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Performance of Geogrid Reinforced Sand Layer overlaying Encased Stone Peirs for Founding on Soft Clay Deposits

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ABSTRACT

Reinforcing deep soft clay layers with rammed aggregate piers is one of the most effective and economical techniques. However, the un-replaced soft clay area weakens the reinforced system and results in a relatively large amount of differential settlement. The present numerical investigation aims at examining the usefulness of reinforcing the fill layer overlaying the piers with Geogrid sheets. The soil –pier - Geogrid interaction is investigated by considering the following factors: Geogrid tensile stiffness, pier spacing, pier–soil stiffness ratio and preloading deformation of Geogrid reinforcement layer. Geogrid reinforcement of fill layer above piers significantly improved the carrying capacity of the system and reduced maximum and differential settlement, soil arching and stress concentration. Pier-soil stiffness ratio of relatively high range has little effect on the performance of the system. When the footing is placed over the pier Geogrid reinforcement does not have an influence on reinforced system. Forming a dish shaped Geogrid sheet between piers effectively improved system performance.

Keywords : Numerical analysis, Earth reinforcement, Geopiers, Soft soil, Stress Concentration.

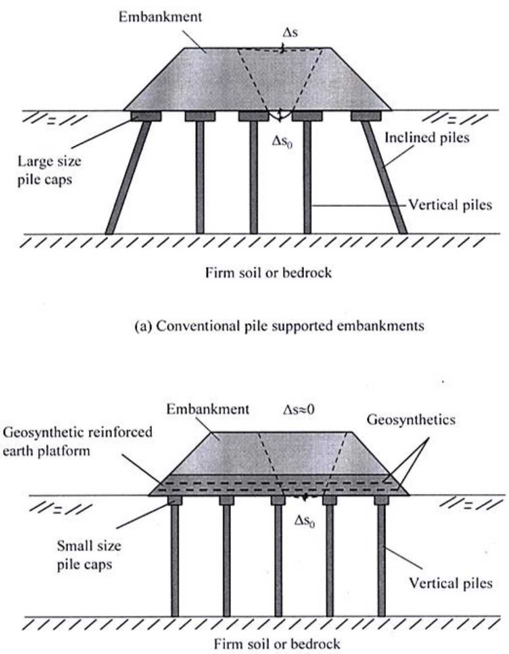
I. INTRODUCTION

Soft clay regions are widely present all over the world and commonly of a deep height, so difficult to be totally replaced. Hence, partial replacement by highly compacted aggregate piers (termed Geopiers) is one of the most effective and economical solutions. However, the remaining unreplaced soft soil zones will still affect the overall caring capacity of the foundation soil matrix as the shear planes will experience weak shearing resistance through the unreinforced zones passing through the soft soil. Relatively high values of total and differential settlement between the stiff Geopiers and the soft soil regions may be also of the main short comings of this technique. These two short comings of the reinforcing technique are mainly due to relatively high stiffness difference between the soft soil and the Geopiers or more commonly the piles, Pham et al., [1] and the lack of efficiency of soil arching phenomenon of over laying backfill and surcharge or foundation loading onto the stiff Geopiers, Han and Gabr [2].

Conventional methods used for overcoming these problems include: closely spaced piles, large pile caps and stiff raft foundation, Han and Akins [3]. However, the previously stated technique will in general affect the economical consideration of the reinforcing technique.

One of the alternative solutions that have been gaining confidence during the last two decades is the usage of Geosynthetic reinforced and pile supported earth platform (GRPS) to enhance bridging of soft soil regions to stiff piers or piles, Lin and Wong [4], Alzamora [5]. Fig. (1) as presented by Han and Akins [3] illustrates a comparison between the conventional pile supported embankments and Geosynthetic reinforced platform over pile supported embankments. This figure illustrates that the reinforced platform allows using less closely spaced piles as the platform resists the differential movement of yielding soil mass between piles and the stiff standing piles. The figure also illustrates that there will be no need for inclined piles under the slope of embankment as the reinforced platform layer resists the tendency of horizontal spreading of the embankment slope.

However, the available literature investigates the usage of this technique for enhancing the performance of embankments founded on soft clay deposits. This directed the attention to investigate the usage of this technique to support shallow foundations on a Geopier



(a) Conventional pile supported embankments

(b) Geosynthetic reinforced and pile supported embankments

Fig. (1) Comparison Between The Conventional Pile Supported and Geosynthetic Reinforced Platform Embankments, [3].

reinforced soft clay deposit. Due to the complicity of the load transfer mechanism a numerical study was conducted to investigate the effect of spacing of piers, stiffness ratio of pier and surrounding soil, tensile stiffness of Geogrid, through observing their effect on: ultimate bearing capacity to the footing load, total and differential settlement, stress concentration between piers and soft soil, soil arching and straining actions in Geogrid sheets.

A. Mechanism of Load Transfer

Load transfer from shallow foundations resting on Geopier reinforced soft clay deposit covered by Geosynthetic reinforced platform may depend on the followings as reported by Han and Wagne, [4].

B. Soil Arching Effect:

Terzaghi [6] defined the soil arching effect as the relief of pressure on the soil portion undergoing settlement while being concentrated on the stationary soil mass adjoining the yielding mass. Terzaghi presented an illustrative example for soil arching when he mentioned that the pressure on a trap door decrease when the door is lowered slightly while increasing on adjoining soil mass. In the (GRPS) system the fill soil overlaying the platform, when loaded by the foundation pressure, tends to settle between the piers as it rests on soft clay. The relative movement between this yielding soil mass and the stationary soil mass above the piers results in development of shear stresses between the two soil masses which results in redistribution of stresses and resistance to settlement of yielding mass. McNulty, [7] presented the following equation for soil arching ratio:

$$\delta = \frac{Pb}{\gamma H + q_o} \qquad (1)$$

Where:

δ = soil arching ratio, = (0.0 or 1.0) for complete and no soil arching, respectively.

γ = unit weight of fill soil.

H= height of fill soil

q_o = additional surcharge or foundation pressure applied at the surface of fill soil.

Pb = applied pressure on the top of trap door of McNulty study (Geosynthetic in this study).

C. Effect of Geosynthetic reinforced platform:

When deformation occurs to the reinforced platform it acts as a plate or a membrane, the Geosynthetic sheet is dished down between piers and as a result of the vertical component of the tensile force stresses are concentrated on piers resulting in an enhancement of the system performance. The tensile force in the Geosynthetic sheet is generated due to the vertical deformation of the sheet. The tensioned sheet serves to reduce the differential settlement between soil and piers, Pham et al. [1] and Collin et al., [8]. Debnath and Kante [9] conducted an experimental and numerical study on the effect of reinforced platform on enhancement of bearing capacity of a circular footing and reported 8.5 times increase compared to unreinforced case.

D. Stress concentration:

The relatively high ratio of stiffness between the stiff piers and the surrounding soft soil results in stress concentration on the piers, [1], [2] and [4]. Stress concentration ratio (S_c) may be defined as the ratio between stress on piers (σ_p) and stress on soil (σ_s)

Modes of Failure of GRPS

Collin et al. [8] presented a schematic representation shown in Fig. (2) of different modes of failure involving limit and serviceability state of failure modes.

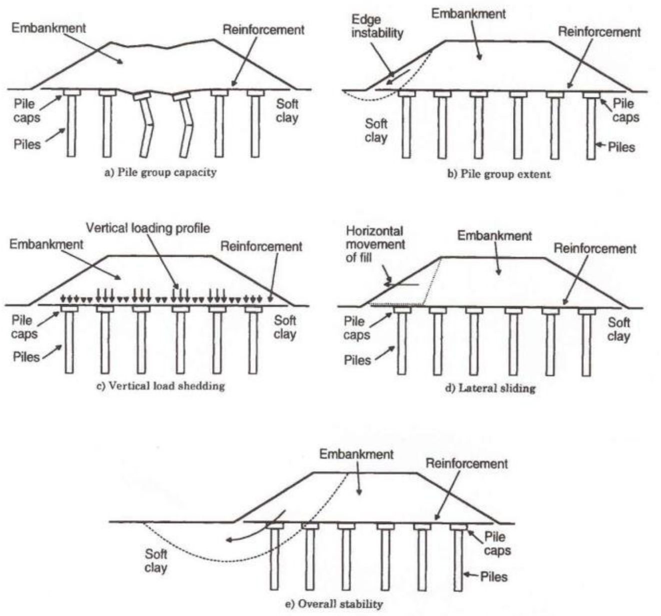


Fig.(2-I) Limit State Failure Modes, [8]

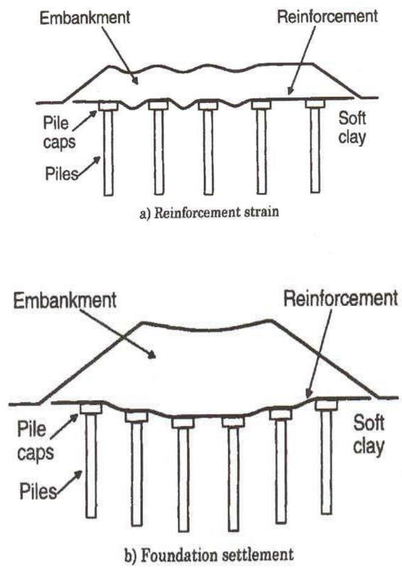


Fig.(2-II) Serviceability State Failure Modes, [8]

II. MODEL GEOMETRY

The Numerical analysis was Carried out using PLAXIS (Version 8) Finite Element Code. Fig (3-a) shows an example of the 2D plane-Strain model used to model the Geogrid reinforced and Geopiers Supported Platform (GRPS), the first Geogrid layer was positioned 10cm above the top of piers and with inbetween spacing of 30cm. The three layers were placed in a so called soil blanket of highly compacted granular soil. This soil blanket was positioned over the Geopier elements (with diameter d = 1.0m) and foundation matrix Soil. The soil blanket was over laid by a fill layer 40cm in thickness of a compacted granular Soil. The modeled strip footing (with a breadth b = 1.0 m) was positioned on the surface of the fill soil. The top 4.0m of Geopier elements was shellded with a Geogrid shell of tensile stiffness of 1200 kN/m which is a technique believed to enhance the carrying capacity of the Geopier as reported by El- Tuhami, [9]. Fig.(3-b)shows the model for the case of dished bottom Geogrid sheet.

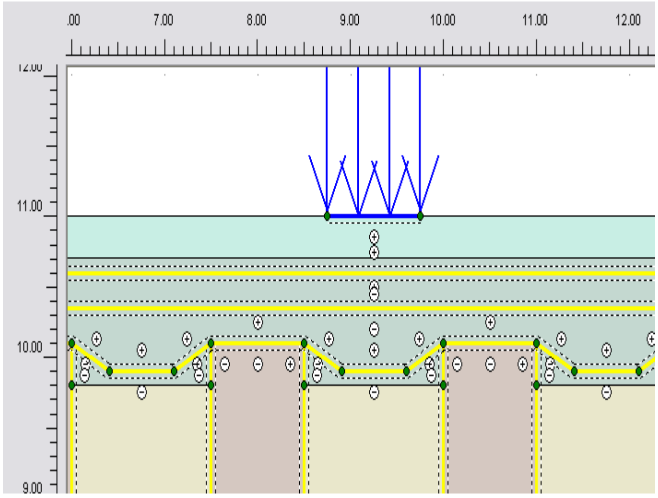


Fig.(3-b) Finite Element Model of Dished Geogrid Bottom Sheet.

III. INPUT PARAMETERS AND ANALYSIS PROGRAM

Eight Materials were used in the finite element model including soft soil, Geopier rammed aggregates, and Geopier shellded rammed aggregates, soil blanket, Geogrid reinforcement, fill Layer, and the footing. The footing was modeled as a beam element. The Geogrid was modeled as a Geotextile structural element, which carries only tensile forces, the remaining materials were modeled using Mohr-Coulomb constitutive parameters. Different input Parameters are illustrated in Table I.

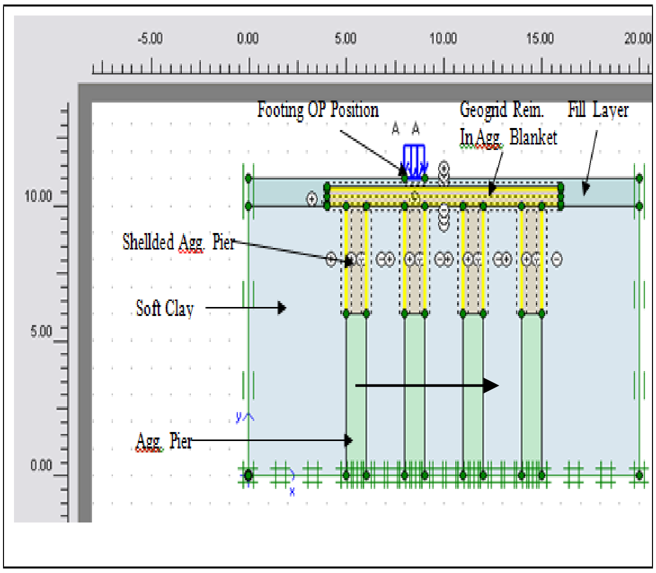


Fig.(3-a) Finite Element Model of Straight Geogrid Sheets.

TABLE I

Finite Element Input Parameter Values

Property	Soft Clay	Geopier Rammed Aggr.	Shellded Geopier Rammed Aggr.
Elastic Modulus E (KN/ m²)	1400	1400*m	1400*n
Poisson's Ratio	0.35	0.4	0.3
Friction Angle Φ	5	48	53
Cohesion C (kN/m²)	25	0	0

Cont. TABLE I

Property	Aggr Blanket	Geo grid Rein.	Fill	Footing
Elastic Modulus E (KN/ m²)	95000	-----	50000	----
Poisson's Ratio	0.4	-----	0.4	-----
Friction Angle Φ	48	-----	42	-----

Cohesion C (kN/m²)	0	-----	0	-----
EA (kN/m)		1200		5000000
EI (kN.m²/m)				8500

Where m= (n / 1.15)

According to Pham et al. [1] an equivalent Geopier modulus values derived from the true values were used because of the 2 D- Plane Strain model:

$$Egeq = \frac{EgAg + EsAs}{At} = Eg\left[\frac{\pi D}{4S}\left(1 - \frac{1}{n}\right) + \frac{1}{n}\right] \quad (2)$$

Where:

Egeq = the equivalent Geopier Modulus.

Eg = true Geopier Modulus Es= foundation matrix soil modulus

A_g, A_s and A_t= Geopier, soil and over all areas, respectively.

The Geogrid- soil interface was modeled using an interaction coefficient, Ri= 1.0. Table II illustrates the analysis program adopted in this research.

TABLE II
Analysis Program

Code	Footing Position	Spacing s (m)	Modouls Ratio (n) Geopier/ Soil
geo 300 geo 600 geo 1200 geo 2400	On Pier(OP)/ Between Piers(BP)	3d*	150
n 125 n 100 n75 n 50	On Pier/ Between Piers	3d	125 100 75 50
s 2 s 2.25 s 2.5	On Pier/ Between Piers	2 2.25 2.25	150
s 2.75		2.27d	
Dgeo	On Pier/ Between Piers	2.5d	150
no geo	On Pier/ Between Piers	2.5d	150

Cont. Table II

Code	Tensile Stiffness EA (kN / m)	Remarks
geo 300 geo 600 geo 1200 geo 2400	300 600 1200 2400	Straight /Dished Geogrid
n 125 n 100 n75 n 50	600	Straight /Dished Geogrid
s 2 s 2.25 s 2.5 s 2.75	600	
Dgeo	600	
nogeo	600	Without Geogrid Reinf. of Soil blanket

*d= 1.0 m

In the case coded Dgeo the first Geogrid sheet is laid directly on the top of piers and a dish shaped layer is formed.

IV. RESULTS AND DISCUSSION

Geogrid Tensile Stiffness (GTS)

For footing position above pier (which will be abbreviated as OP) Fig. (4) illustrates ultimate bearing capacity for different (GTS) for the cases of straight and dished Geogrid. As can be seen from this figure the Geogrid blanket reinforcement improves q_{ult} by a ratio of 173% for different (GTS) values compared to the unreinforced case. The improvement ratio reaches a value of 176% for dished Geogrid case. This reflects that (GTS) has no effect on q_{ult} for the (OP) case for both cases of straight Geogrid for different pier spacing and dished Geogrid with pier spacing of 2.5d. q_{ult} improvement ratio for the case of footing between piers (BP) as shown in Fig.(5) reaches values of 117,108 and 136% for (GTS) of 300 kN/m for pier spacing of 2, 2.5 and 3d, respectively. Improvement ratios reach values of 137.117 and 152% at higher tensile Stiffness of 600 kN/m and then remain nearly constant with further increase in (GTS).

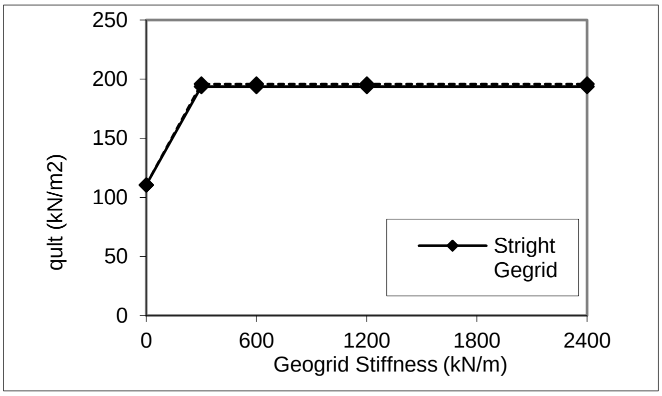


Fig.(4) Ultimate bearing capacity vs. geogrid tensile stiffness for footing on pier.

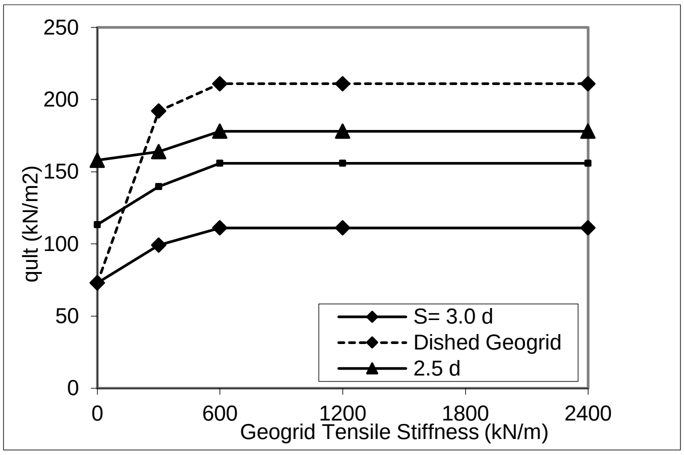


Fig.(5) Ultimate bearing capacity vs. geogrid tensile stiffness for footing between pier.

Improvement ratios are relatively low for the case of S= 2d compared to other cases due to relatively high soil arching for this case without reinforcement. Improvement ratio is considerably increased for the case of s= 3d due to reduction of soil arching effect with longer pier spacing. Smallest improvement ratio values have been recorded with the case of S = 2.5 d compared to the other two pier spacing as being an optimum pier spacing that results in heights soil arching effects as will be illustrated later. As for the dished Geogrid case with S = 2.5d the improvement ratios reach values of 163 and 189 % for (GTS) of 300 and 600 kN/m, respectively and remains nearly constant with higher (GTS). It can be concluded that it is adequate to reinforce the soil blanket by Geogrid sheets of intermediate stiffness. The pier spacing of 2.5 d has proved to be an optimum spacing resulting in relatively high soil arching in the unreinforced case. It can be also concluded that dishing the Geogrid layer between piers significantly improves the carrying capacity of the (GRPS) compared to the straight Geogrid sheet. As can be seen from Fig. (6) maximum settlement (Smax) is reduced as the (GTS) increases for the (OP) case. The reduction ratios for (GTS= 600 kN/m) reach 37 and 49% compared to unreinforced case for the at ground and at pier surfaces, respectively. Smax at ground surface is higher than at pier surface with a similar trend as (GTS) increases. Dishing of Geogrid sheet did not cause a variation of Smax. compared to straight Geogrid sheet. Changing of piers spacing did not also result in a change of Smax. This is due to the majority of stresses reaching the pier surface is transferred to the pier itself as the footprint of the footing is positioned on the pier. As shown in Fig.(7) for the (BP) case a similar trend has been observed for different (GTS) but with higher difference of Smax between the (at ground surface)and (the at the pier surface) cases without reinforcement and with the case of relatively low tensile stiffness of 300 kN/m.

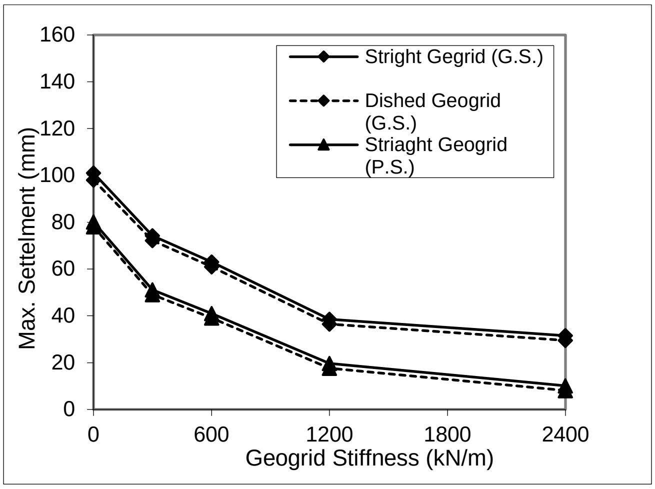


Fig.(6) Maximum settlement vs. geogrid tensile stiffness for footing above pier

The reduction ratios for (GTS=600 kN/m) reach 61 and 29 % compared to unreinforced case for the at ground and at pier surfaces. The higher reduction ratio recorded at ground surface compared to the (OP) case is due to higher settlement of Geogrid sheets between piers the matter that results in a higher efficiency of Geogrid reinforcement. On other, hand the lower reduction ratio ratio recorded at pier surface is due to the existence of soft clay surface at this level with its high compressibility potential.

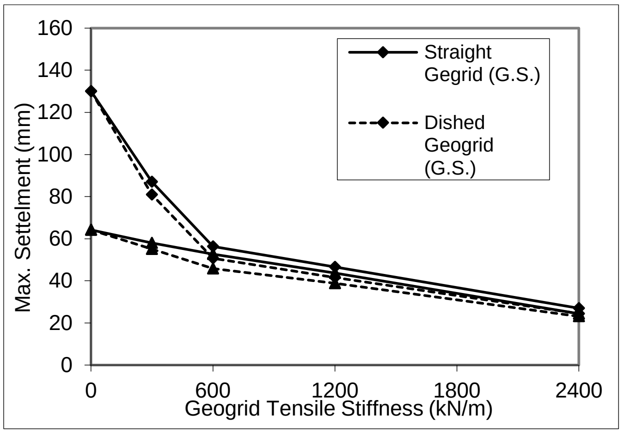


Fig.(7) Max. Settlement vs. Geogrid Tensile Stiffness for Footing between Pier

This difference is significantly reduced at higher tensile stiffness of 600 kN/m. Han and Gabr, [2] observed a similar relation between tensile stiffness and maximum settlement but their study covered a wider range of (GTS) up to 8500 kN/m, however their study indicated that increasing the (GTS) above 4000 kN/m does not produce further reduction in maximum settlement. As can be seen from Fig.(8) increasing (GTS) has no effect on differential settlement (ΔS) for the (OP) case for at the ground and at pier surfaces. This applies also for the case of dished Geogrid , which had no effect in reducing (ΔS) as compared to the straight Geogrid case. On the other hand, for the (BP) position as shown in Fig (9), increasing (GTS) effectively reduces (ΔS) for both the at ground and the at pier surface .Higher efficiency of Geogrid reinforcement has been observed with dished Geogrid case and the corresponding reduction ratios reached 75 and 86 %, respectively. For the case of (OP), (GTS) had no effect on (Smax) and (ΔS) for different pier spacing of 2, 2.5, 3d this applies also the case of (BP) for (GTS)>1200 kN/m. Curves representing such cases will not be presented in this report. A similar trend of the influence of (GTS) on (Smax) and (ΔS) has been reported by Han and Gabr, [2]. However, Pham , et al. , [1] reported that (GTS) had no effect on (ΔS) , this may be due to that in their study, a constant value has been assigned to pier elastic modules (Eg = 100000 kN/m) with different elastic module of soil (Es) according to a ratio n= 5, 10, 20, 40, 80. This resulted in surrounding soil of relatively high modules of elasticity compared to constant value adopted in this research of 1000kN/m^2 and the corresponding elastic modulus of pier according to n= 50, 75, 100, 125, 150.

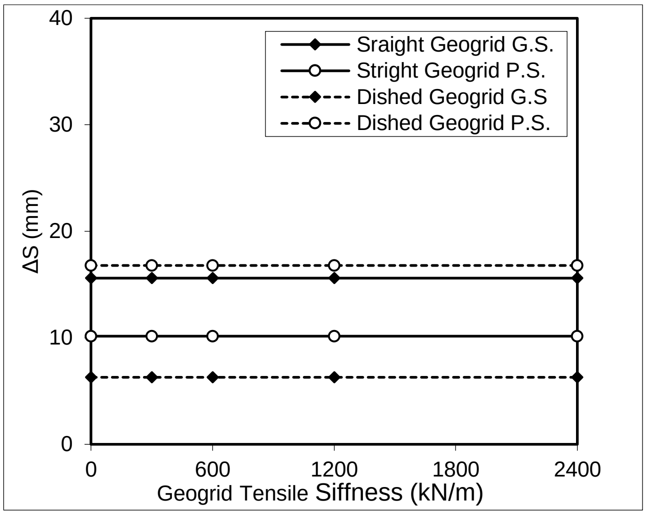


Fig. (8) Differential settlement vs. tensile stiffness of geogrid for footing above Pier.

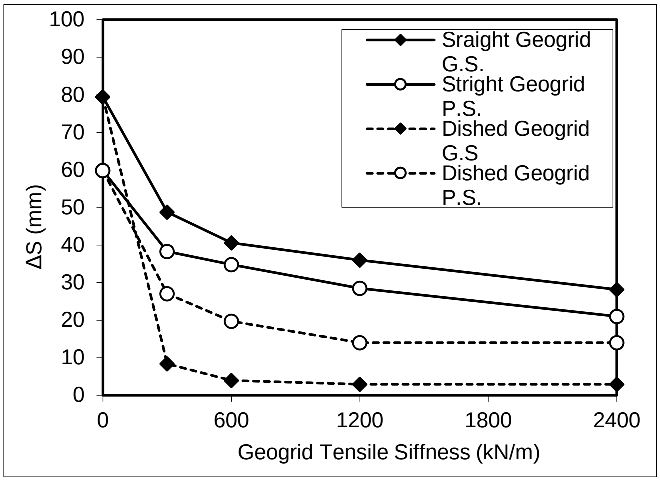


Fig.(9) Differential Settlement vs. Tensile Stiffness of Geogrid for Footing in between Piers.

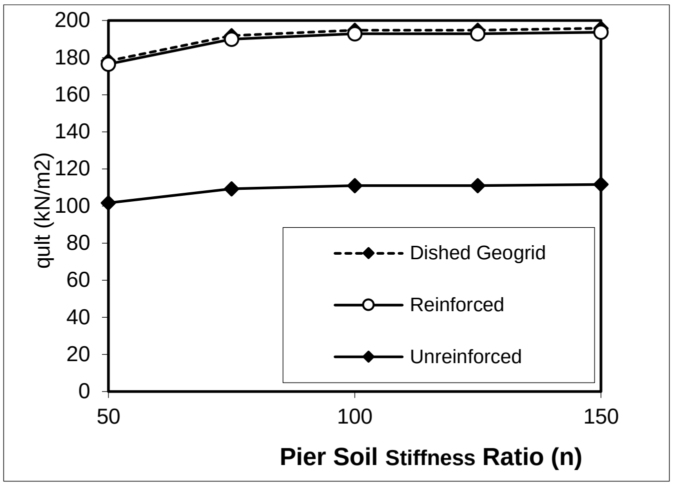


Fig.(10) Ultimate Bearing Capacity vs. Pier- Soil Modulus Ratio for Footing above Piers.

Soil Pier Stiffness Ratio (n)

Fig. (10) illustrates the relation between (q_{ult}) and pier soil stiffness ratio for the case of (OP). From this figure it can be noticed that for relatively high range of n (150-100) stiffness ratio does not have a significant effect on (q_{ult}) for each of unreinforced and dished Geogrid. However, at relatively low (n) value of 50 about 9% reduction in (q_{ult}) has been recorded compared to (n)=150 which is relatively small reduction ratio. Changing the pier spacing did not have an effect on the previously mentioned trend of the relation between (q_{ult}) and (n). This general trend has been also recorded with the case of (BP but with significant effect of pier spacing of 2.5d as can be seen in Fig.(11). High efficiency of (n) can be also observed for this case. An enhancement ratio of (q_{ult}) for pier spacing of 2.5d reaches a value of 15% compared to straight Geogrid.

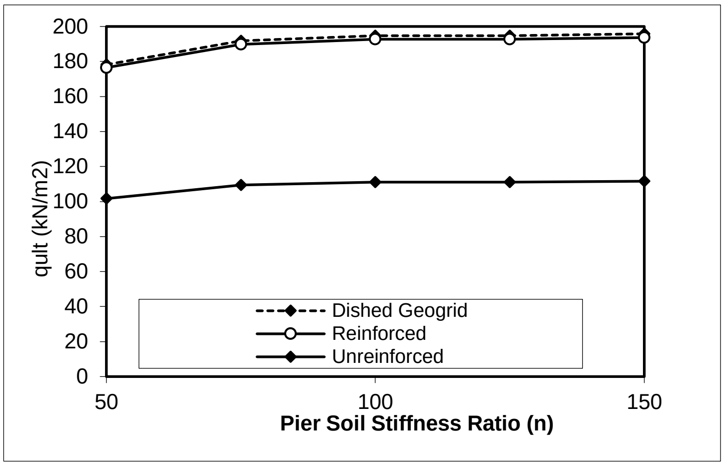


Fig.(11) Ultimate Bearing Capacity vs. Pier- Soil Modulus Ratio For Footing Between Piers.

Fig. (12) illustrates the relation of (Smax) and (n), as can be noticed an increase in stiffness ratio (n) results in a considerable reduction of (Smax) for the case of (OP). This is due to higher concentration of stresses on the relatively stiff piers. This applies to the at ground and at pier surface cases and to different pile spacing (s). Using a dished Geogrid sheet did not result in a change in (Smax). A similar trend has been also observed for the case of (BP) except that the (Smax) recorded with the dished Geogrid case was recorded to be 30% larger than the straight Geogrid sheet , see Fig (13).

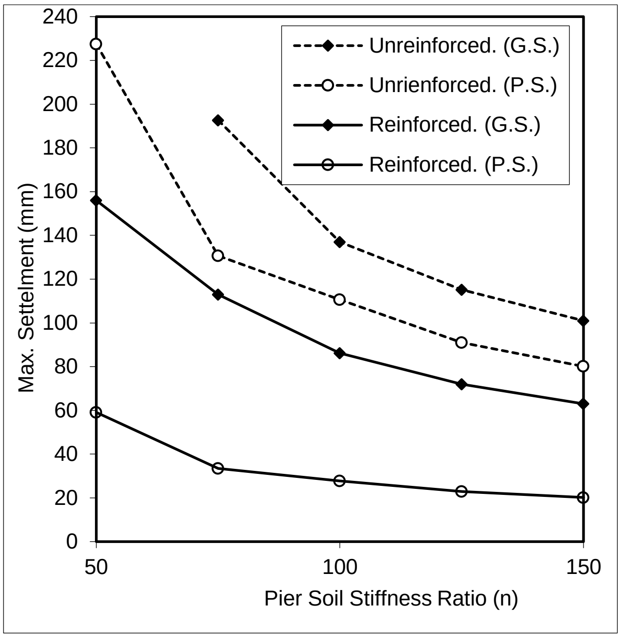


Fig.(12) Maximum Settlement vs. Pier Soil Modulus Ratio for Footing above Piers.

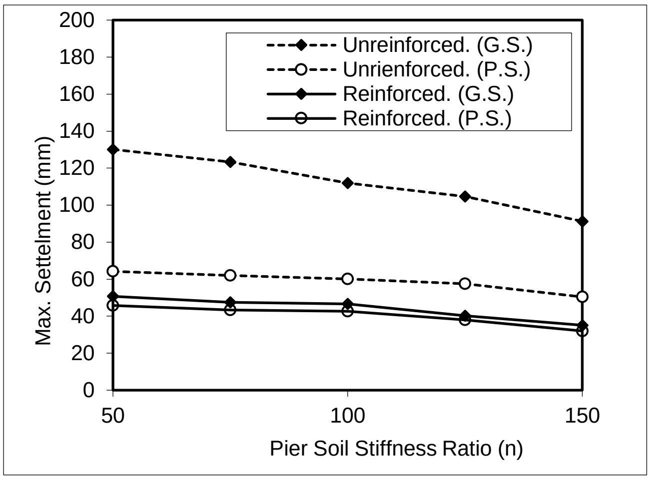


Fig.(13) Maximum Settlement vs. Pier Soil Modulus Ratio for Footing Between Piers.

Pier Spacing (s)

As can be observed from Fig.(14) pier spacing (s) has no effect on (q_{ult}) for unreinforced and reinforced cases. A slight enhancement in (q_{ult}) has been recorded with the dished Geogrid case. The case of (n)=150 is the presented case .The same trend applies to the different values of (n). As for the case of (BP) presented in Fig.(15), (q_{ult}) increases with the increase of pier spacing up to the optimum spacing of 2.5d and then reduces with further increase in pier spacing. This applies to unreinforced, reinforced and dished cases. The enhancement ratios recorded for s=2.5d were79 and 111% for straight and dished Geogrid, respectively.

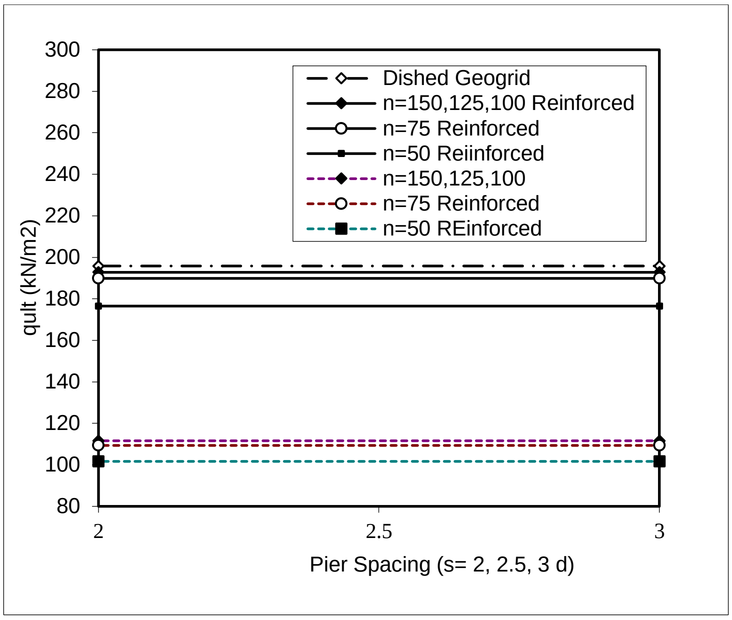


Fig.(14) Ultimate Bearing Capacity vs. Pier Spacing for Footing Above Piers.

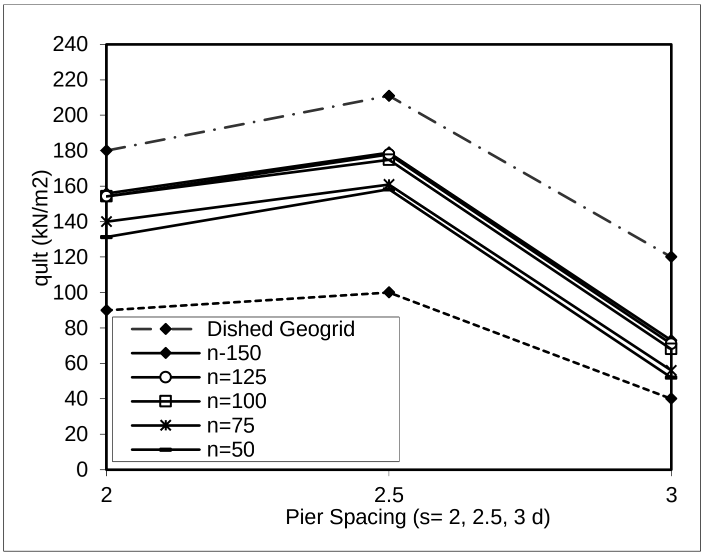


Fig.(15) Ultimate Bearing Capacity vs. Pier Spacing for Footing Between Piers.

Tension in Geogrid (Fgeo)

As can be seen from Fig. (16) for the (OP) case relatively small tension forces have been developed in the bottom, middle, and top layers. Increasing (GTS) appears to have no effect on tension force in Geogrid. Using a dished Geogrid resulted in increasing the tension force by 244% compared to the straight Geogrid case. Changing the pier spacing had no effect on tension force for his footing position of the (OP) case. For the case of (BP), Fig. (17) illustrates the relation between (Fgeo) and (GTS) for the case of pier spacing s = 3.0d. As can be noticed (Fgeo) increases from top to bottom Geogrid layers. A significant increase in (Fgeo) reaching about 200% can be observed when doubling (GTS) from 300 to 600 kN/m for the three layers. Further increase of (GTS) beyond 1200 kN/m does not result in a further increase of (Fgeo).

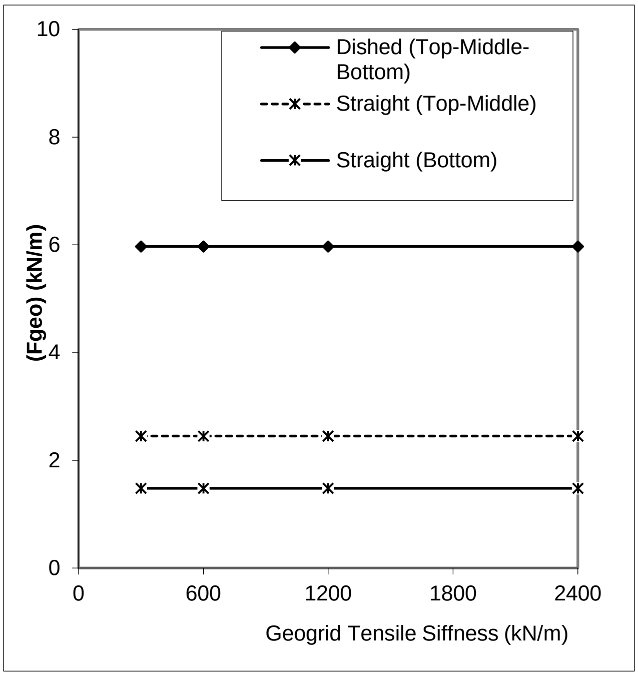


Fig.(16) Tensile Force (Fgeo) vs. Tensile Stiffness (GTS) for Footing above Pier.

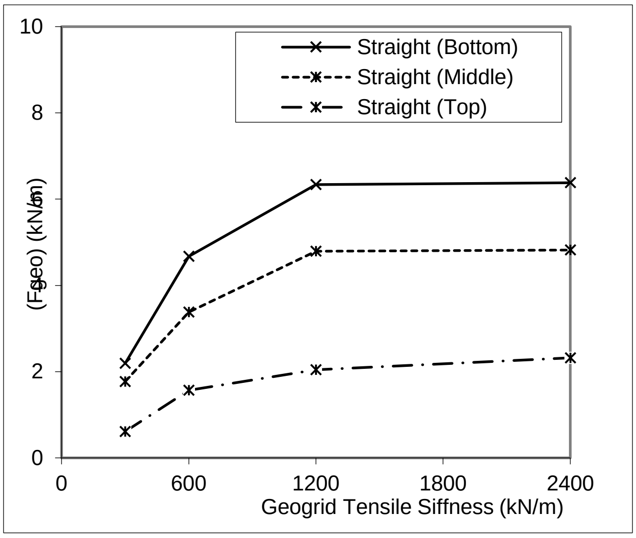


Fig.(17) Tensile Force (Fgeo) vs. Tensile Stiffness (GTS) for Footing between Pier (s= 3d)

Figure (18) Illustrates the same relation for the case of s = 2.5d for both straight and dished Geogrid sheet. Using dished Geogrid sheet results in increasing (Fgeo) at (GTS) of 600 kN/m by 164, 157 and 195 % for top, middle and bottom layers, respectively. For this pier spacing increasing (GTS) significantly increases (Fgeo) for the top and middle layers .As for the relation between (Fgeo) and stiffness ratio (n), (Fgeo)has been observed to linearly increase with the increase of (n). For a 50% increase of (n), (Fgeo) increased by 11, 13, and 26 % for top, middle, and bottom reinforcement, respectively. A similar relation between (Fgeo) and each of (GTS) and (n) has been also observed as in [1] and [2].

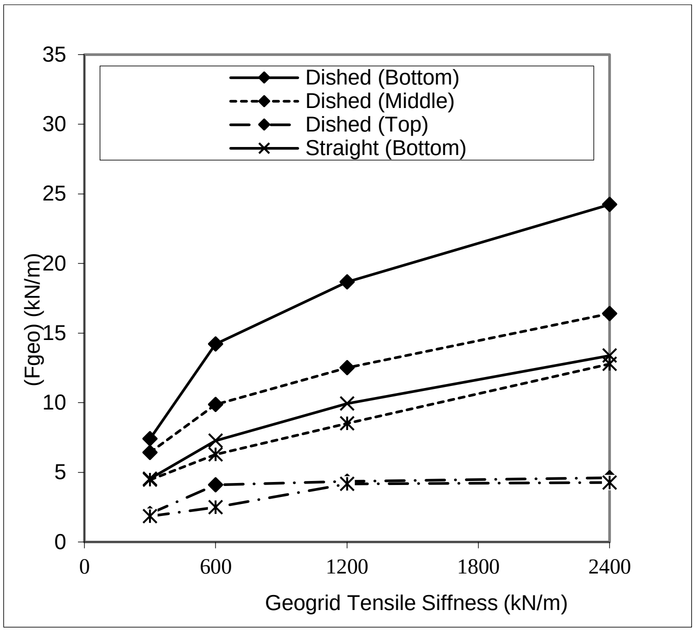


Fig.(18) Tensile Force in Geogrid (Fgeo) vs. Geogrid Tensile Stiffness (GTS) For Footing Between Pier (s=2.5d).

V. CONCLUSION

- Providing Geogrid reinforcement in the range of intermediate tensile stiffness above rammed aggregate piers significantly improves the carrying capacity of the reinforced system, soil arching, stress concentration and reduces maximum and differential settlement.
- Increasing Geopier soil stiffness ratio of relatively

high range has a little effect on improving the Geogrid soil reinforced system.

- In the case of the footing placed above the pier the bearing capacity, maximum settlement, differential settlement and tensile force carried by Geogrid are not affected by top blanket reinforcement.
- The effectiveness of the system (reflected through the tensile force carried by Geogrid) is enhanced by increasing tensile stiffness of Geogrid and pier-soil stiffness ratio.

VI. APPENDIX

A questionnaire is prepared for an academic purpose. The objective of the study is to asses' performance evaluation of three wheeled vehicle (Bajaj) in Hossana town. Your response is very important for the success of the study. Hence you are requested kindly to give your response by selecting or circling your answer among the alternative choice or by describing your opinion. I would like to thank for your cooperation.

A. Questionnaire for passengers

1) Which transport mode do you usually use?
A) Walking B) taxi C) bus D) Bajaj
2) Are you ever over loaded with other passengers?
A) Yes B) no
3) In question no 2, if yes what is the reason behind?
A) Less number of Bajaj in the route B) to reach workplace on time C) Less payment D) no chance to use other transportation system
4) Have you ever fee more than the stipulated amount?
A) Yes B) no
5) If yes in question no 4 what is you reason behind?
A) Cost of fuel increase B) less strict control or less check up by traffic police C) Due to the drivers believe that the payment is not fair
6) The drivers stop the Bajaj where you want?
A) Yes B) No
7) If question no 6 if no what is the reason?
A) Overcrowd of passenger B) punishment of traffic police due to over load C) carelessness of drivers
8) Are you satisfied with the flexibility of Bajaj transportation system?
A) Satisfied B) unsatisfied C) neutral
9) How much time would you waste in Bajaj station?
A) Less than 15 minutes B) 15-20 minutes C) 20-25mints
10) How long would you walk to get Bajaj?
A) 10-15 minutes B) 15-20 minutes C) 20-25 minutes
11) What kind of attitudinal behavior drivers have?
A) Polite B) Dislikable

B. Questionnaire for drivers

1) Do you over load the passengers above the permissible limit?
A) Yes B) No
2) If question No 1 yes what is reason behind?
A) Increased price of fuel B) tariff is not satisfactory C) the route is short
3) Do you work at night time?
A) Yes B) no
4) If question no 3 yes how long do you work at night?
A) Up to 1 o'clock B) up to 2 o'clock C) up to 3 o'clock D) 4 and above E) at night (11- 12PM o'clock)
5) If question no3 yes, what type of payment you take?
A) Normal payment B) contract
6) If also question no 3 yes, do you agree that working at night expose for accident?
A) Agree B) Disagree
7) Is the payment sufficient for the route you work?
A) Yes B) no
8) If question no 8 No, why?
A) The route is not comfortable for drive B) less passenger in the route C) Many numbers of Bajaj in route D) the route is long

9) The quality of road you use for driving is,
   A) Poor quality B) not comfortable for driving C) medium quality
11) What kind of attitudinal behavior drivers have?
   A) Polite B) Dislikable

C. Question to for Hossana town transport bureau

1) How many Bajaj are there in Hossana town (since 2006-2010 E.C)?
2) The history of town Bajaj
3) How many routes are there in Hosanna town?
4) What is the economic importance of Bajaj in Hossana town?
5) Why additional transport system is not permissible in Hossana town?

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