by factor of 2 and geocell G1 increased the factor by 1.5.

4) The critical height (h) of the geocell reinforcement giving maximum performance improvement depends on the relative density (ID) of the infill sand. The relative density of 80% increased the bearing capacity by factor of 1.2 as compared to relative density of 60%. The maximum benefit from the geocell reinforcement is obtained when the geocells are filled with dense sand. So it is to be noted that the overall bearing capacity continues to increase with the increase in the relative density of the soil. Hence, in general, it is advantageous to fill the geocells with sand compacted to the densest state.
5) The effect of content of tire crumbs to be used as reinforcement is discussed in chapter 5. Of the three tire crumbs content used i.e., 5% tire crumb content, 15% tire crumb content and 30% tire crumb content, optimum result was obtained for 5% tire crumb. This shows that the lesser the tire crumb content more is the improvement in the bearing capacity.
6) The 5% tire crumb content increased the bearing capacity factor by 2, 15% tire crumb content increased the capacity by factor of 1.5 and 30% tire crumbs did not have effective improvement over the unreinforced sand.
7) Similar to the result obtained in terms of geocell and unreinforced sand subgrade, the tire crumbs sand subgrade is also affected by relative density. Higher the relative density higher is the bearing capacity.
8) The surface deformation heaving effect decreases with the increase in the tire crumbs content even in the case of geocell reinforced bed.

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