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Load Settlement Characteristics of Sand Bed Reinforced with Woven Glass Fibre

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Abstract. Soil improvement is a significant part of concern in construction activities. Soil reinforcement is a technique where soil properties are improved by reinforcing it with natural and synthetic additives. The present study aims to utilize woven glass fibre as a potential reinforcement material for shallow foundations and thereby to improve the bearing capacity. A series of laboratory load test has been conducted on square mild steel plate resting on the reinforced sand bed to determine the load settlement response of soil reinforced with woven glass fibre for different parameters such as length, depth of placement and number of layers of reinforcement. The maximum improvement in bearing capacity of the soil is obtained when a single layer of reinforcement is provided at a depth of .25 times of the width of footing. For multiple layers, maximum improvement is seen when four layers of woven glass fibre layers are used after that increasing the number of layers of reinforcement has no significant improvement in the bearing capacity of the soil.

Keywords: Woven glass fibre(WGF), bearing capacity, soil reinforcement.

1 Introduction

Geosynthetic inclusions within a soil mass can provide a reinforcement function by developing tensile forces which contribute to the stability of the geosynthetic-soil composite (a reinforced soil structure). Design and construction of stable slopes and retaining structures within space constrains are aspects of major economic significance in geotechnical engineering projects. For example, when geometry requirements dictate changes of elevation in a highway project, the engineer faces a variety of distinct alternatives for designing the required earth structures. Traditional solutions have been either a concrete retaining wall or a conventional, relatively flat, unreinforced slope. Although simple to design, concrete wall alternatives have generally led to elevated construction and material costs.
On the other hand, the construction of unreinforced embankments with flat slope angles dictated by stability considerations is an alternative often precluded in projects where space constraints control design. Geosynthetics are particularly suitable for soil reinforcement. Geosynthetic products typically used as reinforcement elements are nonwoven geotextiles, woven geotextiles, geogrids, and geocells. Reinforced soil

vertical walls generally provide vertical grade separations at a lower cost than traditional concrete walls. Reinforced wall systems involve the use of shotcrete facing protection or of facing elements such as precast or cast-in-place concrete panels. Alternatively, steepened reinforced slopes may eliminate the use of facing elements, thus saving material costs and construction time in relation to vertical reinforced walls. A reinforced soil system generally provides an optimized alternative for the design of earth retaining structures.Use of the biodegradable geotextiles has created durability issues, whereas the use of some synthetic geotextiles has created environmental issues. Woven glass fibre solves both of our problems and proves to be a better option as a reinforcing agent. There is a wide variety of glass fibre available in the market which can be used as the reinforcing agent.

2 Overview of the Analysis Approach

Experimental procedure of investigation involves the following steps.
The test set up:

- Layout of reinforcement
- Preparation of test bed
- Testing procedure
- Testing program

2.1. Test set up

a) Footing: Model square footing of 15cm x15cm made of mild steel plate 15mm thick has been used in the study (Photo 1). A semi-spherical depression is provided at the centre of the footing to place a steel ball on it for normal transmission of the load. To simulate the roughness of the actual foundation, the base of model footing is made rough by pasting sandpaper.

Fig.1. Square footing used in the study

b) Sand-filled steel tank: The size of the tank is designed keeping in view the size of footing to be tested and its zone of influence. The inside dimension of tank is 1m × 1 m × .75 m high (Photo 2). The size has been chosen in a manner that failure zone remains well within the dimension of the tank, and there is no confining effect of walls of the tank on results. Sand is filled in the tank up to the desired height and is levelled with a straight wooden edge.

Fig.2. Model Test Tank

c) Loading arrangement and measuring devices: Reaction loading mechanism having reaction beam fitted with screw jack has been devised. The loading system is designed to ensure that the application of load on footing is vertical, and there is no possibility of developing eccentric loading. Load on the footing has been applied in increments of 50 kg by screw jack calibrated through 5-ton capacity proving ring (with a load gauge of 0.002mm) (PRC – 10 kg/division). Any release of load due to the settlement of footing is compensated by operation of the jack. Steel ball is placed between the footing and proving ring and also between the proving ring and the screw jack to maintain vertically of loads. Settlement of the footing is recoded at every load increment with the help of two sensitive dial gauges (fixed diagonally), with a least count of 0.01mm mounted on magnetic stands fixed on independent datum bars (Photo 3.4).

Fig.3. Loading arrangement

2.2 Layout of reinforcement

The reinforcement layout of woven glass fibre is shown in the figure below. The parameters studied are given as follows.

u = depth of the first layer of reinforcement from the base of the footing.
Bg = width of woven glass fibre, five times the width of footing.
N= number of glass fibre layers.
d = spacing between woven glass fibre layers.

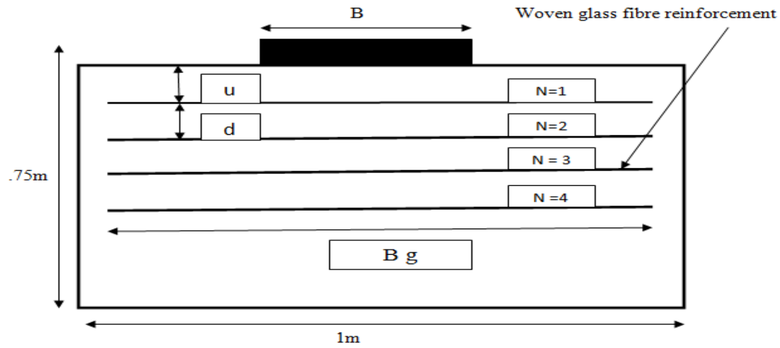

Fig.4. The layout of WGF reinforcement

All the parameters are standardized with foundation width as u/B, Bg/B, d/B. For all the tests for glass fibre reinforcement, d/B has been kept equal to u/B. Since the foundation is a square footing, all the reinforcement configurations are made square in shape.

2.3 Preparation of testbed

Procedure: The sand raining technique was adopted to fill sand in the test tank, and a relative density of 41.38% was fixed for all the tests carried out. The sand raining technique ensured homogeneity, repeatability and better replication of soil deposition in the field. According to IS: 2720 (1983), a relative density of 35-65% is classified as medium dense. This condition was adopted because higher relative densities cannot be achieved with the test sand using the sand raining technique. In the case of the glass fibre -reinforced sand bed, sand raining was done up to the specific markings on the sides of the tank as indicators. After proper placement of reinforcement, sand raining was carried on up to the level of the foundation. The sand surface in all cases was levelled through a special levelling ruler.

2.4 Testing procedure: After filling the sand, a square test plate 15cm × 15 cm was placed centrally on the surface of the sand. Before commencing the load test, a seating load of 70 gm/cm2 was applied, which is released before the actual test starts.

This is done to ensure proper contact of the base of footing and soil and to account for any looseness due to disturbance of topsoil. A screw jack was carefully positioned above the footing and was given loading with small increments. The displacements were measured using the dial gauges positioned at either end of the footing. The average of the two dial readings was taken as final settlement. As per IS: 1888 (1982), the load increment was maintained until the rate of settlement reduced to a value of 0.02 mm/min. Settlement under various load increments has been observed until the soil fails in shear. A summary of the testing programme has been given in Table 2.

3 Results and Discussions

Table 1. Index properties of sand

S. No.	Property	Value
1	Effective size (D10)	0.190 mm
2	D60	0.450 mm
3	D30	0.300 mm
4	Coefficient of Uniformity (Cu)	2.368
5	Coefficient of curvature (Cc)	1.05
6	Type of soil	SP
7	Specific gravity	2.67
8	Minimum Dry Density	1.42 g/c.c.
9	Maximum Dry Density	1.68 g/c.c.
10	Minimum Void Ratio(emin)	0.60
11	Maximum Void Ratio(emax)	0.89
12	Angle of Shearing Resistance	370
13	Test density	1.50 g/c.c. (e = 0.77) (RD=41.38%)

Table 2. Summary of the testing programme

Test series	Reinforcement type	Placement depth and number of reinforcement layers	Reinforcement width	Purpose
1	Unreinforced	-	-	To evaluate the degree of improvement
2	Single woven glass fibre layer	u/B varied (0.25,0.50,0.75,1.0)	$B_g/B = 5$	To find the optimum depth of the first layer of reinforcement
3	Multiple glass fibre layers	u/B optimum & N varied as 2,3 and 4	$B_g/B = 5$	To study the effect of the number of reinforcement layers

Table 3. Load vs settlement for unreinforced and single layer reinforced bed

Load (kg)	Settlement (mm)				
	Unrein-forced	$u = 0.25$B	$u = 0.5B$	$u = 0.75B$	$u = 1B$
0	0	0	0	0	0
50	0.48	0.26	0.29	0.44	0.37
100	0.92	0.42	0.58	.98	.86
150	1.86	.98	1.10	1.54	1.26
200	3.25	1.35	1.565	2.42	2.24
250	5.68	1.96	2.34	3.26	3.68
300	8.24	2.84	3.12	4.24	4.86
350	10.23	3.62	3.98	5.36	5.6
400	11.22	4.32	4.42	6.28	7.45
450	13.32	5.20	5.85	7.40	9.04
500	-	6.60	6.88	8.62	-
550	-	7.54	7.96	9.86	-
600	-	8.22	9.98	10.83	-
650	-	9.56	10.56	11.86	-
700		-	11.46	-	-
750		-	12.58	-	-
ubc(kg/cm^2)	.78	1.444	1.4	1.356	1

Table 4. Improvement factor for various u/B ratio for single layer reinforcement

u/B	s/B=1.5%	s/B=3%	s/B=4.50%	s/B=6%	s/B=7.50%
0.25	1.42	1.58	1.6	1.9	-
0.5	1.67	1.41	1.71	1.796	1.98
0.75	1.25	1.18	1.27	1.47	1.78
1	1.13	1.06	1.14	1.26	-

Table 5. Load vs settlement for unreinforced, single and multiple layers reinforced bed

	Settlement (mm)				
Load (kg)	N=0	N=1	N=2	N=3	N=4
0	0	0	0	0	0
50	0.48	0.29	0.16	0.30	0.32
100	0.92	0.54	0.38	0.72	0.64
150	1.86	.94	0.66	1.02	1.12
200	3.25	1.48	.88	1.35	1.63
250	5.68	2.20	1.24	1.95	2.06
300	8.24	3.08	1.46	2.24	2.72
350	10.23	4.16	1.94	2.88	3.18
400	11.22	4.98	2.20	3.12	3.56
450	13.32	5.86	2.76	3.62	4.35
500	-	6.43	3.04	4.04	4.95
550	-	7.88	3.26	4.42	5.10
600	-	9.56	3.64	4.86	5.56
650	-	11.86	4.06	5.23	5.98
700	-	13.78	4.34	5.98	6.46
750	-	-	4.92	6.24	6.86
800	-	-	5.14	6.98	7.35
850	-	-	5.56	7.48	7.92
900	-	-	6.04	8.18	8.75
950	-	-	6.32	9.02	9.88
1000	-	-	6.94	9.82	10.66
1050	-	-	7.76	10.24	12.34
1100	-	-	8.16	11.52	-
1150	-	-	8.72	-	-
1200	-	-	9.22	-	-
1250	-	-	9.88	-	-
1300	-	-	10.64	-	-
1350			11.08		
1400			11.78		
ubc (kg/cm2)	.78	1.86	3.38	3.6	3.76

Table 6. Improvement factor for various s/B ratio for multiple layer reinforcement

	IMPROVEMENT FACTOR (u/B = 0.5, d/B = 0.5)				
N	s/B=1.5%	s/B=3%	s/B=4.50%	s/B=6%	s/B=7.50%
1	1.33	1.41	1.64	2.39	2.26
2	1.82	2.22	2.83	3.12	3.36
3	2.12	2.46	3.33	4.26	4.21
4	2.42	3.12	3.6	4.39	4.36

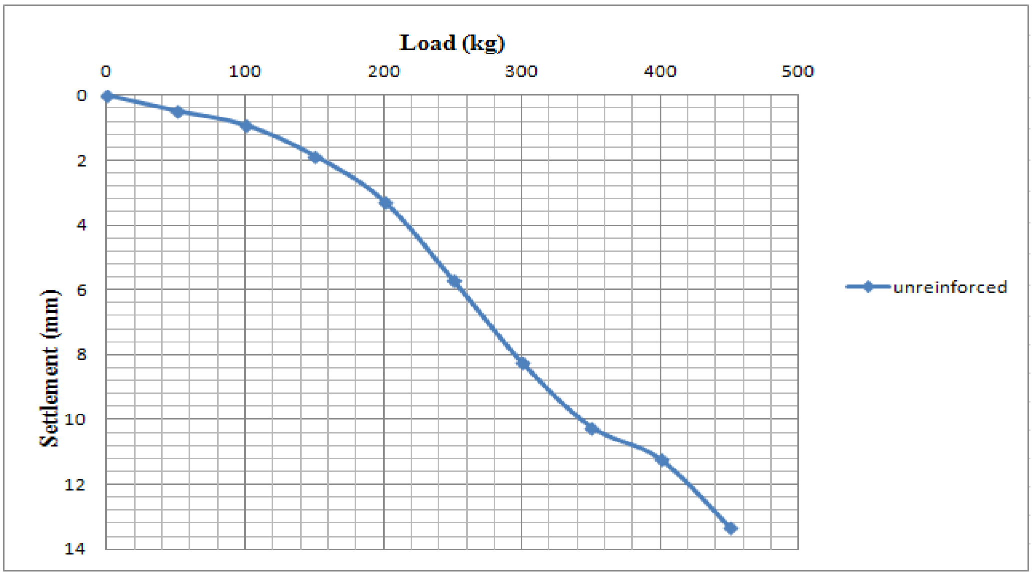

Fig.5. Load vs settlement curve for unreinforced sand bed

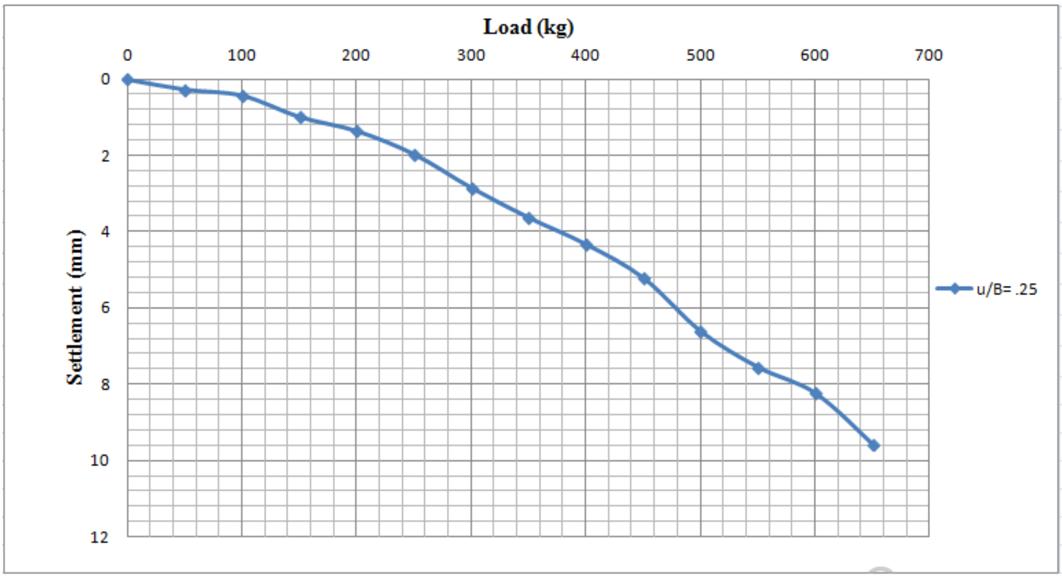

Fig.6. Load vs settlement curve for reinforced sand bed having u/B=0.25

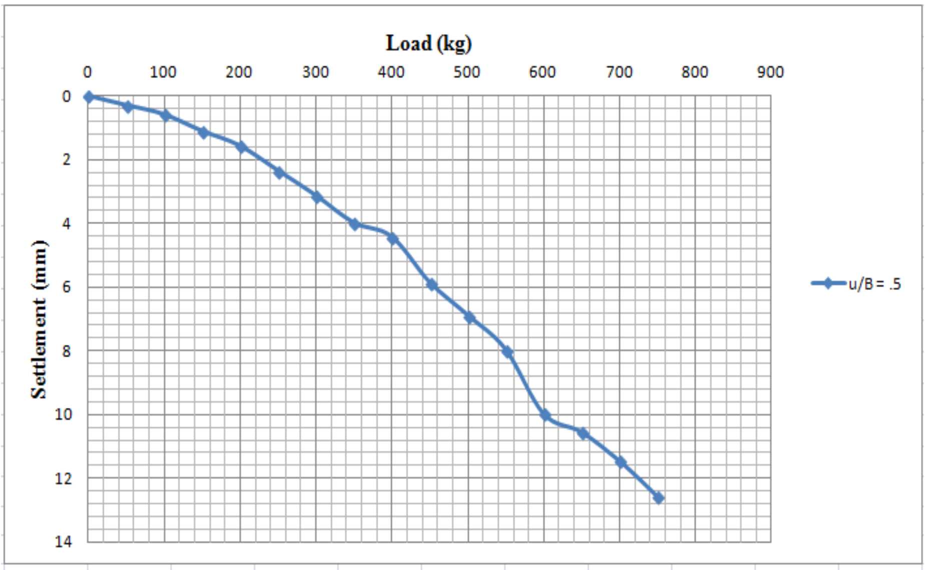

Fig.7. Load vs settlement curve for reinforced sand bed having u/B=0.5

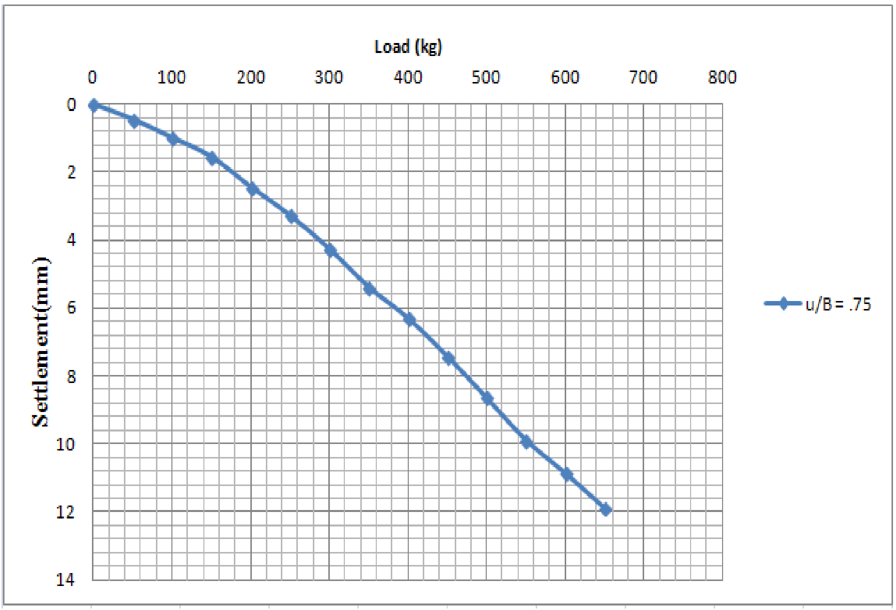

Fig.8. Load vs settlement curve for reinforced sand bed having u/B=0.75

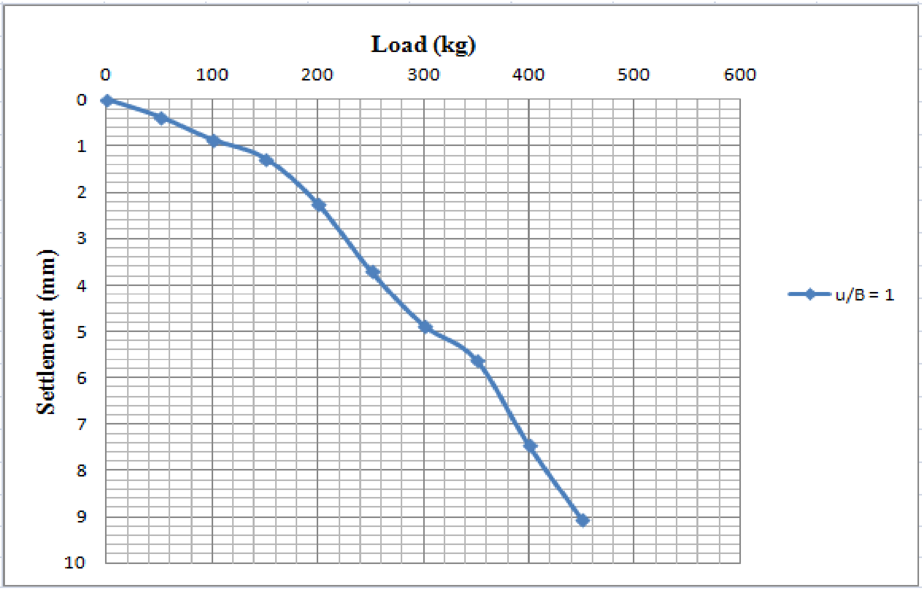

Fig.9. Load vs settlement curve for reinforced sand bed having u/B=1.0

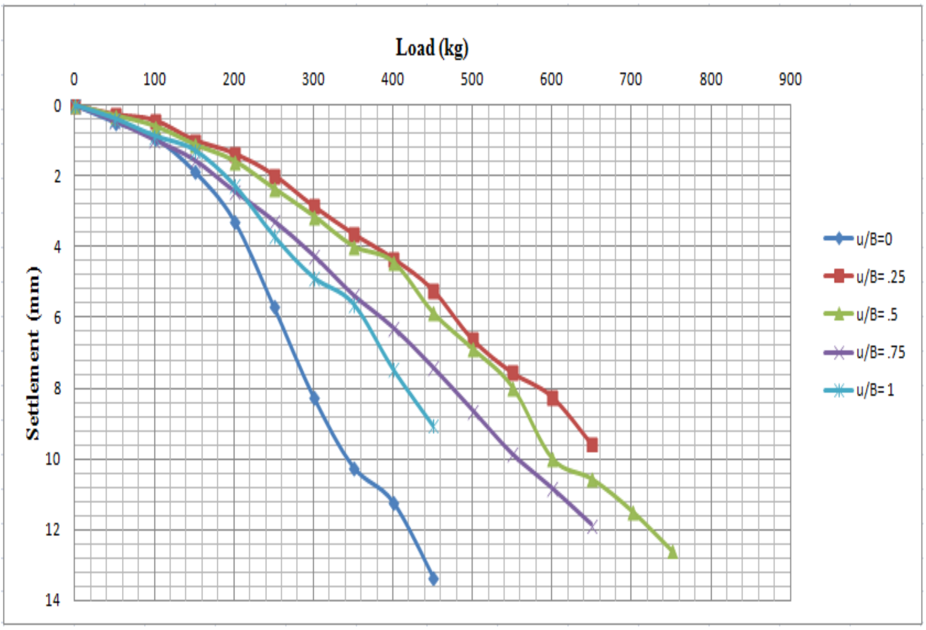

Fig.10. Combined load vs settlement at various u/B ratio

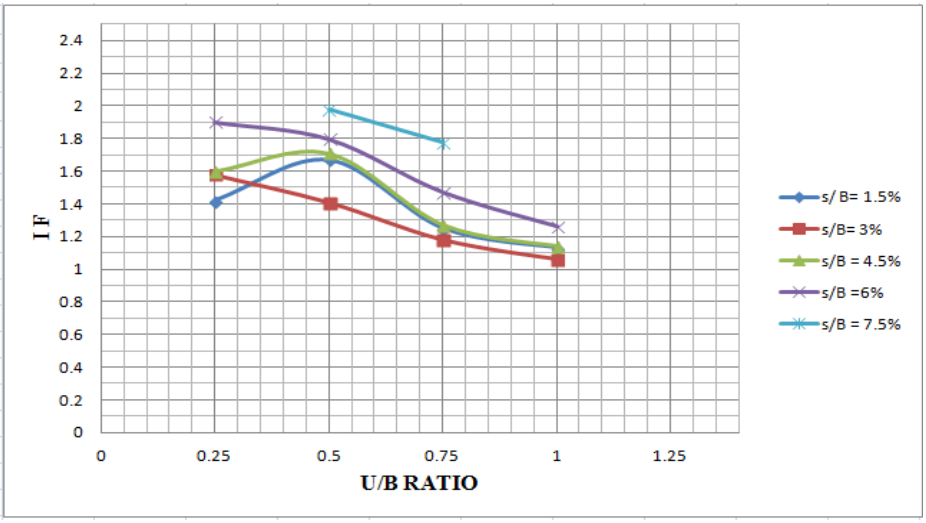

Fig.11. Improvement factor vs u/B ratio for various s/B ratio

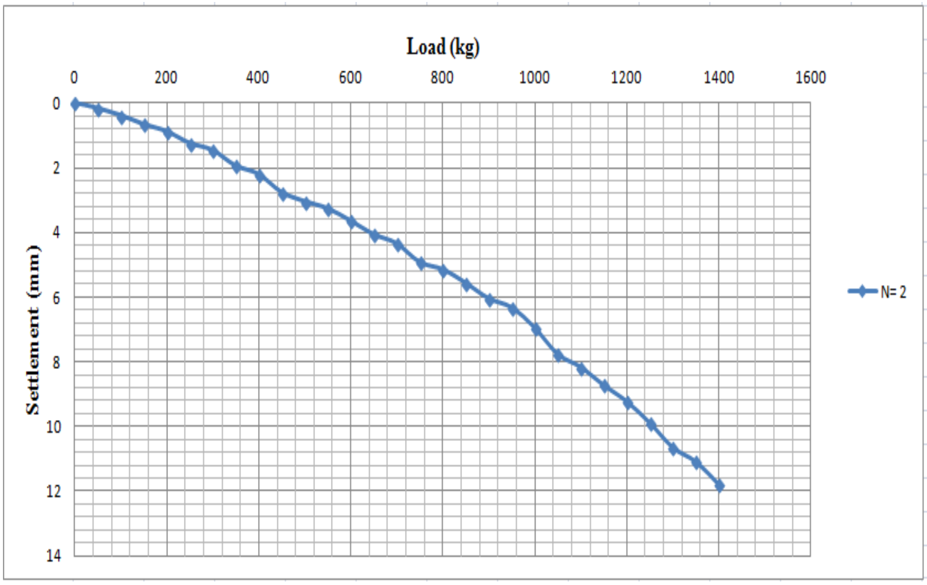

Fig.12. Load vs settlement curve for two layers of WGF reinforcement

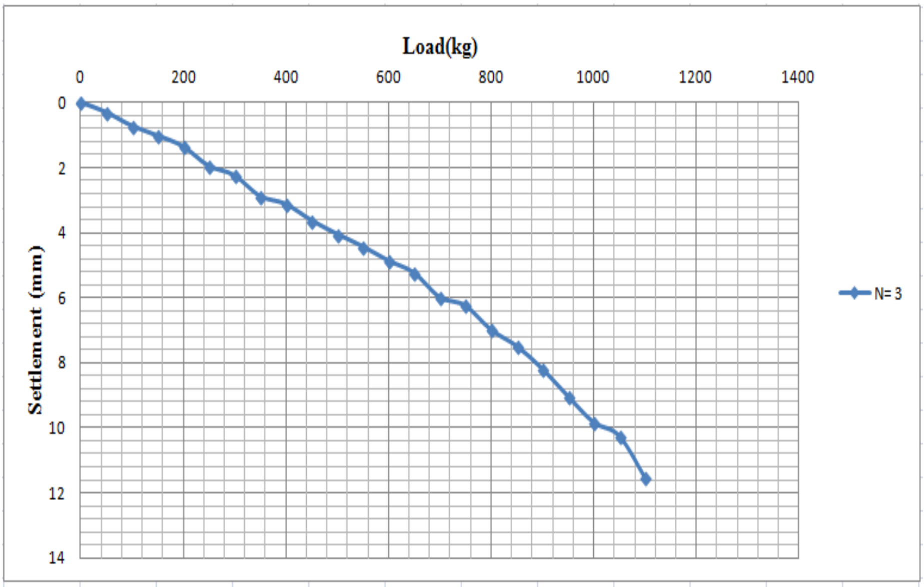

Fig.13. Load vs settlement curve for three layers of WGF reinforcement

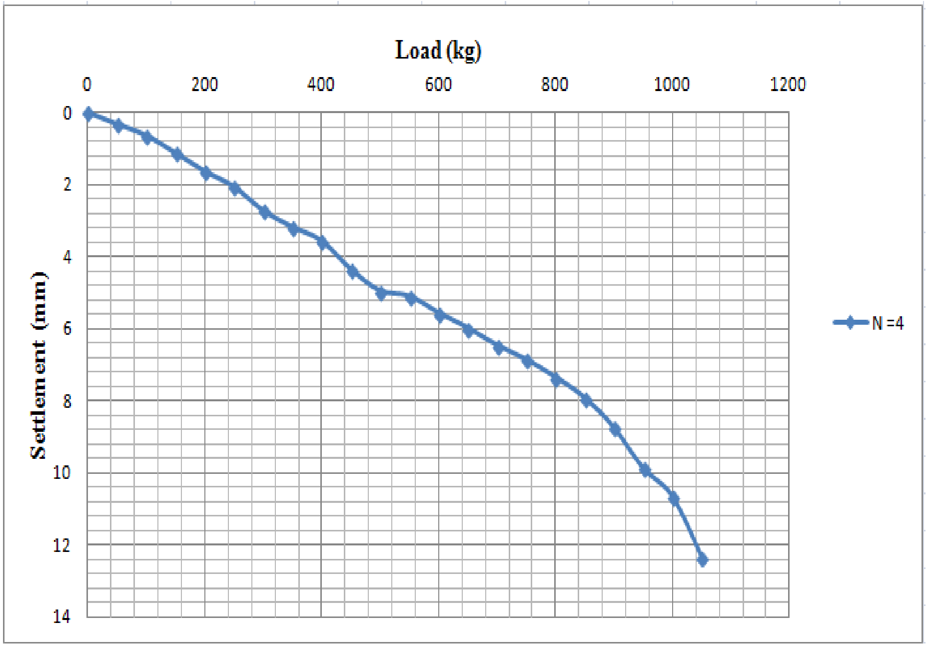

Fig.14. Load vs settlement curve for four layers of WGF reinforcement

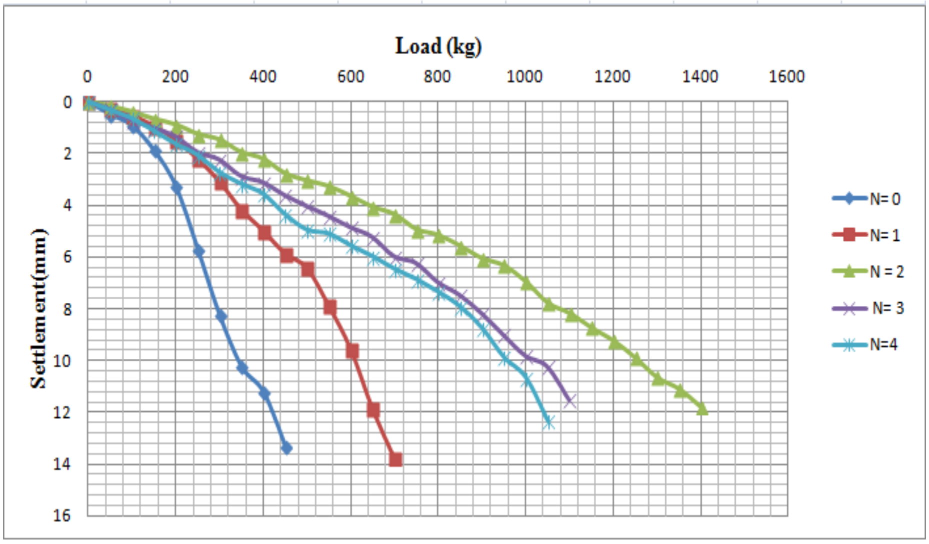

Fig.15. Combined load vs settlement for multiple layer reinforcement

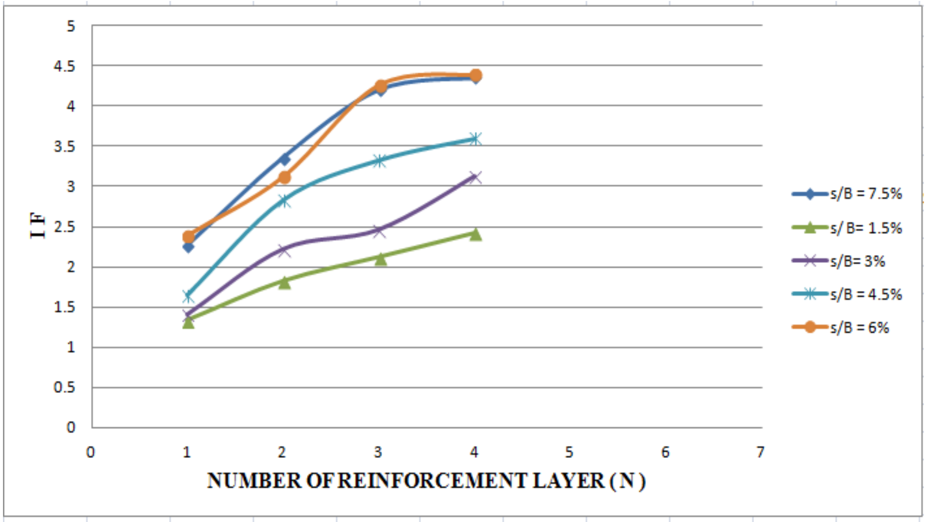

Fig.16. Improvement factor vs the number of reinforcement layers at s/B ratios

4 Conclusions

1. It has been observed that the ultimate bearing capacity reaches to the maximum value of 1.85 kg/cm2 at u/B ratio of 0.25 for a single layer of WGF reinforcement at s/B ratio of 7.5% and after that it reduces.

2. It has been observed that the ultimate bearing capacity reaches to the maximum value of 3.96 kg/cm2 for four reinforcement layers (N=4) at u/B ratioof 0.5 with d/B ratio of 0.5 for s/B ratio of 7.5%, and thereafter no significant improvement in bearing capacity is observed.
3. It can be concluded that lateral spreading of soil is prevented by WGF reinforcement, thereby improving the bearing capacity of the soil.
4. The rate of improvement in strength with increasing values of the normalized settlement was significant only for a multi-layer reinforced soil system.

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