

CHAPTER 4

MODEL TESTS ON SINGLE COLUMN

4.1 General

Meeting the infrastructure demands of a growing economy with limited space availability has put engineers and geotechnical experts in challenging positions. Construction in soft soil deposits, especially soft clays, is difficult as the soil possesses low shear strength and is susceptible to excessive settlements (Sharma et al. 2004). The use of granular columns in such soil is one of the significant techniques that has grown over the years (Ghazavi et al. 2018; Malarvizhi and Ilamparuthi 2007; Murugesan and Rajagopal 2010). Granular columns, also known as stone columns, are cylindrical columns generally made up of stones or some other granular materials embedded into soft soil deposits. The behavior of stone column-reinforced ground has been studied by researchers in the past (Fattah et al. 2016; Ghazavi and Nazari Afshar 2013; Malarvizhi and Ilamparuthi 2007; Murugesan and Rajagopal 2010; Yoo and Abbas 2020). These studies indicated several factors affecting soft soil response improved with stone columns. The length-to-diameter ratio, the replacement ratio of the granular column, the shear strength of the surrounding soil, and the stiffness of the column material are major parameters governing its behavior. Narasimha Rao (Roa et al. 1992) reported the bulging of columns into the neighboring soil is predominant in soft clays. The studies done by previous researchers have established that granular columns used in soil derive their load-bearing capacity from the confining effect of the surrounding soil (Guétif et al. 2007; Hughes et al. 1975). Granular columns installed in very soft soil may not develop significant load-bearing capacity due to insufficient confining support from the surrounding soil. There is a greater probability of the intrusion of column material in the neighboring soft soil, thus reducing the stiffness of the column and its overall

loading capability. Geosynthetics have helped to improve the performance of stone columns by providing an encasing layer of geosynthetic material (Dheerendra Babu et al. 2013; Gniel and Bouazza 2009; Gu et al. 2016; Hosseinpour et al. 2015; Miranda et al. 2017). The inclusion of geosynthetic encasement alters the lateral deformation of soft soil beds (Ali et al. 2014; Cengiz and Guler 2018; Mohapatra et al. 2016). Additional lateral confinement is provided to the soil using geosynthetics to tackle bulging for column material into the soft surrounding soil (Hamidi and Lajevardi 2018). Pandey (Pandey et al. 2022) demonstrated that incorporating encased stone columns enhanced the loading capacity of soft soil, noting that the encasement significantly contributed to the load-bearing capacity of the composite soil structure.

The extensive utilization and exploitation of sand and natural aggregates have degraded and depleted their natural reserves in recent years. This depletion has resulted in environmental damage, shortages of material, and a significant price increase. Therefore, exploring and establishing a sustainable substitute for natural aggregates in constructing granular columns is crucial. There have been few studies in the recent past on the use of recycled materials such as glass, plastic, and demolition waste in ground improvement. The use of shredded rubber tyre chips in stone columns to improve the performance of soft soils has been reported by (Ayothiraman and Soumya 2015; Shariatmadari et al. 2018). Kazmi (Kazmi et al. 2022) used crushed waste glass in stone columns as an alternative to traditional backfill material. The Central Pollution Control Board (CPCB) annual report shows that the estimated plastic waste generation in India during 2019-20 was approximately 3.5 MMT. Also, based on the baseline report on plastic waste by The United Nations Environment Programme (UNEP), India is the 5th most significant generator of plastic waste. Plastics are a primary source of land and water body pollution. UNEP 2016 report on marine plastic debris mentions that plastic

makes up 85% of the total marine pollutants (Agamuthu et al. 2019; Law et al. 2014). The presence of plastic residue in aquatic species like fish and other mammals has been reported by several studies (Rochman et al. 2019; Steer et al. 2017).

The use of recycled waste plastic granules is being done in the present study to promote a sustainable way of using the granular column technique for ground improvement. Laboratory model tests were performed on soft soil beds improved with granular columns made of stone aggregates and recycled plastic aggregates of similar gradation. A 40 mm diameter column was used to improve the soft clay bed, and the tests were performed as stated in Table 4.1 for floating and end-bearing column conditions. Tests were also performed on the geosynthetic encased column. An area replacement ratio of 25% was adopted for the tests using a loading plate twice the column diameter. The loading of the composite soil is done using a metal plate, and the corresponding deformations of the soil bed are recorded using a displacement transducer connected to the plate. This paper presents the results of the laboratory model tests and compares them with existing analytical results.

4.2 Experimental Program

Static strain-controlled load tests were performed on soil specimens prepared at different shear strengths under different conditions by variation of parameters such as the length-to-diameter ratio of the column, undrained shear strength of the soil, granular material (aggregate and plastic granules), and geosynthetic encasement of the column material. The tests details with different parameters are shown in Table 4.1.

Static load tests were performed on soil bed and column under configurations as mentioned previously. Floating columns had length-to-diameter ratios of 6 and 8, whereas end-bearing column had a length of 10 times the column diameter. The model test setup and instrumentation used for the test on single column is shown in Fig. 4.1.

The granular column (GC) was made using stone aggregates, and the plastic granular column (PGC) was made from recycled plastic granules. Geogrid was used as vertical reinforcement in the form of geosynthetic encasement for the installation of encased columns.

Table 4.1 Summary of model tests performed on single column under static loading.

Test series	Type of soil reinforcement	Parametric details
1	UR	$S_u=5,10,15$ kPa
2	GC	Constant: $d=40$ mm; $S_u=5$ kPa, Variable: $l=6d,8d,10d$
3	GC	Constant: $d=40$ mm; $S_u=10$ kPa, Variable: $l=6d,8d,10d$
4	GC	Constant: $d=40$ mm; $S_u=15$ kPa, Variable: $l=6d,8d,10d$
5	PGC	Constant: $d=40$ mm; $S_u=5$ kPa, Variable: $l=6d,8d,10d$
6	PGC	Constant: $d=40$ mm; $S_u=10$ kPa, Variable: $l=6d,8d,10d$
7	PGC	Constant: $d=40$ mm; $S_u=15$ kPa, Variable: $l=6d,8d,10d$
8	EGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=5$ kPa, Variable: $l=6d,8d,10d$
9	EGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=10$ kPa Variable: $l=6d,8d,10d$
10	EGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=15$ kPa Variable: $l=6d,8d,10d$
11	EPGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=5$ kPa Variable: $l=6d,8d,10d$
12	EPGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=10$ kPa Variable: $l=6d,8d,10d$
13	EPGC	Constant: $d=40$ mm; $l_e/l=1.0$; $S_u=15$ kPa Variable: $l=6d,8d,10d$

Stress controlled cyclic loading tests were conducted as per the test program mentioned in Table 4.2. A total of nine cyclic load tests comprising of four stages were conducted. The soft clay bed used in the cyclic tests was prepared at a S_u value of 10 kPa. The test methodology and instrumentation have already been discussed in detail Chapter 3.

Table 4.2 Summary of model tests performed on single column under cyclic loading.

Test series	Type of soil reinforcement	Length, l (mm)	Column configuration	Type of loading
1	UR			Cyclic
2	GC	320	Floating	Cyclic
3	GC	400	End bearing	Cyclic
4	PGC	320	Floating	Cyclic
5	PGC	400	End Bearing	Cyclic
6	EGC	320	Floating	Cyclic
7	EGC	400	End bearing	Cyclic
8	EPGC	320	Floating	Cyclic
9	EPGC	400	End bearing	Cyclic



Fig. 4.1 Test setup and the instrumentation.

4.3 Results and Discussions

The vertical stress-settlement response of the soft clay bed and GC-embedded soft clay bed subjected to monotonic loading has been discussed in this section.

4.3.1 Static test on single column model

In this section, results are reported for soft clay beds having undrained shear strengths of 5, 10 and 15 kPa, respectively. For all the loading tests conducted during the present study, the vertical stress undertaken by the soil bed at the 50 mm settlement is reported as peak stress for that soil sample. The effect of different parameters on the performance of improved soil mass is discussed in the following sections.

The load was applied onto the soil bed using a pneumatic actuator of 20 kN capacity through a steel footing plate of 10 mm thickness and 80 mm diameter, corresponding to an area ratio of 25%. A coarse sand mat of 20 mm thickness was provided below the footing plate for uniform load transfer to the column. The load was applied in a strain-controlled manner with a 1.2 mm/min rate of sample deformation to maintain undrained conditions (Murugesan and Rajagopal 2010). Loading was conducted in all the tests till the footing reached a settlement of 50 mm; this was decided based on the limitation of the actuator used for the load tests. The load was measured through a load cell connected to the loading piston, and the corresponding deformation of the footing plate was measured using LVDT, as illustrated in Fig. 4.1.

4.3.1.1 Effect of shear strength, S_u

Tests were performed on unreinforced soil beds prepared at varied moisture content corresponding to different values of undrained shear strength S_u , as mentioned in Table 4.1. Tests were also performed on the soft soil bed reinforced with GC and PGC. Fig. 4.2 illustrates the effect of the undrained shear strength of soil on the performance of an unreinforced and GC-reinforced soil bed. The load-settlement

behavior of the soil bed shown in Fig. 4.2 indicates that there had been 28 % and 78 % enhancement in the loading capacity of the soil bed for S_u values of 10 kPa and 15 kPa, respectively, over the soft soil bed with S_u of 5 kPa. Similarly, for the soil bed reinforced with GC, the increase in undrained shear strength resulted in the loading capacity improvement of the soft soil bed by 69 %, 58%, and 51 %, respectively, for the corresponding unreinforced soft soil bed.

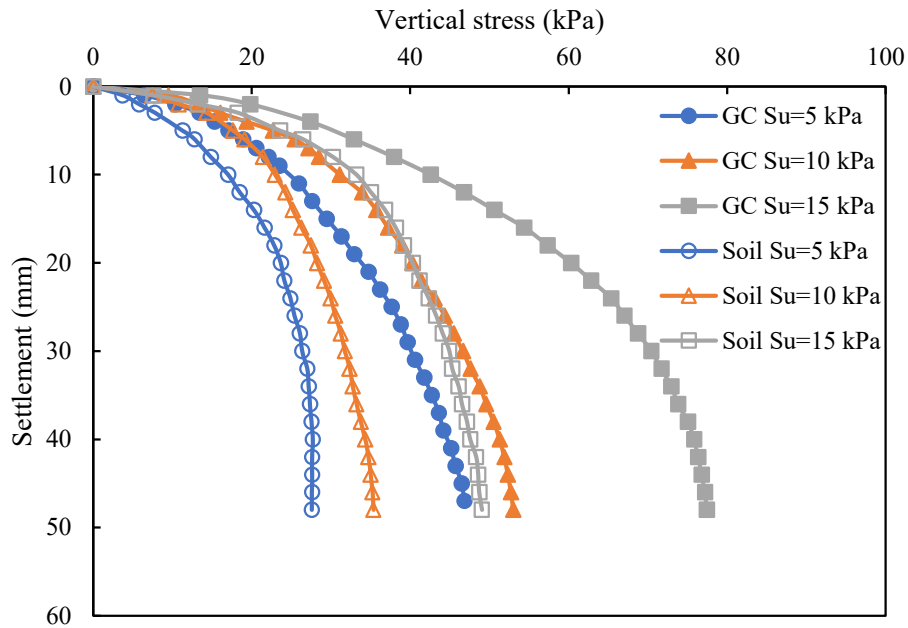


Fig. 4.2 Effect of undrained shear strength on the unreinforced soil bed and GC with column $l/d=6$.

It can be observed that with the increase in S_u , the bearing capacity of both the unreinforced and reinforced soil bed increases so that the soil bed with S_u of 15 kPa exhibits the highest resistance to external load-induced deformations. The increase in the loading capacity of soil bed with higher undrained shear strength could be attributed to the enhanced stiffness of the soil as observed in the laboratory.

The test results indicate that the effectiveness of a granular column-reinforced soil bed is enhanced with the increase in S_u of the clay bed. A similar improvement was

observed by another study (Ambily and Gandhi 2007). This may be attributed to the enhanced lateral support provided to the column from the neighboring soil (Najjar 2013).

4.3.1.2 Effect of length to diameter ratio (l/d)

Model tests were performed on a soft soil bed reinforced with (GC) and (PGC) by varying the column length to study the effect of the length of the column on the deformation behavior of the reinforced soil bed subjected to vertical stress. Fig. 4.3 illustrates the effect of the length of GC on the vertical stress-carrying capacity of an improved soil bed having an undrained shear strength of 5 kPa. It can be observed that the strength of the reinforced soil bed increases with the increase in the length of GC. The loading capacity of the soft soil bed is enhanced by 70 %, 110 %, and 123% for the GC lengths of $6d$, $8d$, and $10d$, respectively. For the floating column, the incremental improvement of the loading capacity is less for the column with a length of $8d$ over $6d$, thus indicating that the loading capacity of soil with column length of $8d$ is close to the end-bearing configuration. The load-carrying capacity of the granular column improved soil bed increases with the increase in the l/d ratio of the column. However, for a floating column with an l/d ratio of 8, the improved strength is significantly closer to that of an end-bearing column. Thus, $8d$ is reported as the limiting length for the floating column.

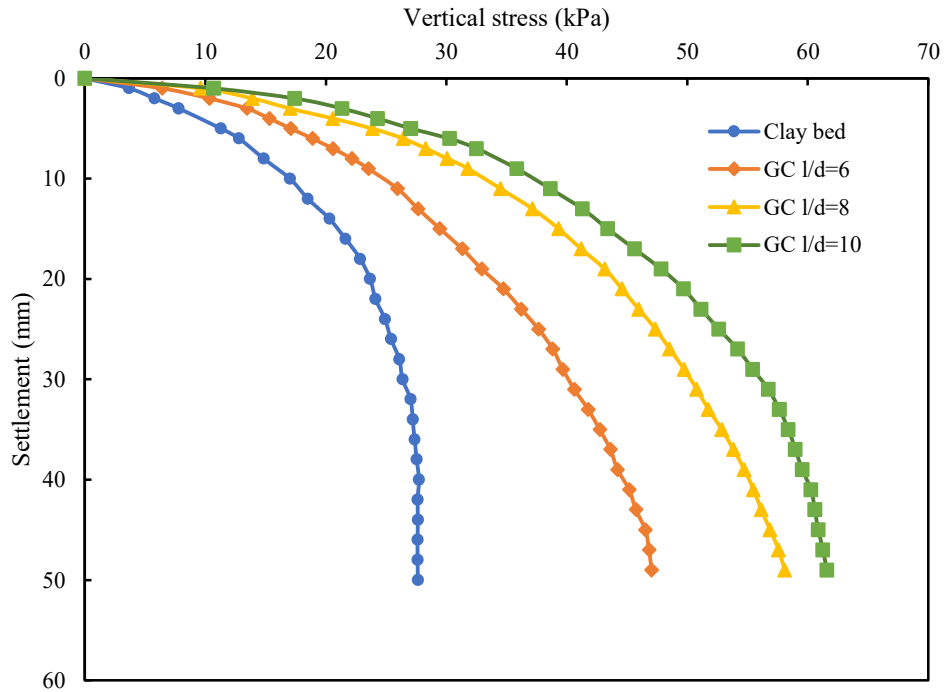


Fig. 4.3 Effect of l/d ratio on the vertical stress-displacement of GC-reinforced soil with $S_u=5$ kPa.

Also, Fig. 4.4 demonstrates a similar phenomenon for PGC, where the improvement in the strength of the reinforced soil bed was observed to be 49%, 83%, and 93%, respectively, for the different column lengths. From the test results, it could be concluded that for both GC and PGC, the magnitude of loading capacity improvement is close to end-bearing condition beyond the length of $8d$ for floating columns.

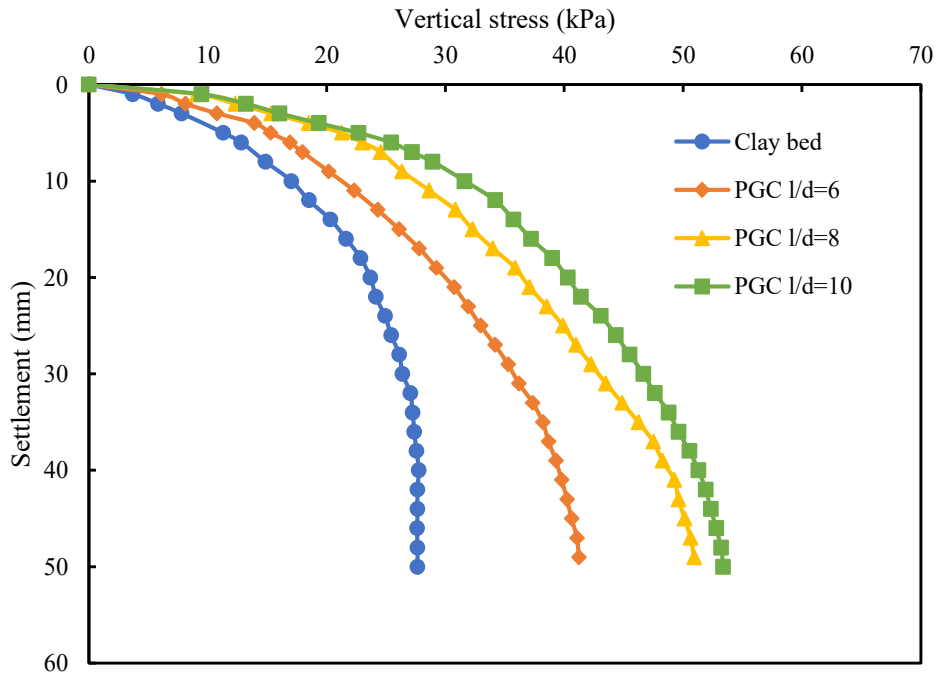


Fig. 4.4 Effect of l/d ratio on the vertical stress-displacement of PGC-reinforced soil with $S_u=5$ kPa.

4.3.1.3 Effect of alternative granular material

The present study envisages the application of two different materials as aggregates in columns, namely stone aggregates and recycled waste plastic granules. Recycled waste plastic granules were used as an alternative material for stone aggregates in granular columns. Fig. 4.5 depicts the vertical stress-deformation behavior of the granular column as well as the plastic granular column embedded in the soft soil bed. It is illustrated in Fig. 7 that the use of PGC as an alternative to the GC has a significant effect on the strength of the improved soft soil bed for varying lengths of columns. For a S_u value of 10 kPa of the soil bed, the loading capacity of the composite soil mass is improved by 57%, 96%, and 118 %, respectively, by using GC having a length-diameter ratio of 6, 8 and 10. Also, using PGC improves the vertical load-carrying capacity by 32 %, 50%, and 69 %, respectively, for the column lengths mentioned earlier. This implies

that PGC-reinforced soil can significantly improve ground when used as an alternative with a larger length-diameter ratio.

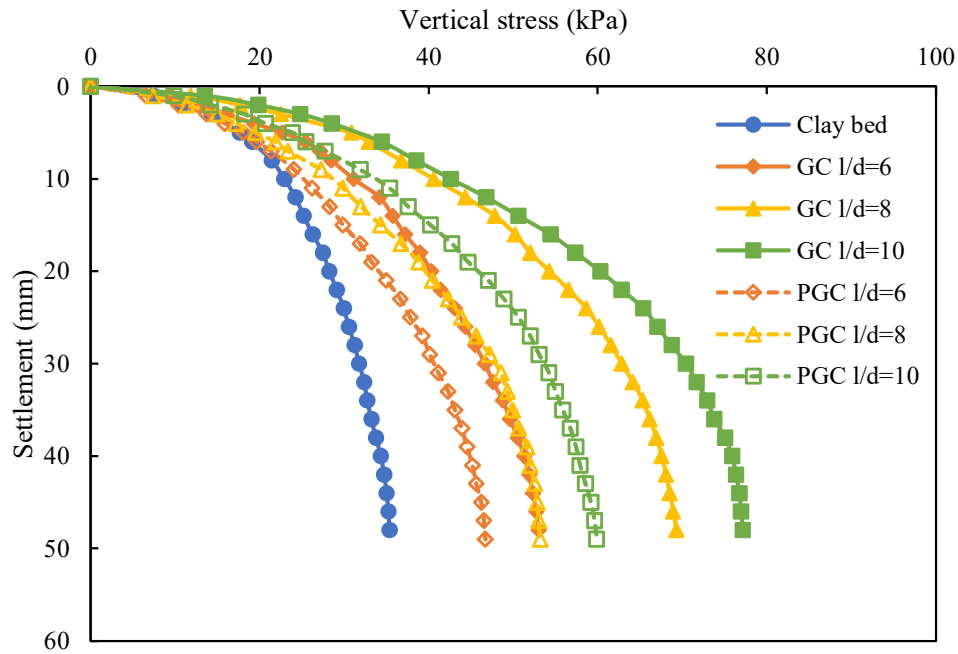


Fig. 4.5 Effect of granular material on reinforced soil bed with $S_u=10$ kPa.

Also, from Fig. 4.6, it can be inferred that the use of recycled waste plastic granules has a relatively similar enhancement effect on the vertical stress-bearing capacity of reinforced soft soil with different undrained shear strengths. Thus, the use of plastic granules as granular material in columns has significant application prospects in relation to the improvement of soft soil. The loading capacity of the soil bed with S_u of 5 kPa is improved by 83 % and 107 % using PGC and GC having a length of $8d$. Similarly, for S_u values of 10 kPa and 15 kPa, the vertical loading capacity was improved to 1.5, 1.96 times, and 1.32, 1.73 times, respectively.

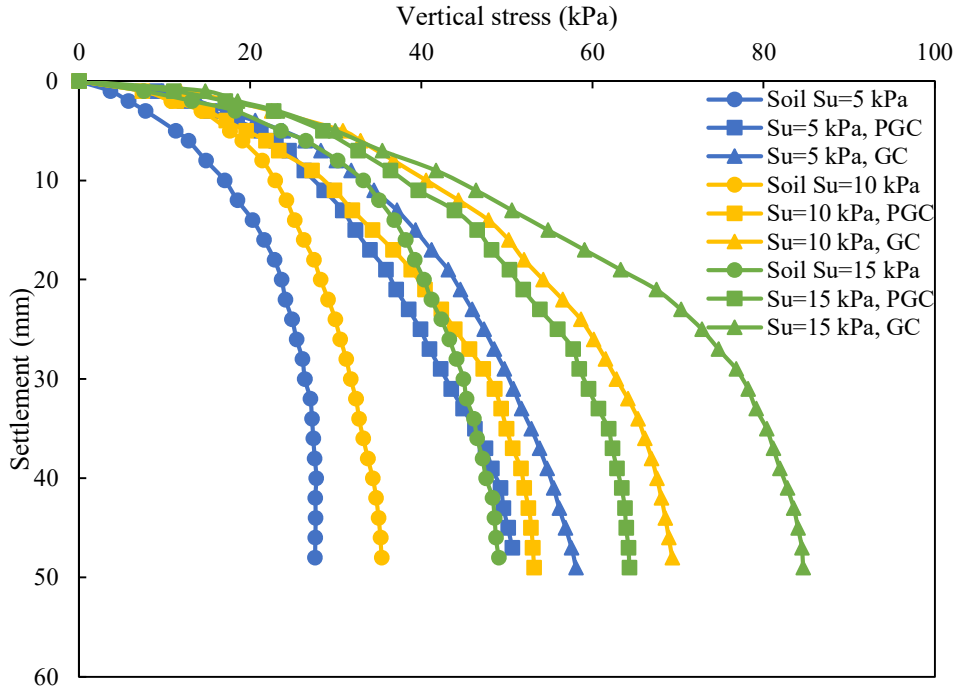


Fig. 4.6 Effect of granular material on reinforced soil bed with $l/d=8$.

4.3.1.4 Effect of geosynthetic encasement

The use of geosynthetic material for encasing the column has been done in the present study. Geosynthetic material as an encasement provides better lateral restraint to the column, thus helping in higher load transfer to the column material (Van Impe and P. Silence. 1986). The strength improvement effect of the geosynthetic improved granular column also referred to as an Encased Granular Column (EGC), is seen in Fig. 4.7.

The use of EGC in soft soil beds significantly improves the vertical stress-bearing capacity as well as its susceptibility to stress-induced deformations. It can also be observed from the plot in Fig. 4.7 that the improvement with the increase in column length follows the trend already reported in this study. The improvement in loading capacity of the GC reinforced soil bed was found to be 1.51, 1.73, and 1.82 times for the l/d values of 6, 8 and 10, respectively, over the soft soil bed having S_u of 15 kPa.

Also, the loading capacity improvement induced by EGC was 1.75, 2.03, and 4.1 times for the floating and end-bearing columns, respectively.

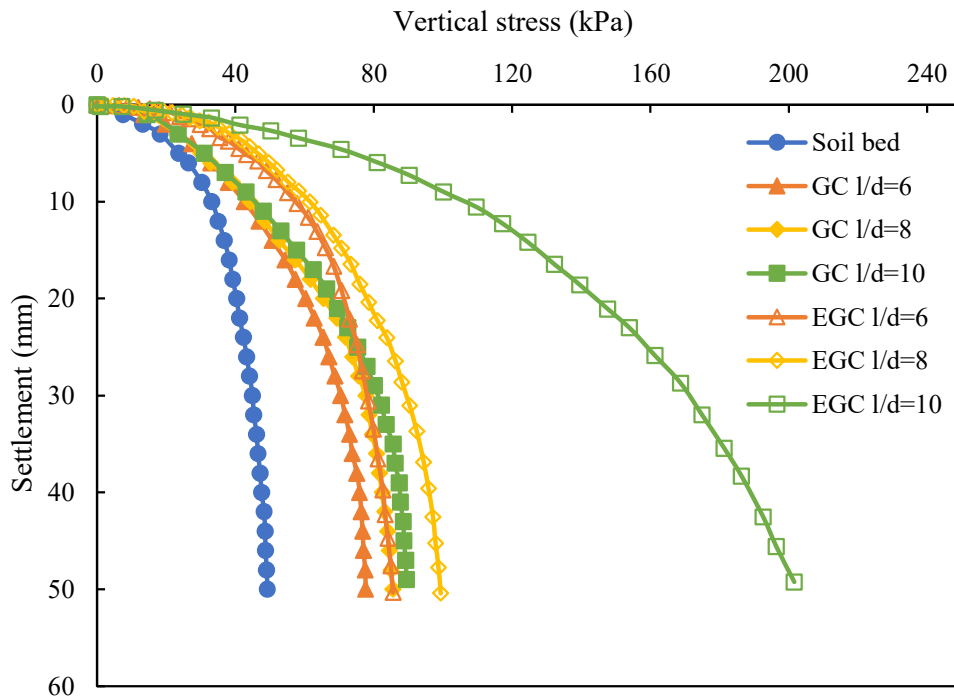


Fig. 4.7 Effect of geosynthetic encasement on GC reinforced soil bed with $S_u=15$ kPa.

The improvement in the capacity of reinforced soil bed for different column lengths presented in Fig. 4.8 was found to be 1.2, 1.31, and 1.41 times for PGC and 1.33, 1.72, and 3.35 for EPGC over the soft soil bed having S_u of 15 kPa. This suggests that incorporating plastic granules as substitutes for traditional aggregates in columns could yield a similar enhancement effect, especially when accompanied by geosynthetic encasement.

The extent of improvement exhibited by the EGC for an end-bearing condition is 2.03 times that of the floating column. Also, from Fig. 4.8, it can be observed that the ultimate capacity of the end-bearing EPGC improved soil bed is 1.90 times that of the floating EPGC. The higher vertical stress-bearing capacity of end-bearing EGC and EPGC could

be attributed to the combined effect of resistance against the punching of the column due to rigid bottom support and the confining effect of the geosynthetic encasement.

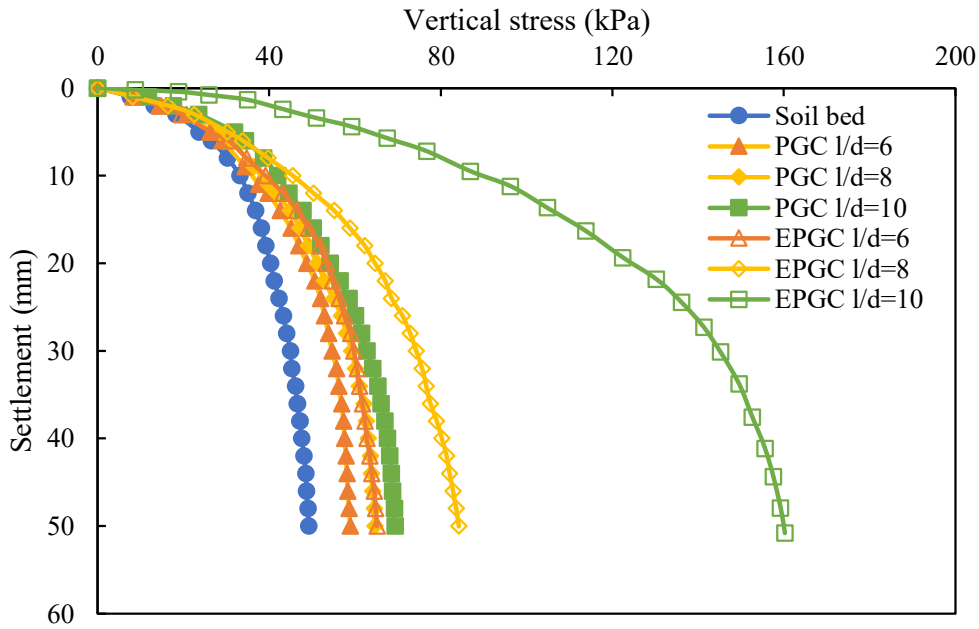


Fig. 4.8 Effect of geosynthetic encasement on PGC reinforced soil bed with $S_u=15$ kPa.

4.3.1.5 Column deformation behavior

Following the completion of load tests, the deformation patterns of both granular and encased columns were captured through exhumation and casting of deformed columns using plaster material. Fig. 4.9 illustrates the deformation patterns observed in granular and encased columns across different length configurations. Similar deformation patterns were observed by (Ghazavi and Nazari Afshar 2013), (Ali et al. 2012) and (Hasan and Samadhiya 2017), which had similar trends. The columns fail due to bulging and poor lateral support from adjoining soft clay. The bulging was predominant in the top portion of the column, extending up to a depth of 1-1.5 times the column diameter from the top. The bulging of the column near the top was observed to reduce significantly with encasement, which is evident from Fig 4.9.

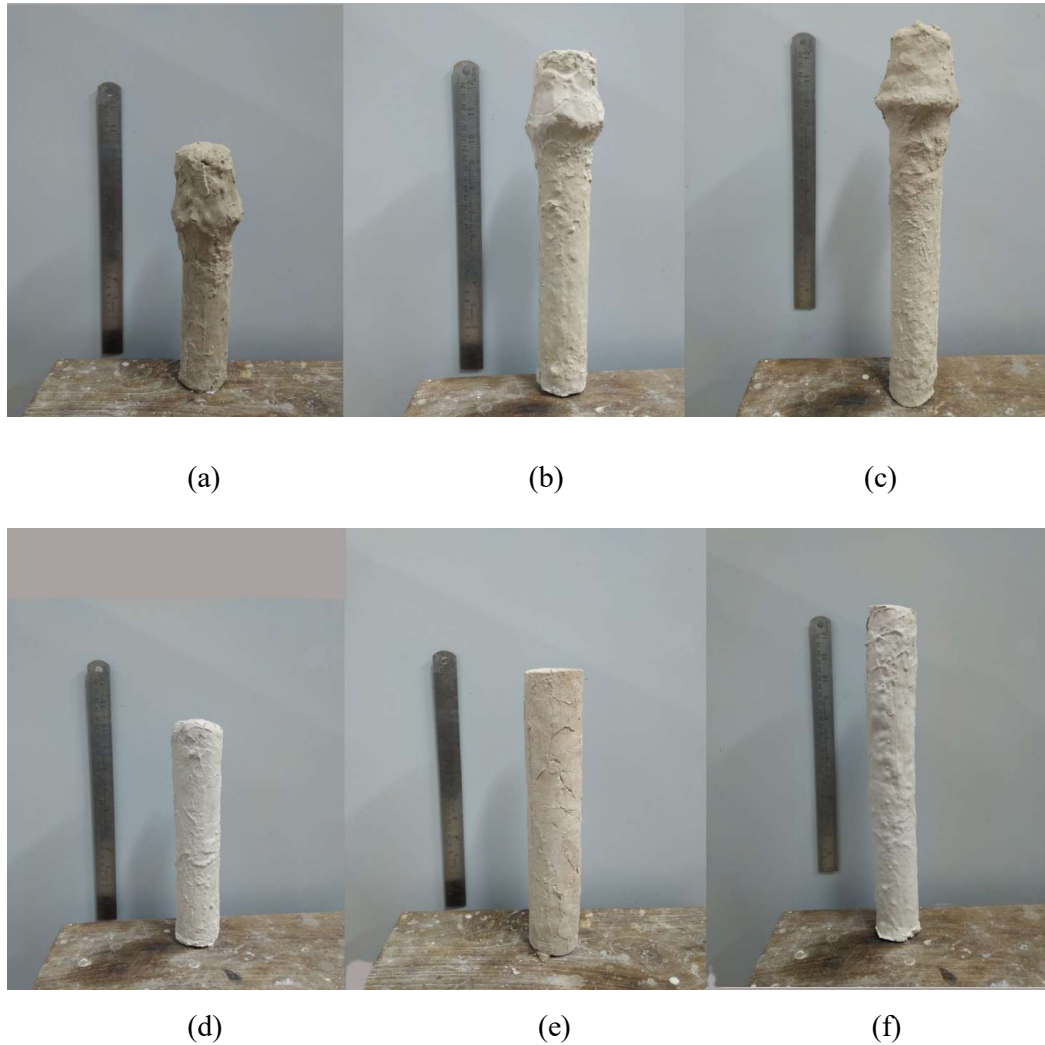


Fig. 4.9 Typical deformed shapes of columns after the load tests of (a) GC 1/d 6, (b) GC 1/d 8, (c) GC 1/d 10, (d) EGC 1/d 6, (e) EGC 1/d 8, (f) EGC 1/d 10.

4.3.1.6 Bearing capacity improvement factor

The improvement of the soft soil due to the installation of GC and PGC is quantified by calculating an Improvement factor (IF), defined as the ratio of peak stress applied to the improved soil bed to the peak stress applied to the unreinforced clay bed. A similar improvement factor was used by Dash (Dash and Bora 2013). Ghazavi (Ghazavi and Nazari Afshar 2013) used the term load ratio to determine the improvement in the loading capacity of soft soil due to the provision of a stone column. A summary of the test results is presented in Table 4.3 and Table 4.4.

Table 4.3 Vertical stress improvement factors for soft soil beds improved with GC and PGC.

S_u (kPa)	Improvement factor (IF)					
	5		10		15	
	GC	PGC	GC	PGC	GC	PGC
Column type						
$l/d=6$	1.70	1.49	1.57	1.32	1.51	1.20
$l/d=8$	2.10	1.83	1.96	1.50	1.73	1.32
$l/d=10$	2.23	1.93	2.18	1.69	1.82	1.41

From the values shown in the tables it can be inferred that the loading capacity of the reinforced clay bed increases consistently with the increase in the column length with the highest improvement factor obtained for end-bearing column. However, the relative improvement in the loading capacity is found to reduce with the increase in the S_u value of the clay bed. This observation could be attribute to the higher contribution of the soft clay bed at increased shear strength leading to reduced incremental effect of the column. The improvement factors obtained for clay bed reinforced with encased columns is found to be significantly higher than that obtained for the soil bed reinforced with non-encased column. Higher improvement factors indicate the contribution of the geosynthetic encasement in enhancing the bearing capacity of the clay bed by laterally stiffening the column. The trend observed in the values obtained are consistent with the previous observation for different lengths and shear strength values.

Table 4.4 Vertical stress improvement factors for soft soil beds improved with EGC and EPGC.

S_u (kPa)	Improvement factor (IF)					
	5		10		15	
	EGC	EPGC	EGC	EPGC	EGC	EPGC
Column type						
$l/d=6$	2.11	1.88	1.99	1.57	1.75	1.33
$l/d=8$	2.45	2.20	2.35	2.02	2.03	1.72
$l/d=10$	3.54	3.05	3.83	3.17	4.11	3.35

4.3.2 Comparison of model test results with analytical data

Priebe (Priebe 1995) introduced a theory highlighting the enhancements achieved by incorporating granular columns into a soft soil foundation through an analytical expression. This expression incorporates an improvement factor for the treated soil, denoted as 'n'. The primary parameters influencing this factor include the area replacement ratio (A_r), the angle of internal friction of the column material, and the Poisson's ratio of the soft soil material. The comparative behavior of the experimental results and the values predicted by Priebe's analysis is presented in Fig. 4.10. The values predicted by the analytical expression were plotted for ϕ values of 45° and 40° for GC and PGC materials and Poisson's ratio of 0.49 for soft clay. The experimentally obtained improvement factor values are found to fit closely with the values predicted by Priebe's equations shown in Fig. 4.10.

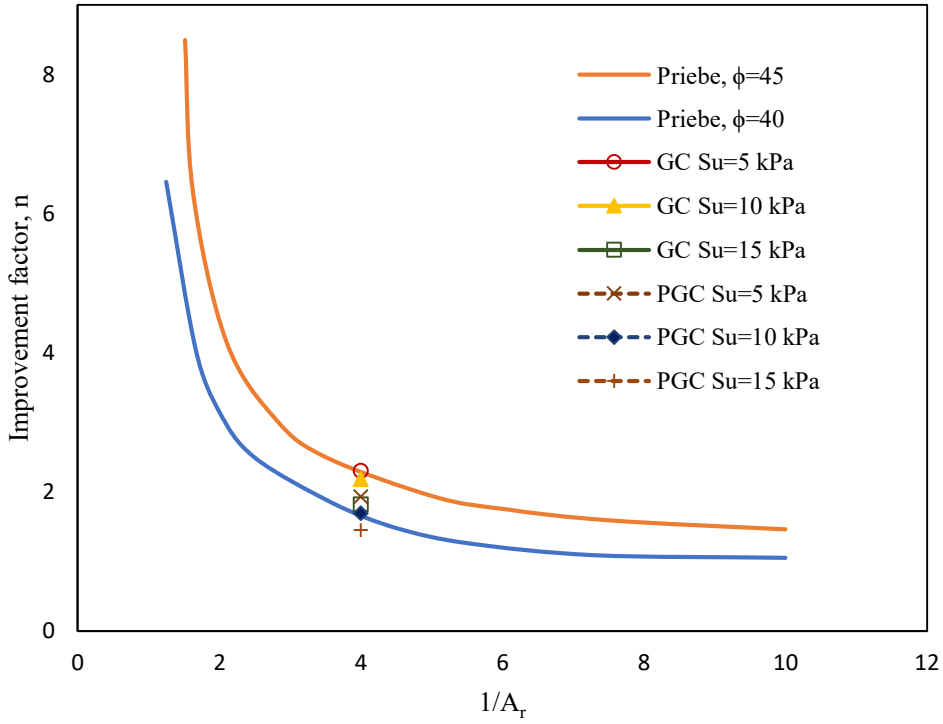
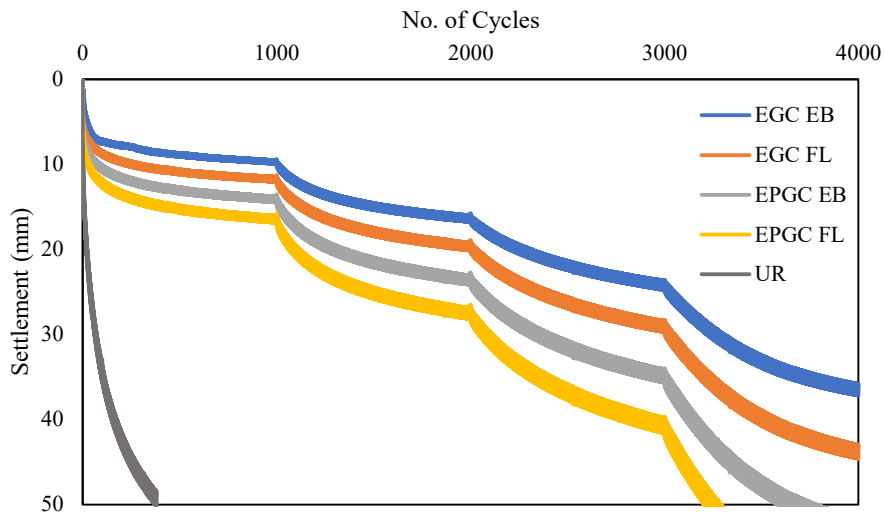


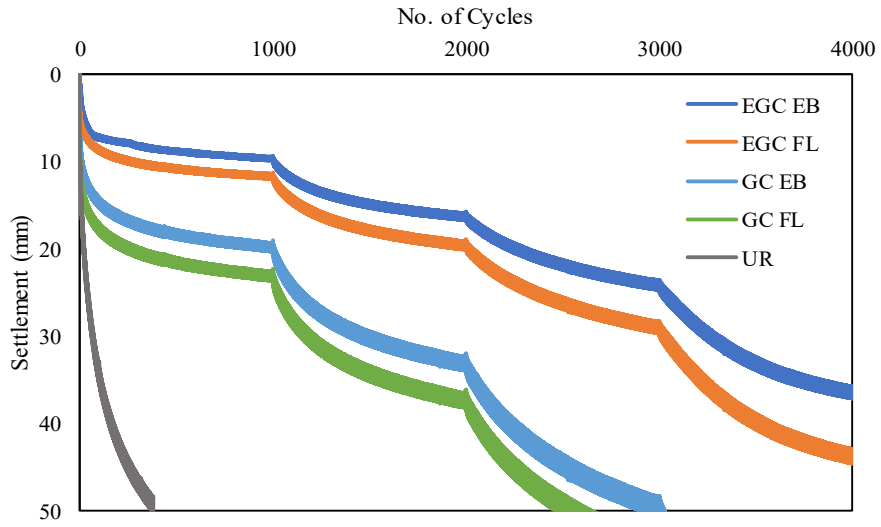
Fig. 4.10 Comparison with Priebe's analytical results.

4.3.3 Cyclic loading response of single column model

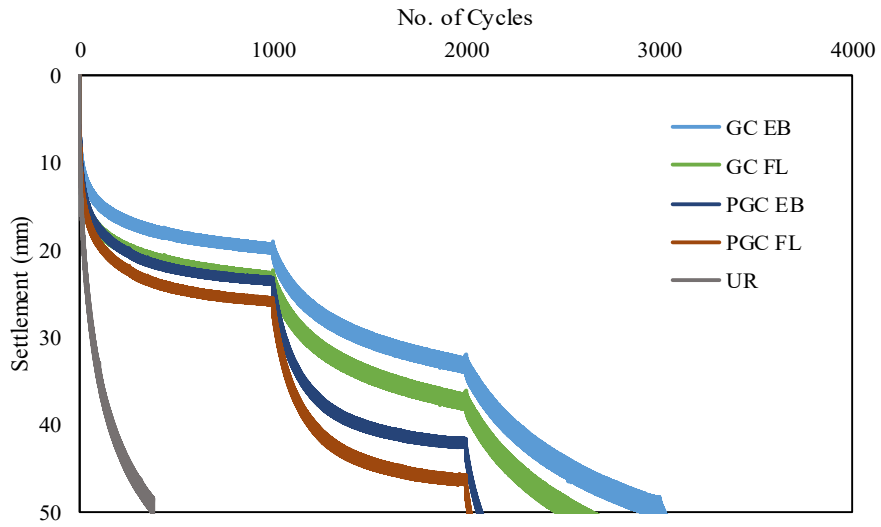
The settlement response of soft clay bed subjected to multistage cyclic loading is presented in Fig. 4.11. It can be observed from the plot that the settlement is non-linear.



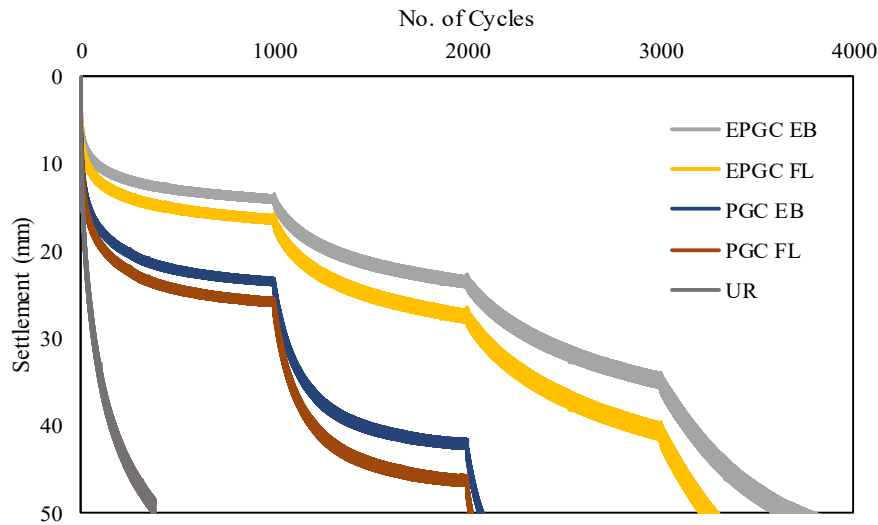
(a)



(b)



(c)



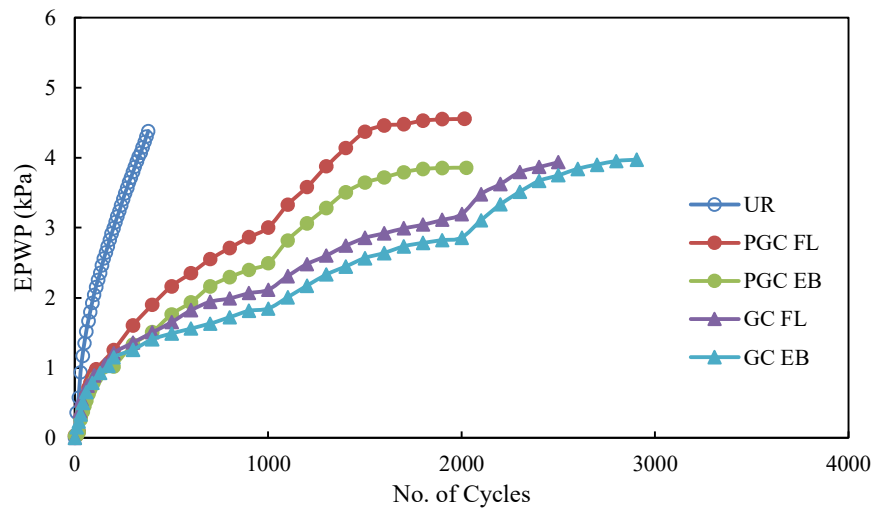
(d)

Fig. 4.11 Settlement response of soft clay bed improved with a single column subjected to staged cyclic loading with different column configuration: (a) EGC and EPGC, (b) EGC and GC, (c) GC and PGC, (d) EPGC and PGC.

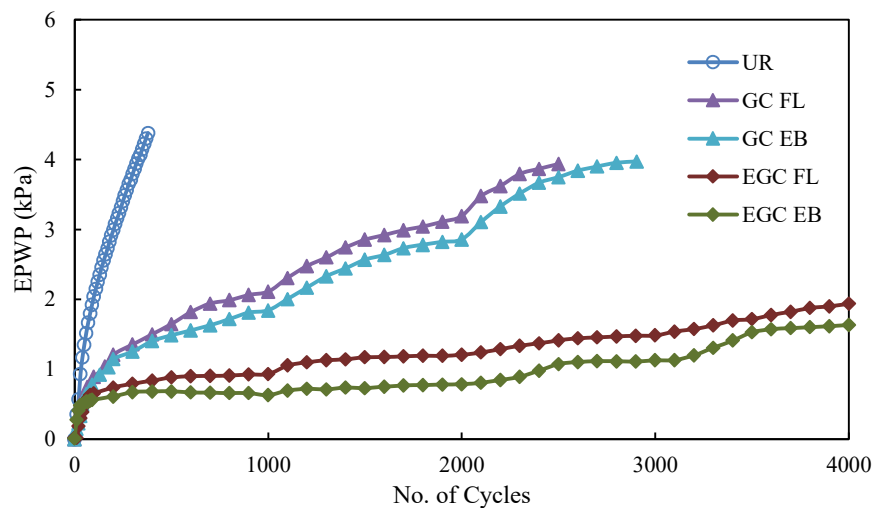
It can be observed from the settlement plot that the footing supported by unreinforced clay undergoes drastic deformation which reaches 50 mm settlement in just 380 cycles of cyclic loading. However, the corresponding vertical settlement of EGC EB, EGC FL, EPGC EB and EPGC FL reinforced clay bed was reduced to 8.81 mm, 10.88 mm 13.05 mm and 15.23 respectively for same 380 number load cycles. It can also be inferred that the end-bearing column is more effective in resisting cyclic stress induced deformations. The cumulative settlement of the footing is significantly reduced by the use of geogrid encasement. The EGC and EPGC supported soft clay bed undergoes significantly higher number of loading cycles when compared to the GC and PGC supported clay bed as shown in Fig. 4.11 (b) and (d).

The variation of excess pore water pressure is presented in Fig. 4.12. A nonlinear response was observed for the excess pore water pressure with an increasing number of load cycles, as shown in Fig. 4.12. The EPWP increases rapidly up to 4.38 kPa at 50

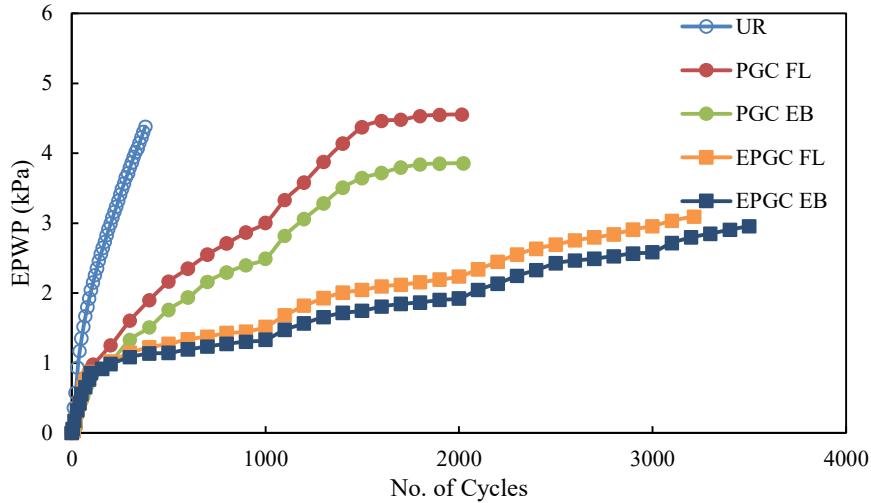
mm settlement for the unreinforced clay bed. The peak of the EPWP plot is observed at the end of the cyclic loading stages. The presence of GC and PGC reinforcement results in a relative reduction of EPWP through all the stages of cyclic loading. The EPWP in the unreinforced clay bed at the end of 380 load cycles was found to be 4.38 kPa; this value of EPWP is reduced to 1.86 kPa for PGC FL, 1.46 kPa for GC FL and 1.32 kPa for GC EB as seen in Fig. 4.12 (a). Similarly, the peak EPWP found in the GC EB improved soil bed was found to be 3.97 kPa and it was significantly reduced to 1.48 kPa with EGC FL improved soil under cyclic loading as shown in Fig. 4.12 (b) and (c).



(a)



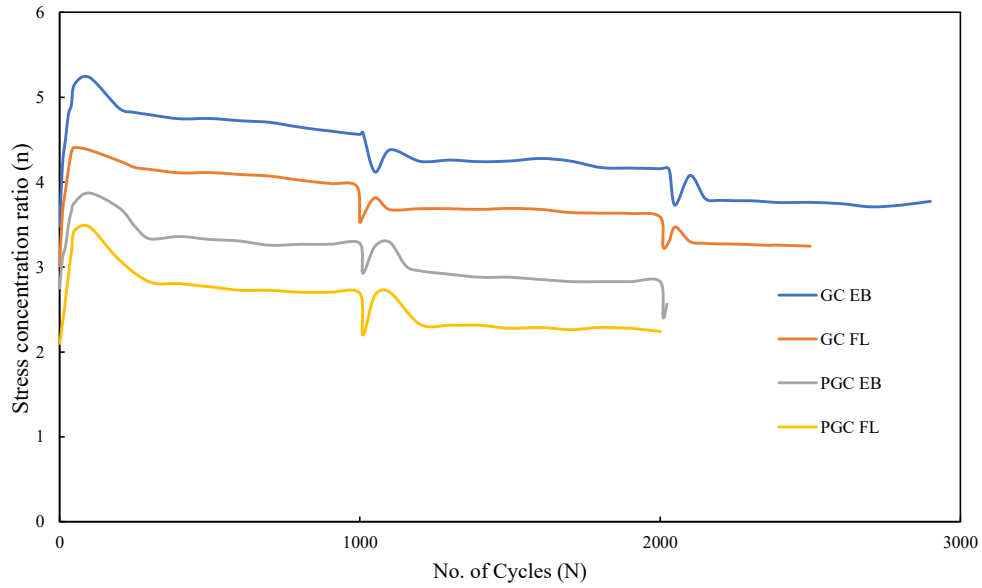
(b)



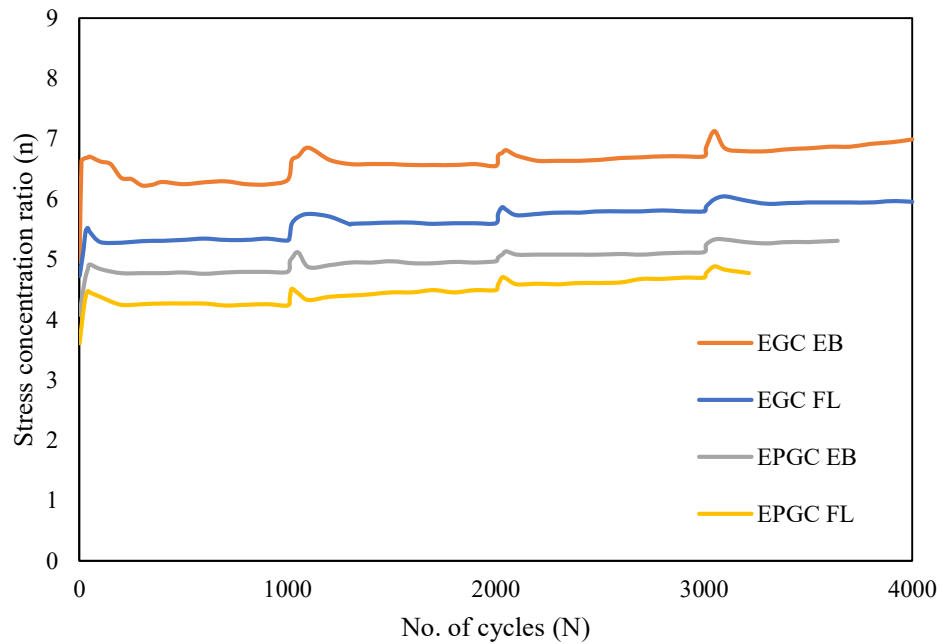
(c)

Fig. 4.12 Variation of excess pore water pressure under cyclic loading for : (a) GC and PGC, (b) GC and EGC, (c) PGC and EPGC; improved clay bed.

The stress concentration ratio for the reinforced clay bed with the number of loading cycles; this is shown in Fig. 4.13 (a) and (b). The stress concentration ratio shows a sharp rise in the early loading cycles, which decreases gradually and tends to stabilize at the end of each stage. Since n is calculated as a ratio of stress on the column to that on the surrounding soil, a higher n indicates that more significant stress is shared by the granular column. Fig. 4.13 (a) shows that the n vs. loading cycles plot forms a downward-stepping trend. Since the cyclic stress amplitude increases for every successive loading stage, the soil, and the column stress increases. The effective increase in stress on the soil is higher, thus the reason for the observed trend. The presence of geosynthetic encasement causes the columns to share higher stresses in subsequent loading; as such, an upward-stepping trend of variation is observed in EGC and EPGC-improved clay beds.



(a)



(b)

Fig. 4.13 Variation of stress concentration ratio for floating and end-bearing cases under cyclic loading: (a) GC and PGC, (b) EGC and EPGC.

A comparative study was done on the settlement behavior of soft clay bed improved with single column in different configurations under multi-stage cyclic loading and the

result is shown in Fig. 4.14. It is evident from the plot that the end-bearing column performs better in settlement reduction under cyclic loading for all combinations of granular columns. Also, only the encased GC and PGC reinforced beds had sustained highest number of loading cycles, with EGC exhibiting 37.17 mm settlement at the end of 4000 cycles of staged loading.

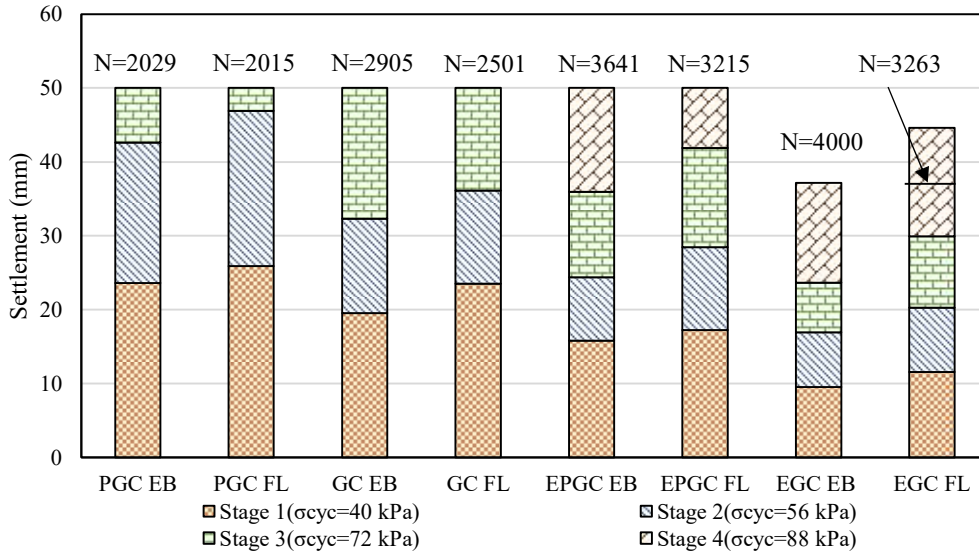


Fig. 4.14 Comparison of settlement response for floating and end-bearing column under cyclic loading.

4.4 Conclusions

The work presented here describes the performance of GC and PGC-reinforced soft clay beds through the results obtained from experimental and numerical investigations. The following conclusions could be drawn for the various range of test conditions mentioned in the manuscript:

- 1) Soft soil modified with granular columns exhibits improved resistance to vertical load-induced settlement. The improvement is primarily influenced by the presence of stiffer granular material in the form of columns within the soil mass.

- 2) The load-carrying capacity of the granular column improved soil bed increases with the increase in the l/d ratio of the column. However, for a floating column with an l/d ratio of 8, the improvement is significantly closer to that of an end-bearing column. Thus, $8d$ is reported as the limiting length for the floating column.
- 3) GC and PGC undergo bulging failure under the action of vertical load. It is evident from the shape of the exhumed granular column after the test and from the numerical modeling results.
- 4) The use of recycled plastic granules as an aggregate for making the columns has exhibited significant improvement in the load settlement behavior of soft soil. The clay bed having S_u of 5 kPa shows 1.83- and 1.9 times improvement in loading capacity for floating and end-bearing PGC, respectively. These results prove the usefulness of recycled plastic as an alternative and sustainable material for the construction of granular columns.
- 5) Using geosynthetic encasement improves the effectiveness of GC and PGC in soft soil beds. EGC and EPGC provide further enhancement over the use of GC and PGC in soft soils, but the improvement is drastic for the end-bearing condition. The use of geosynthetic encasement for an end-bearing column almost doubles the capacity of an encased floating column.
- 6) The variation of stress concentration for non-encased and encased granular columns under cyclic loading was reported in this study. A stepwise decreasing trend of stress concentration was observed for GC and PGC improved soil bed over multistage cyclic loading. A contrasting stepwise increasing trend was reported for EGC and EPGC improved soil bed.

- 7) Excess pore water pressure variation over multistage cyclic loading has shown a successive increasing trend for granular column-improved soil beds. However, the rate of increment in EPWP is significantly reduced for EGC and EPGC reinforcement combinations.