CHAPTER 6

MODEL TESTS ON GROUP OF GRANULAR PILES

6.1 General

The main objective of this chapter is to analyze the behavior of a group of granular piles composed of the optimum tire chips - aggregates mixture subjected to static and cyclic loading. To achieve this, a series of comprehensive laboratory model tests were carried out on a group of 12 granular piles installed in a soft soil bed under axisymmetric conditions. These tests were meticulously designed to replicate field conditions and provide reliable data for analysis.

In addition to the primary focus on granular piles with the optimum tire chips - aggregates mixture, the study also examined the performance enhancement provided by three different types of encasement materials: geotextile, geogrid, and combi-grid. These materials were selected for their potential to improve the structural integrity and load-bearing capacity of the granular piles. The comparative analysis of these encasement materials aims to identify the most effective solution for enhancing pile performance.

The cyclic loading characteristics analyzed in this study included key parameters such as cyclic loading amplitude (q_{cy}), cyclic stress ratio (CSR), and cyclic loading frequency (f_{cy}). These parameters are critical in understanding how the granular piles respond to repetitive loading conditions, which are common in real-world applications such as transportation infrastructure and foundation systems subjected to dynamic loads.

Several metrics were measured to assess the performance of the granular piles under cyclic loading. The loading plate's cyclic-induced settlement (S_c) was recorded to determine the extent of vertical displacement over time. The pile-soil stress distribution was evaluated regarding the stress concentration ratio (n), providing insights into how loads are transferred between the piles and the surrounding soil. Another crucial metric was the accumulation of excess pore water pressure (P_{exc}) in the surrounding soft soil, as increased pore water pressure can significantly affect soil stability and pile performance.

This comprehensive study involved a total of 22 model tests, ensuring a robust dataset for analysis. The model test set-up, illustrated in Fig. 6.1, was meticulously designed to replicate real-world conditions as closely as possible. The outline of the model tests performed, detailed in Tables 6.1 and 6.2, provides a clear overview of the experimental conditions and variables considered in this study.

Overall, the findings from these laboratory model tests are expected to provide valuable insights into the optimal design and application of granular piles with tire chips-aggregate mixtures and various encasement materials. This knowledge will contribute to developing more efficient and sustainable ground improvement techniques, enhancing the performance and longevity of infrastructure projects built on soft soils.

Table 6.1 Summary of static model tests conducted (5 model tests).

Test series A	**GP**	***D* (mm)**	***L* (mm)**	**GP Type**	**A_r (%)**	**I_D**	**S_u (kPa)**	**ET**
1	OSB	---	---	Only soil	---	---	8.5	---
2	OGP	60	240	EB	25	70	8.5	None
3	VEGP	60	240	EB	25	70	8.5	GT
4	VEGP	60	240	EB	25	70	8.5	GG
5	VEGP	60	240	EB	25	70	8.5	CG

Table 6.2 Summary of cyclic model tests conducted (17 model tests).

Test series	S_u (kPa)	L/D	ET	f_{cy} (Hz)	CSR	q_{cy} (kPa)	N	GP	No. of tests
B	8.5	4	None	1	0.65	77	5000	OSB, OGP	2
C	8.5	4	GT,GG ,CG	1	0.65	77	5000	VEGP	3
D	8.5	4	CG	1	0.50,0.65, 0.72,0.8,1	59,77,85, 94,118	5000	OGP, VEGP	8
E	8.5	4	CG	0.5,1, 2	0.65	77	5000	OGP, VEGP	4

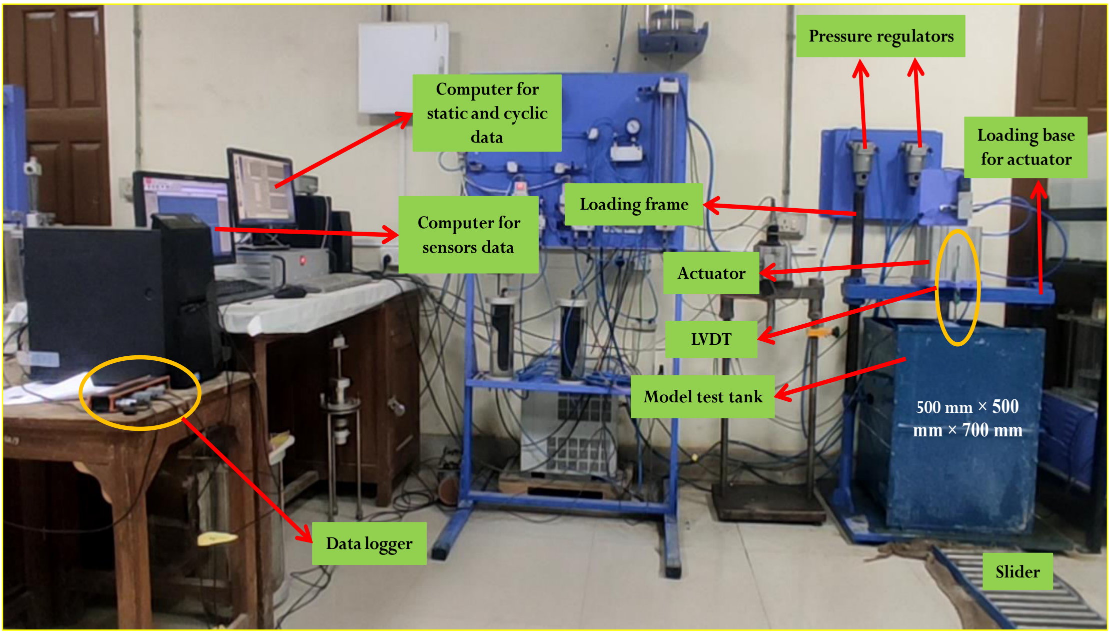


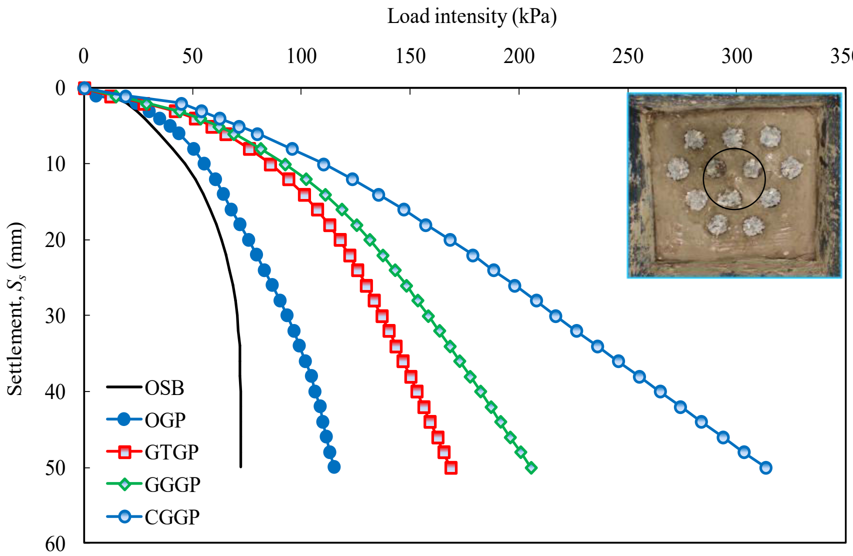
Fig. 6.1 Pictorial representation of model test set-up for a group of granular piles.

6.2 Results and Discussion

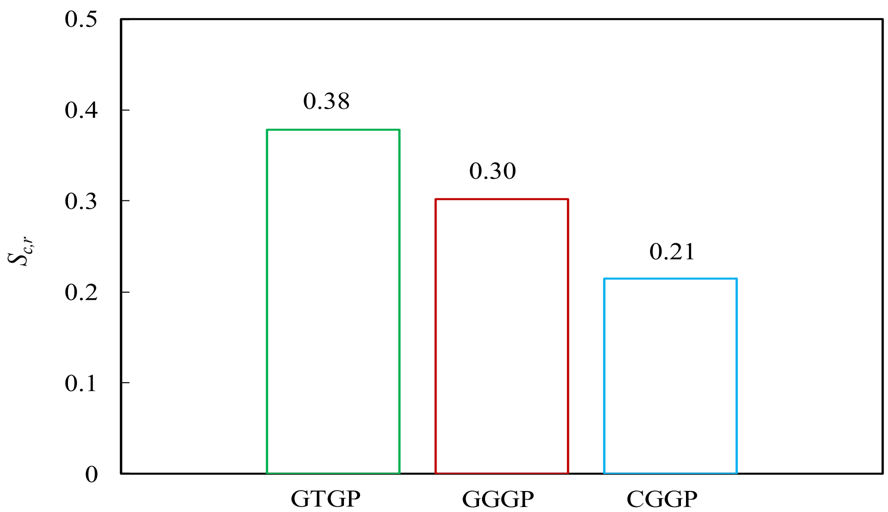
6.2.1 Effect of geosynthetic encasements

6.2.1.1 Performance of group of granular piles under static loading

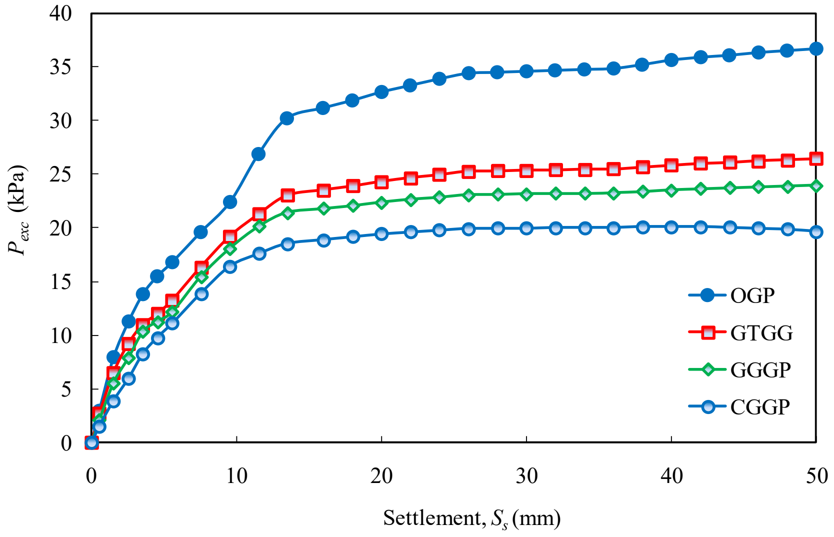
The load intensity-settlement results from group static model tests on only soil bed (OSB), ordinary granular piles (OGPs), and granular piles encased with geotextile (GT), geogrid (GG), and combi-grid (CG) are presented in Fig. 6.2.



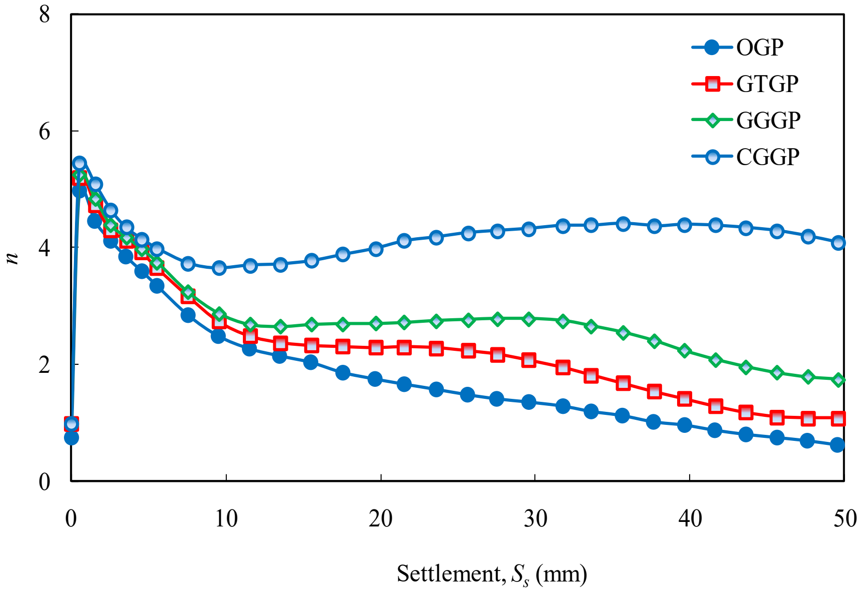
(a)



(b)



(c)



(d)

Fig. 6.2 Behavior of OSB, OGP, and VEGP under static loading.

The ultimate load intensity (q_{us}) is considered at a loading plate settlement of 50 mm, similar to a single granular pile. The q_{us} values for OSB, OGPs, and granular piles encased with GT, GG, and CG are 72 kPa, 118 kPa, 168 kPa, 205 kPa, and 313 kPa, respectively. The percentage increment in load intensity for OGPs is 58% compared to OSB. The load intensity for geotextile encased granular piles (GTGPs), geogrid encased granular piles (GGGPs), and combi-grid encased granular piles (CGGPs) increased by 133%, 185%, and 335% compared to OSB. Similarly, the increments are 47%, 80%, and 175% compared to OGPs. The key inferences from the model test results are that the load-bearing capacity is significantly increased with the installation of a group of OGPs (by 58%) and substantially increased with combi-grid encasement (by 335%). This concludes that combi-grid is a very effective encasement material for granular piles.

The effectiveness of encasements is also explained in terms of the settlement reduction ratio ($S_{c,r}$), accumulation of excess pore water pressure (P_{exc}), and stress concentration ratio (n), using the results from test series A in Table 6.1(a). Fig. 6.2(b) shows $S_{c,r}$ values of 0.38, 0.30 and 0.21 for GTGPs, GGGPs, and CGGPs, respectively. The combi-grid encasement reduced the settlement of the granular pile by about 79% compared to OGPs under static loading. This highlights that combi-grid encasement substantially improved the ultimate load-bearing capacity and significantly reduced granular pile settlement.

The settlement performance of granular pile-improved ground is directly related to the generation of excess pore water pressure due to static loading. The generation of excess pore water pressure decreases the effective stress in the soft bed, thereby reducing the ultimate load intensity of the improved ground. In certain soil types, this phenomenon can even lead to liquefaction. Fig. 6.2(c) shows that in both OGP and VEGP cases, pore water pressure accumulation increases with settlement during static loading. Additionally, encased granular piles significantly reduced the P_{exc} in the soft bed compared to OGPs. The results from the miniature pore pressure sensor installed in the middle (150 mm from the loading plate) were considered. The peak P_{exc} values for OGPs, GTGPs, GGGPs, and CGGPs are 36.71 kPa, 26.44 kPa, 23.96 kPa, and

19.67 kPa, respectively. The percentage decrease in P_{exc} was nearly 28%, 34%, and 54% for GTGPs, GGGPs, and CGGPs compared to OGPs. This reduction occurs because encased granular piles bear the majority of the static load, reducing the static loads transmitted to the surrounding soft soil. This pattern emphasizes the effectiveness of combi-grid as the most valuable encasement material for granular piles under static loading conditions.

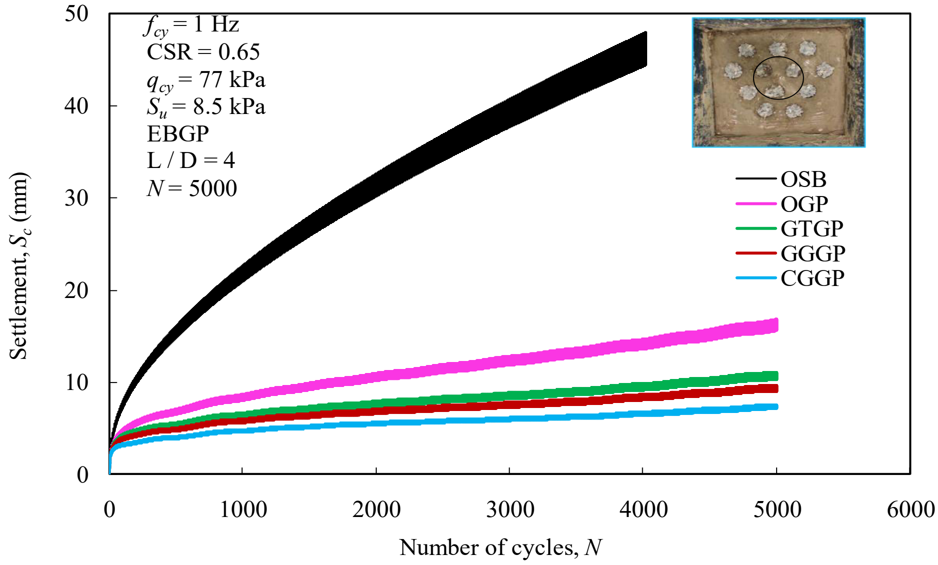
The stress distribution within the soil-pile interface is a pivotal attribute for granular pile-improved soft ground. The applied stress on the loading plate is dispersed between the granular pile and the soft soil, presented in terms of the stress concentration ratio (n). The stress concentration ratio is defined as the ratio of stresses on a granular pile (σ_{GP}) to stresses on soft soil (σ_{SB})(Ghazavi and Nazari Afshar 2013; Zhang et al. 2020). The stresses on the granular piles are higher than those on the surrounding soft soil because the stiffness of the granular piles is greater than that of the soft soil. Fig. 6.2(d) shows the n variation with the granular pile settlement, both with and without encasements. Miniature earth pressure sensors recorded the stresses. As observed, the n value is not constant for all the granular piles and differs with the increase in granular pile settlement. The encasements resulted in 75%, 182%, and 560% increments in the stress concentration ratio for GTGPs, GGGPs, and CGGPs, respectively, compared to OGPs.

The results for the settlement reduction ratio, accumulation of excess pore water pressure, and stress concentration ratio emphasize that combi-grid are the most beneficial material for granular piles subjected to static loading.

6.2.1.2 Performance of group of granular piles under cyclic loading

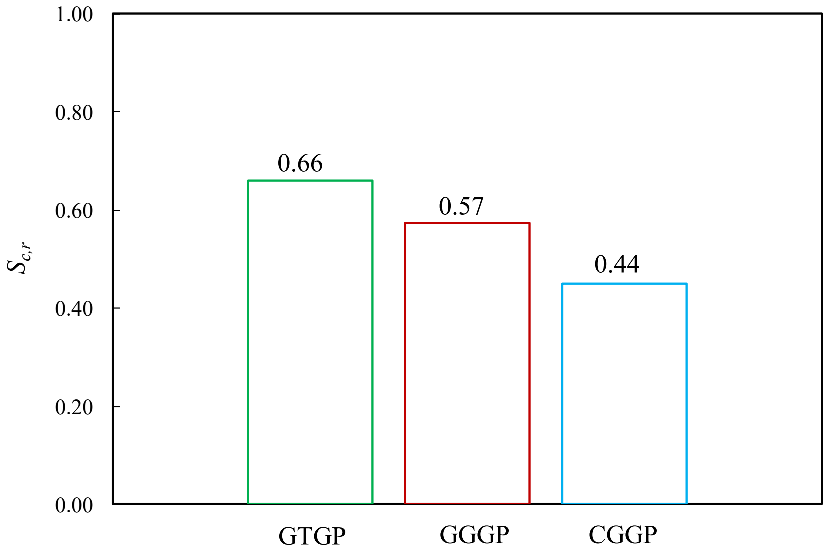
This section discusses the findings of a study on the group of granular piles with and without encasements to highlight the performance of encasements under cyclic loading. The baseline cyclic characteristics considered are f_{cy} = 1 Hz, CSR = 0.65, q_{cy} = 77 kPa, and end-bearing condition with 5000 cycles. The performance of the granular piles is assessed in terms of cyclic induced settlement (S_c), accumulation of excess pore water pressure (P_{exc}), variation in surrounding soft soil, and stress concentration ratio (n), using the results from test series B and C from Table 6.2. The results are shown in Fig. 6.3.

The progression of the accumulated cyclic-induced- settlements of granular piles with and without encasements is illustrated in Fig. 6.3(a). This study examines the accumulated settlement data up to 5000 cycles, excluding any data beyond that time frame similar to a single granular pile. It is noticed that all three encasements follow the same pattern of cyclic-induced settlement versus the number of loading cycles. In the case of OGPs and VEGPs, the cumulative settlements exhibit rapid development in the initial loading stages and become progressive as the number of cycles increases. However, in the case of OSB, the settlement rate remains quick, up to 5000 cycles. Installing either OGPs or VEGPs into the soil bed reduces cyclic-induced settlements. In this study, the OGPs significantly reduced the cyclic-induced settlement from 50 mm to 16.78 mm, achieving nearly a 66% reduction compared to OSB. The VEGPs with GT, GG, and CG substantially reduced the cyclic-induced settlement to 11.05 mm, 9.63 mm, and 7.52 mm, respectively, achieving reductions of approximately 78%, 81%, and 85% compared to OSB. This suggests that improvement with a group of ordinary granular piles is an effective ground improvement method for a soft soil bed under cyclic loading, and the combi-grid encasement has the potential to enhance this effect even further.



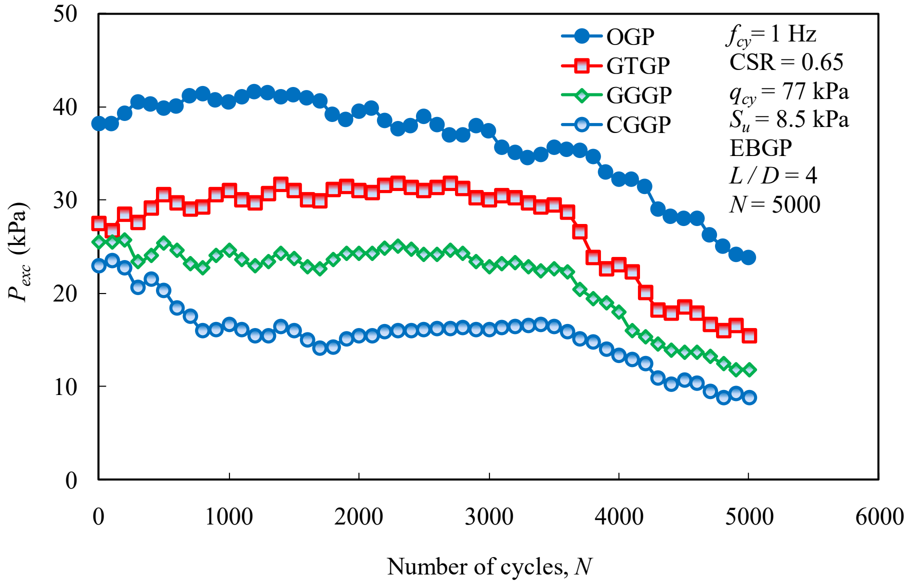
f_{cy} = 1 Hz
CSR = 0.65
q_{cy} = 77 kPa
S_u = 8.5 kPa
EBGP
L / D = 4
N = 5000
OSB
OGP
GTGP
GGGP
CGGP
Settlement, S_c (mm)
Number of cycles, N
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000

(a)



$S_{c,r}$
1.00
0.80
0.60
0.40
0.20
0.00
0.66
0.57
0.44
GTGP
GGGP
CGGP

(b)



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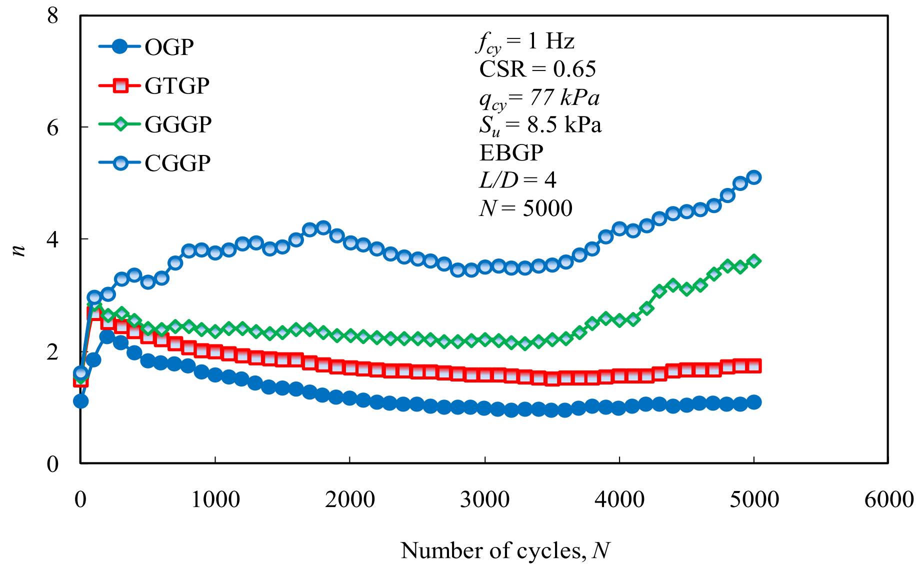


(d)

Fig. 6.3 Behavior of OSB, OGP, and VEGP under different encasements; (a) S_c versus N curve, (b) settlement reduction ratio ($S_{c,r}$), (c) P_{exc} versus N, and (d) n versus Ncurve.

The effectiveness of encasements on granular pile-improved ground is also analyzed in terms of the settlement reduction ratio ($S_{c,r}$), as shown in Fig. 6.3(b). The $S_{c,r}$ values of GTGPs, GGGPs, and CGGPs are 0.66, 0.57, and 0.44, respectively, emphasizing that a smaller $S_{c,r}$ indicates a greater reduction in cyclic-induced settlement of granular piles. The GT, GG, and CG encasements reduced the cyclic-induced settlement of the granular piles by about 34%, 43%, and 56% compared to OGPs. This trend demonstrates that combi-grid is the most beneficial material for granular piles subjected to cyclic loading. These results are consistent with the findings of previous studies (Yoo and Abbas 2019; Zhang et al. 2020) for OGPs and VEGPs. Similar results were also reported in single granular pile tests.

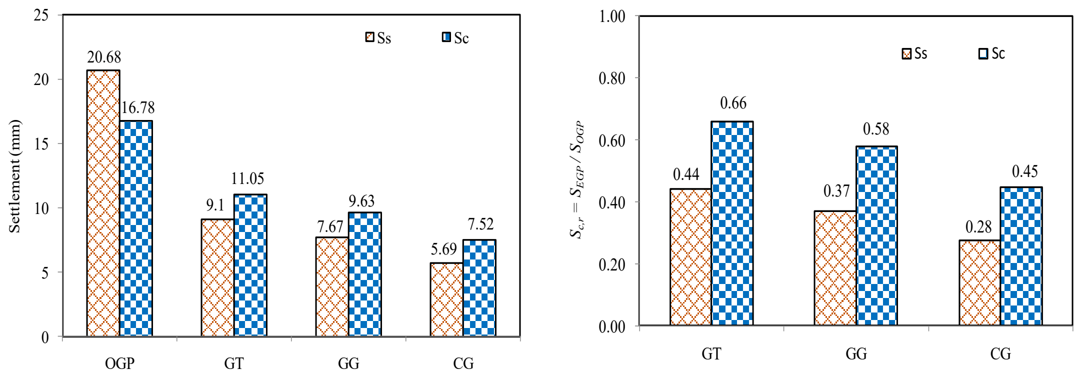
The performance of granular pile-improved ground is directly related to excess pore water pressure generation. The effect of geosynthetic encasement on the variation of P_{exc} with the number of cycles is presented in Fig. 6.3(c). The results from miniature pore pressure sensors installed at the midpoint (150 mm from the loading plate) were considered. In both OGPs and VEGPs cases, pore water pressure accumulates rapidly during cyclic loading. Additionally, the encased granular piles considerably reduced P_{exc} in the soft bed compared to OGPs. The peak P_{exc} values for OGPs, GTGPs, GGGPs, and CGGPs are 41.73 kPa, 31.86 kPa, 25.16 kPa, and 16.43 kPa, respectively. The percentage decreases in Pexc were approximately 24%, 40%, and 61% for GTGPs, GGGPs, and CGGPs compared to OGPs. Encased granular piles bear most of the load, resulting in reduced cyclic load transfer to the surrounding soft soil. These results are consistent with the findings of previous studies (Yoo and Abbas 2019; Zhang et al. 2020) for OGPs and VEGPs. Similar results were also reported in single granular pile tests.

The distribution of applied loads between the granular piles and surrounding soft soil was analyzed in terms of the stress concentration ratio (n). Fig. 6.3(d) illustrates the variation in stress concentration ratio values with the number of cycles for OGPs, GTGPs, GGGPs, and CGGPs. It can be observed that the stress concentration ratio increases gradually up to 5000 cycles in the case of CGGPs and GGGPs. However, for

GTGPs and OGPs, the n value rises rapidly during the initial loading cycles before stabilizing with further increments in loading cycles. At 5000 load cycles, the n values for OGPs, GTGPs, GGGPs, and CGGPs are 1.09, 1.75, 3.63, and 5.12, respectively. The provision of encasements led to a 60%, 233%, and 370% increase in the n value by applying GT, GG, and CG encasements, respectively. This is attributed to the fact that all encasements increased stresses on the granular piles while reducing stresses on the surrounding soft soil compared to unimproved ground, resulting in an overall increase in the n value. These results are consistent with the findings of previous studies (Yoo and Abbas 2019).

The results of the settlement reduction ratio, accumulation of excess pore water pressure, and stress concentration ratio highlight the efficacy of combi-grid as the most valuable material for granular piles under cyclic loading conditions.

The comparison between static and cyclic loading is explained in Fig 6.4. In Fig. 6.4(a), static settlement (S_s) and cyclic settlement (S_c) for OGP, GTGP, GGGP, and CGGP at load intensity of 77 kPa are presented. Additionally, Fig. 6.4(b) illustrates the effectiveness of different encasements in terms of settlement reduction ratio ($S_{c,r}$). The $S_{c,r}$ values are 0.44, 0.66 for GT; 0.37, 0.58 for GG; and 0.28, 0.45 for CG in both static and cyclic loading, respectively. These results demonstrate that GT, GG, and CG encasements reduced granular pile settlement by approximately 56%, 35%; 63%, 42%; and 72%, 55%, respectively, compared to OGP for static and cyclic loading conditions. This concluded that VEGP with combi-grid encasement significantly reduced the settlement and substantially increased the ultimate bearing capacity of the granular pile due to the combined effect of geotextile and geogrid. Furthermore, Fig. 6.4(b) highlights the overall advantage of combi-grid encasement in improving granular pile performance, which is greater under static loading than cyclic loading. A similar pattern was also reported by (Yoo and Abbas 2019; Zhang et al. 2020).



(a) (b)

Fig. 6.4 Comparision of static and cyclic loading results under different encasements; (a) settlement data, and (b)settlement reduction ratio ($S_{c,r}$).

6.2.2 Performance of group of granular piles under different cyclic loading amplitudes (q_{cy})

This section discusses the performance of soft soil improved with a group of granular piles, both with and without combi-grid encasement, under different cyclic loading amplitudes (q_{cy}). The range of q_{cy} values considered in this study are 59 kPa, 77 kPa, 85 kPa, 94 kPa, and 118 kPa, corresponding to CSR values of 0.5, 0.65, 0.72, 0.8, and 1, respectively, using the results from test series D from Table 6.2. In all cases, the cyclic loading frequency (f_{cy}) is considered to be 1 Hz.

Figs. 6.5(a-d) explains the effects of cyclic loading amplitudes on granular piles in terms of cyclic-induced settlements (S_c) and settlement reduction ratio ($S_{c,r}$). The S_c values for OGPs are 4.87 mm, 16.78 mm, and 44.76 mm after 5000 load cycles, corresponding to q_{cy} values of 59 kPa, 77 kPa, and 85 kPa, respectively. Similarly, a S_c of 50 mm is achieved within 1700 load cycles for a q_{cy} of 94 kPa and within only 400 load cycles for a q_{cy} of 118 kPa. This suggests that the group of OGPs installed in soft beds are effective up to a q_{cy} of 77 kPa (CSR of 0.65) and experience higher settlements beyond a q_{cy} of 79 kPa. The S_c values for combi-grid encased granular piles are 3.33 mm, 7.52 mm, 10.33 mm, 17.05 mm, and 23.32 mm after 5000 load cycles, corresponding to q_{cy} values of 59 kPa, 77 kPa, 85 kPa, 94 kPa, and 118 kPa, respectively. These findings indicate that CGGPs improve soft beds by undergoing smaller cyclic-induced settlements even at higher q_{cy} values.

The benefit of the combi-grid encasement is explained concerning the settlement reduction ratio ($S_{c,r}$) in Fig. 6.5(d). The $S_{c,r}$ values are 0.76, 0.45, 0.23, 0.18, and 0.22 for q_{cy} values of 59 kPa, 77 kPa, 85 kPa, 94 kPa, and 118 kPa, respectively. These results show that the group of OGPs is very effective at lower cyclic amplitudes (up to a *CSR* of 0.65). In comparison, combi-grid encasement is very effective at higher cyclic amplitudes ($CSR > 0.65$), where OGP improved foundation is subjected to excessive settlements. The maximum permissible settlement limit for railway tracks is considered to be 25 mm according to (RDSO-GE-0011).With combi-grid encasement, the improved soft bed undergoes a settlement of nearly 24 mm (less than the permissible value of 25 mm) even at a higher cyclic amplitude of 118 kPa (*CSR* of 1.0).

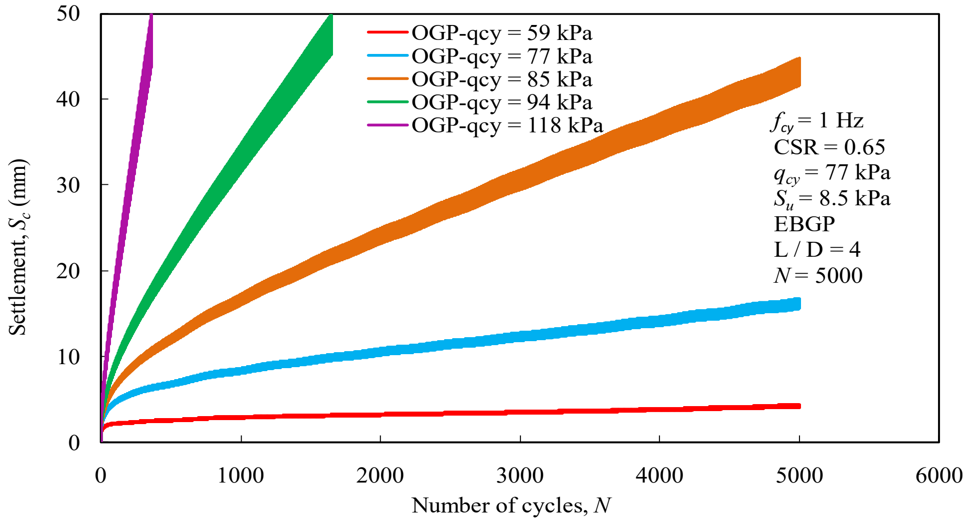
Fig. 6.5(e) shows the effect of q_{cy} on the variation of P_{exc} for both OGPs and CGGPs cases. The peak P_{exc} values for OGPs are 30 kPa and 42 kPa within 5000 load cycles, corresponding to q_{cy} values of 59 kPa and 77 kPa, respectively. At higher q_{cy} values (85 kPa, 94 kPa, and 118 kPa), P_{exc} reached a maximum limit of 50 kPa within 1000 load cycles. Similarly, peak P_{exc} values for CGGPs are 15.6 kPa, 23.6 kPa, 28.8 kPa, 40.9 kPa, and 49.2 kPa, respectively. This occurs because the encased granular piles take most of the load, reducing the degree of cyclic loads transferred to the surrounding soft soil. In both cases, the buildup of P_{exc} rises with increasing q_{cy} values.

The percentage reductions in P_{exc} values are 69.3%, 62.5%, 44.8%, 29%, and 13% for q_{cy} values of 59 kPa, 77 kPa, 85 kPa, 94 kPa, and 118 kPa, respectively, with the application of combi-grid encasement. This highlights that the percentage reduction in P_{exc} decreases with increasing q_{cy} values. A similar trend was reported by (Yoo and Abbas 2019) for different cyclic loading amplitudes.

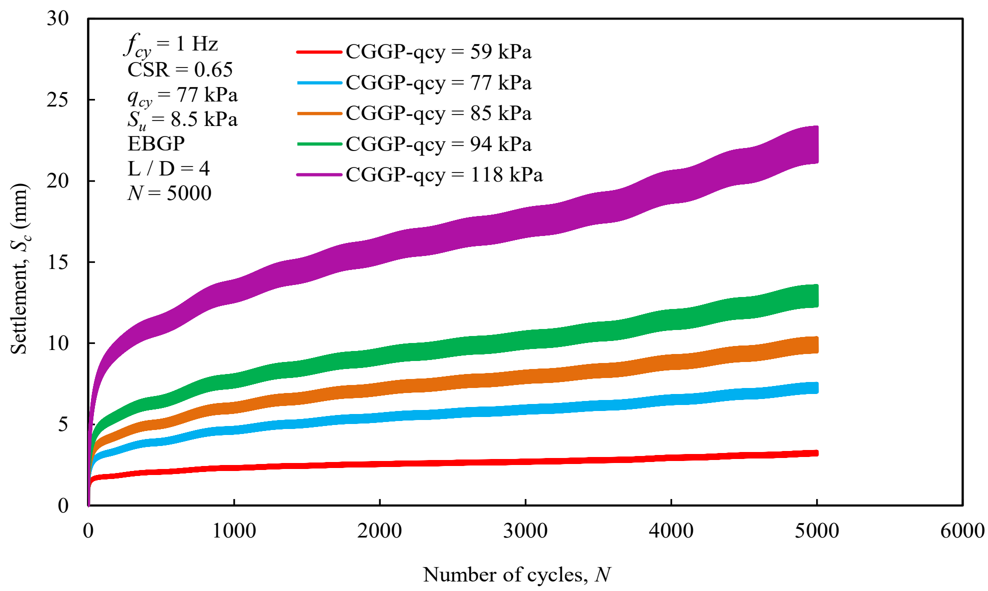
Fig. 6.5(f) shows the effect of q_{cy} on the variation of n for both OGPs and CGGPs. As observed, the n value is not constant for all q_{cy} values and varies with the increment in cyclic loading cycles. Additionally, all the OGP cases follow a consistent pattern of stress concentration ratio, while the CGGP cases follow a uniform pattern for all considered q_{cy} values. In the OGP case, the stress concentration ratio curves show peak values in the initial loading cycles. This can be attributed to the downward movement and rearrangement of granular pile material, leading to a slight increase in densification and mechanical interlocking between granular pile materials.

Consequently, less stress is transferred to the surrounding soft soil. However, as the number of cyclic loading cycles increases, the granular material within the pile gradually shifts laterally towards the surrounding soft soil, resulting in increased stress transfer and a subsequent decrease in the stress concentration ratio. Conversely, in the CGGP case, the stress concentration ratio increases with the number of loading cycles. The combi-grid encasement prevents intrusion of the tire chips - aggregates mixture into the surrounding soft soil and provides additional stiffness to the granular pile, reducing stress transfer to the surrounding soil. Similar results were reported by (Ghazavi and Nazari Afshar 2013).

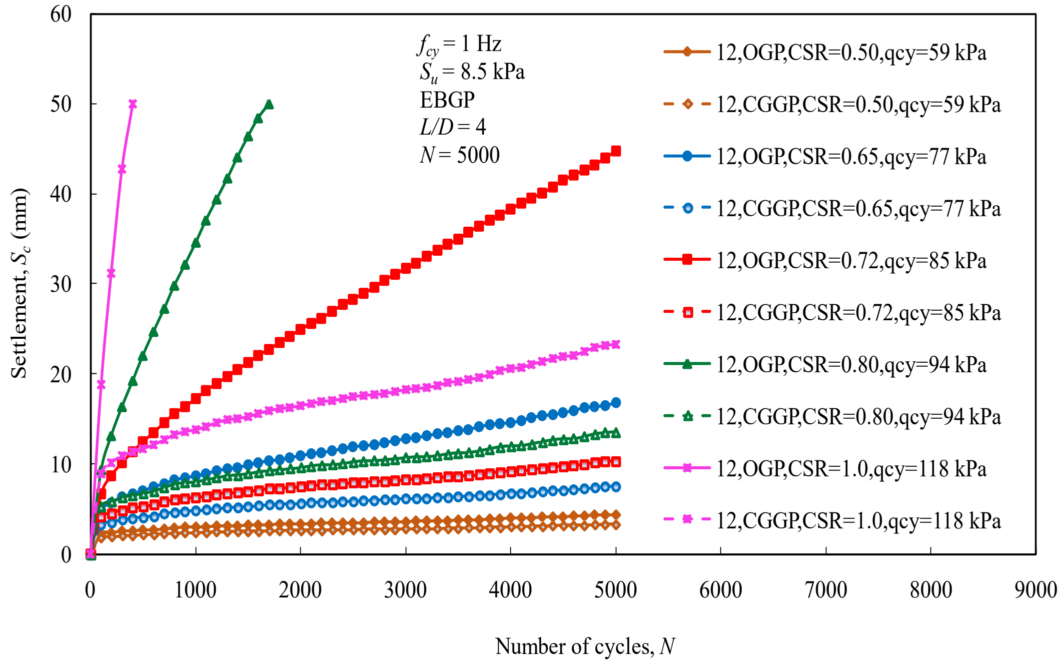
The peak n values for OGPs are 2.64, 2.52, 2.38, 2.09, and 1.72 for q_{cy} values of 59 kPa, 77 kPa, 85 kPa, 94 kPa, and 118 kPa, respectively. Similarly, the peak n values for CGGPs are 4.88, 5.12, 3.88, 3.51, and 3.21 for the same q_{cy} values. These results illustrate that OGPs and CGGPs experience higher stress concentration ratios at lower cyclic amplitudes than higher ones. Additionally, OGPs have lower stress concentration ratios compared to CGGPs. This is because granular piles encased with a combi-grid are subjected to higher stresses than OGPs. In both cases, the *n* value decreases with increasing q_{cy} values. A similar trend was reported by (Yoo and Abbas 2019) for different cyclic loading amplitudes.



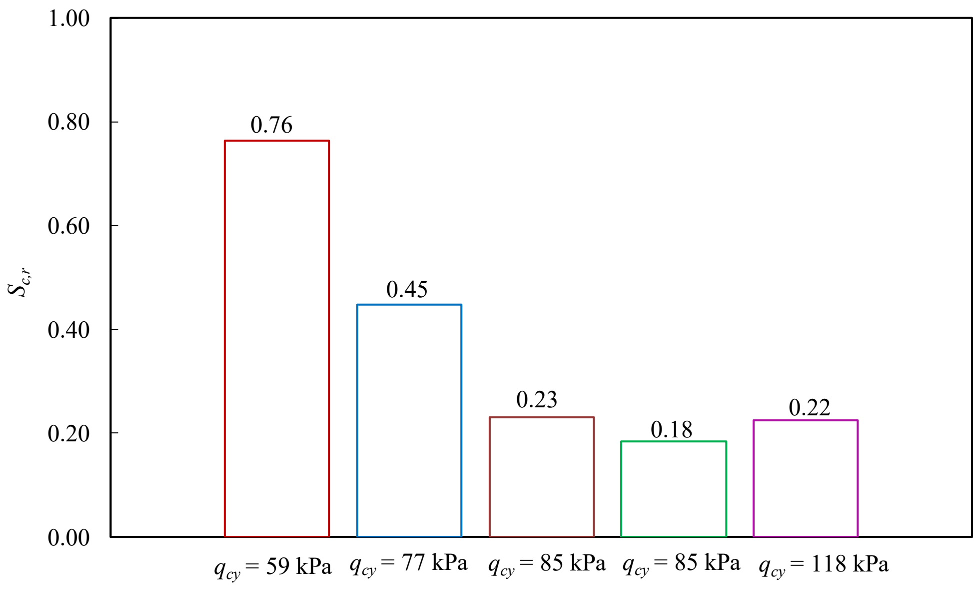
(a)



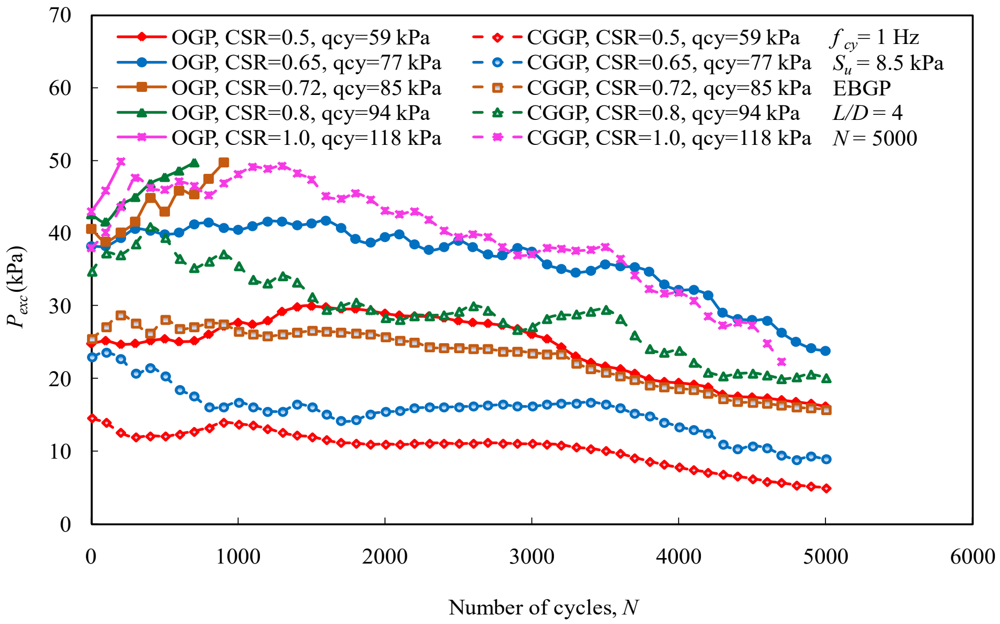
(b)


60
50
40
30
20
10
0
Settlement, S_c (mm)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Number of cycles, N
f_{cy} = 1 Hz
S_u = 8.5 kPa
EBGP
L/D = 4
N = 5000
12,OGP,CSR=0.50,qcy=59 kPa
12,CGGP,CSR=0.50,qcy=59 kPa
12,OGP,CSR=0.65,qcy=77 kPa
12,CGGP,CSR=0.65,qcy=77 kPa
12,OGP,CSR=0.72,qcy=85 kPa
12,CGGP,CSR=0.72,qcy=85 kPa
12,OGP,CSR=0.80,qcy=94 kPa
12,CGGP,CSR=0.80,qcy=94 kPa
12,OGP,CSR=1.0,qcy=118 kPa
12,CGGP,CSR=1.0,qcy=118 kPa

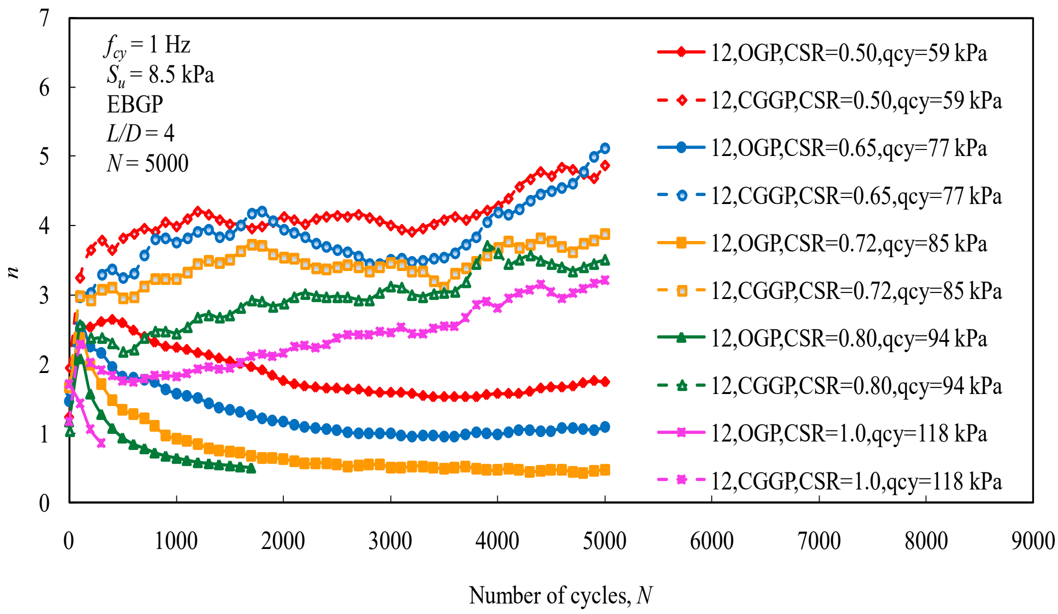
(c)


1.00
0.80
0.60
0.40
0.20
0.00
$S_{c,r}$
0.76
0.45
0.23
0.18
0.22
q_{cy} = 59 kPa
q_{cy} = 77 kPa
q_{cy} = 85 kPa
q_{cy} = 85 kPa
q_{cy} = 118 kPa

(d)



(e)



(f)

Fig. 6.5 Performance of GP under different cyclic loading amplitudes (q_{cy}); (a-c) S_c versus N curve, (d) The settlement reduction ratio ($S_{c,r}$), (e) P_{exc} versus N curve, and (f) n versus N curve.

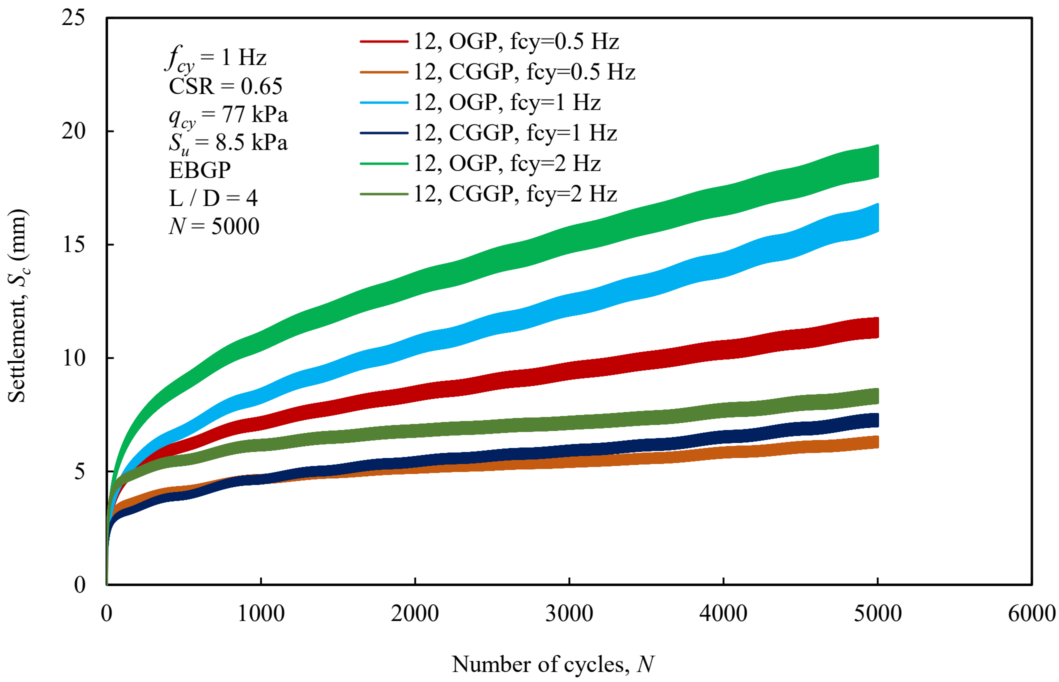
6.2.3 Performance of group of granular piles under different cyclic loading frequencies (f_{cy})

The behavior of granular piles under cyclic loading frequency remains a subject of discussion, as explored in Chapter 5. This section discusses the performance of soft soil improved with a group of 12 granular piles, both with and without combi-grid encasement, under different cyclic loading frequencies (f_{cy}), using the results from test series E in Table 6.2. This study considered three loading frequencies: 0.5, 1.0, and 2.0 Hz, corresponding to train speeds of 50, 90, and 180 km/h, respectively. In all cases, the cyclic loading amplitude (q_{cy}) is considered to be 77 kPa.

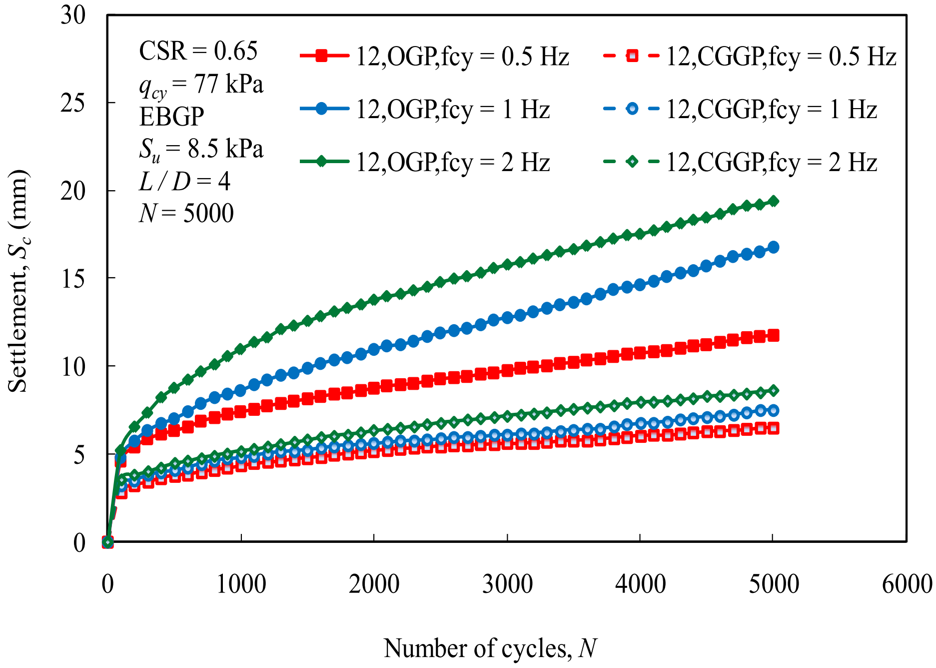
Fig. 6.6(a-b) explains the effects of cyclic loading frequency on a group of granular piles in terms of cyclic-induced settlements (S_c) and settlement reduction ratio ($S_{c,r}$). The S_c values for OGPs are 11.75 mm, 16.78 mm, and 19.36 mm, and for CGGPs, are 6.53 mm, 7.52 mm, and 8.62 mm, corresponding to f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively. The benefit of combi-grid encasement is explained in terms of $S_{c,r}$ in Fig. 6.6(b). The $S_{c,r}$ values are 0.55, 0.44, and 0.44 for f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively. The combi-grid encasement reduced the settlement of the granular pile by about 45%, 56%, and 56% compared to OGPs for f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively, indicating that combi-grid encasement is very effective at f_{cy} values of 1 Hz and 2 Hz.

Fig. 6.6(c) shows the effect of cyclic loading frequency on the variation of P_{exc} for both OGPs and CGGPs. The peak P_{exc} values for OGPs are 35.71 kPa, 41.73 kPa, and 47.04 kPa, and for CGGPs are 17.48 kPa, 23.60 kPa, and 28.96 kPa, corresponding to f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively. In both cases, the buildup of P_{exc} rises with increasing f_{cy}, similar to q_{cy}. The percentage reduction in P_{exc} values is 51%, 43.4%, and 38.4% for f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively, with the provision of the combi-grid encasement. This highlights that the percentage reduction in P_{exc} decreases with increasing f_{cy}, similar to q_{cy}. Similar results were reported by (Yoo and Abbas 2019) for different cyclic loading frequencies.

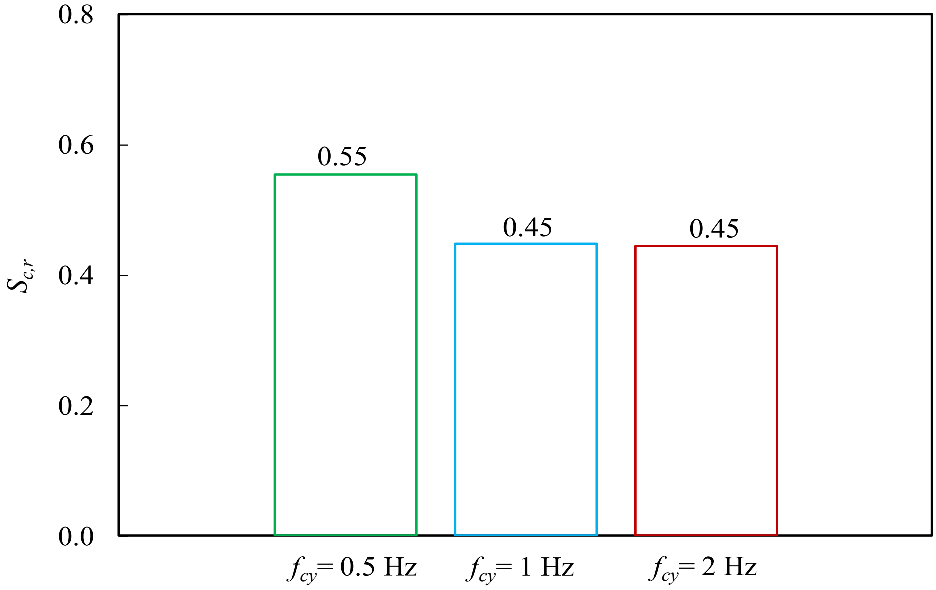
Fig. 6.6(d) illustrates the effect of cyclic loading frequency on the variation of n for both OGPs and CGGPs cases. The pattern of n curves observed for both OGP and CGGP cases at different cyclic loading frequencies is similar to that of q_{cy} cases. The peak n values for OGPs are 2.86, 2.52, and 2.39, and for CGGPs are 6.48, 5.12, and 3.18, corresponding to f_{cy} values of 0.5 Hz, 1 Hz, and 2 Hz, respectively. These results demonstrate that OGPs experience lower stress concentration ratios than CGGPs. Additionally, both OGPs and CGGPs experience higher stress concentration ratios at lower frequencies than higher ones. This suggests that as the loading frequency increases, it decreases stresses on granular piles while increasing stresses on surrounding soft soil. Similar results were reported by (Yoo and Abbas 2019; Zhang et al. 2020) for different cyclic loading frequencies.



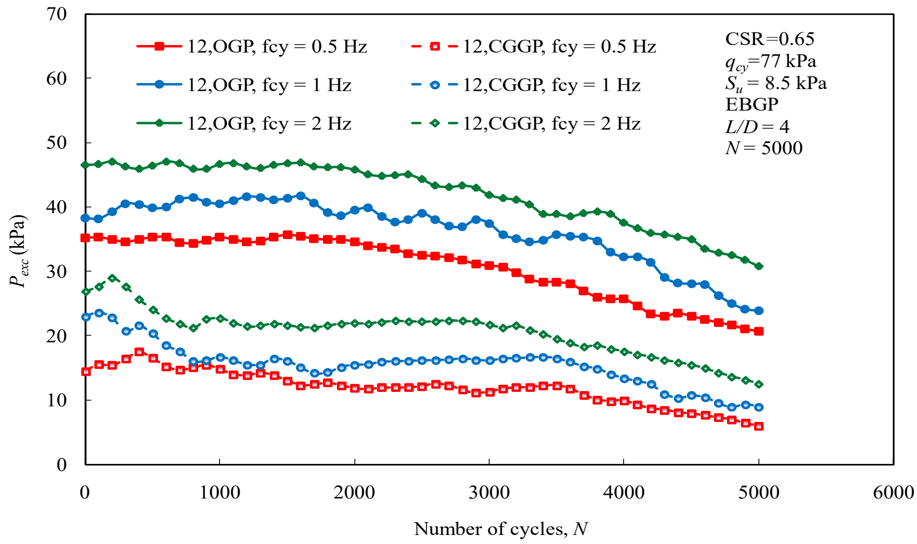
(a)


CSR = 0.65
q_{cy} = 77 kPa
EBGP
S_u = 8.5 kPa
L / D = 4
N = 5000
12,OGP,fcy = 0.5 Hz
12,OGP,fcy = 1 Hz
12,OGP,fcy = 2 Hz
12,CGGP,fcy = 0.5 Hz
12,CGGP,fcy = 1 Hz
12,CGGP,fcy = 2 Hz
Settlement, S_c (mm)
Number of cycles, N
0
5
10
15
20
25
30
0
1000
2000
3000
4000
5000
6000

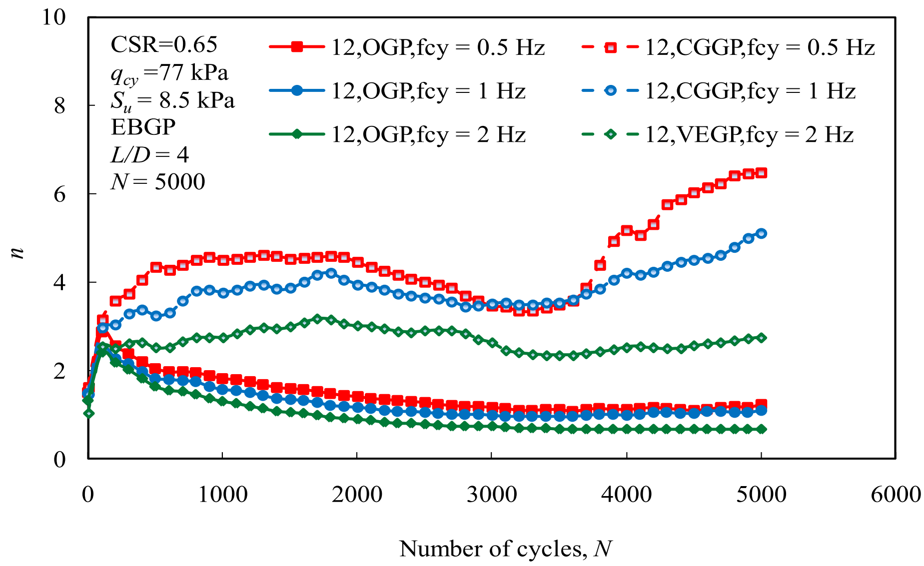
(b)


$S_{c,r}$
0.0
0.2
0.4
0.6
0.8
0.55
0.45
0.45
f_{cy}= 0.5 Hz
f_{cy}= 1 Hz
f_{cy}= 2 Hz

(c)



(d)



(e)

Fig. 6.6 Performance of GP under different cyclic loading frequencies (f_{cy}); (a-b) S_c versus N curve, (b) The settlement reduction ratio ($S_{c,r}$), (c) P_{exc} versus N curve, (d) n versus N curve.

The findings presented in the results and discussion section underscore a significant correlation between key performance indicators, including cyclic induced settlement, excess pore water pressure, and load sharing between granular pile and surrounding soft soil, on the cyclic loading parameters, such as cyclic loading amplitude (q_{cy}) as well as the cyclic loading frequency (f_{cy}). Hence, it is essential to integrate these cyclic loading parameters when designing granular piles for static and cyclic loading conditions.

6.3 Summary

This chapter presents the results obtained from laboratory model tests on a group of granular piles in a soft soil bed under static and cyclic loading using a mixture of (25% TC + 75% AG) and the interpretations of the results. The principle variables include encasement materials such as geotextile (GT), geogrid (GG), and combi-grid (CG), as well as cyclic loading amplitudes (q_{cy}) and frequency (f_{cy}). Results showed that under static loading, ordinary granular piles (OGPs) increased the ultimate load intensity by 58%, while combi-grid (CG) encasement achieved a remarkable 335% enhancement.CG encasements reduced settlements by 56% for cyclic loading, outperforming geotextile (34%) and geogrid (43%). OGPs were effective at lower cyclic amplitudes (CSR ≤ 0.65), while CG was superior at higher amplitudes. CG encasements also minimized cyclic-induced settlements and increased loading capacities across all frequencies.

Additionally, OGPs exhibited nearly double the excess pore water pressure (P_{exc}) compared to CGGPs, regardless of cyclic factors, similar to single granular piles. Both OGPs and CGGPs displayed higher stress concentration ratios at lower cyclic amplitudes and frequencies. Overall, combi-grid encasement proved to be the most efficient in enhancing load-bearing capacity and reducing settlements under both static and cyclic conditions.