Review on Load–Settlement Behavior of Shallow Foundation on Uncoated and Bitumen-coated Geogrid Reinforced Soil Bed

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ABSTRACT

Owing to the abrupt growth in the development of infrastructure activities, the availability of competent land available for construction diminishes slowly. To consummate the accelerating demand, an approach known as soil reinforcement has evolved. Previously, metallic grid reinforcements were used to strengthen geotechnical constructions; however, the synthetic reinforced soil system is now more commonly adopted as a foundation medium due to its cost-effectiveness and benefits for sustainable development. This paper explores a comparison of the bearing capacities between geogrid reinforced soil beds and unreinforced soil beds for shallow foundations. Through literature review, it investigates how different factors such as the end conditions of geogrid reinforcement, top spacing ratio, width of the geogrid, and number of geogrid layers affect bearing capacity.

Keywords: Bearing capacity, geogrid, reinforcement, sand

1. Introduction

Over the past two decades, the use of Geosynthetic Reinforced Soil (GRS) has increased significantly due to the reduction of available land caused by rapid infrastructural development. Since foundation soil is typically weak in tension, reinforcement techniques can greatly enhance load carrying capacity. Geosynthetics not only add tensile strength to the soil but also perform additional functions such as drainage, filtration, and separation. These man-made materials improve the compression and shear characteristics of soil. Among various soil reinforcement methods, geogrid reinforcement is particularly effective for enhancing the load-settlement behavior of shallow foundations. The large apertures of geogrid materials facilitate effective interlocking with granular materials, creating a composite material. Recent reports indicate that geosynthetic reinforcement with wraparound ends requires less land width for construction and enhances both the load bearing capacity and stiffness of the foundation.

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Reinforced soil has been successfully used in various civil engineering applications, including load bearing structures like pavements and foundations, stabilizing earthen slopes, retaining walls, and embankments. Since there are limited studies available on bitumen coated geogrid, this study compares uncoated geogrid with bitumen coated geogrid reinforced soil bed for shallow foundation.

2. Reinforcing mechanism

Based on the published literatures, reinforcing mechanism of the reinforcement (e.g., geogrid) can be summarized as: (1) lateral restraint effect; (2) tensioned membrane effect, as shown in Fig. 1. The lateral restraint effect refers to the relative movement of soil particles along the surface of reinforcement under the footing load, which mobilizes the friction force at the interface between reinforcement and soil. The interaction between reinforcement and soil can effectively restrict the horizontal displacement of soils, thus increasing the lateral confining pressure and the compressive strength of soils under the footing [9,16]. Therefore, the ultimate bearing capacity of foundation increases. For geogrid, the grid plays a vital role in the soil-reinforcement interaction, which can better restrict the displacement of soils (such as gravel soil or sand with large particle size), and further enhance the constraint to the soils [14]. As for the tensioned membrane effect, the soils and reinforcements in the reinforced zone move downward due to the footing settlement under applied load. The reinforcements below the footing bend and thus the upward force in the curved reinforcements develops to counter the applied footing load, resulting in the improvement of the bearing capacity of soil foundation [8,9].

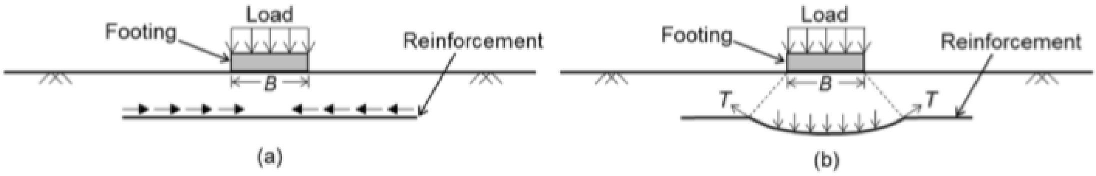

Fig. 1 Schematic view of the reinforcing mechanism a) lateral restraint effect; b) tensioned membrane effect [15]

For the multi-layer geosynthetic reinforced foundation, owing to the combination of the lateral restraint effect and tensioned membrane effect, the overall stiffness of the reinforced zone is significantly improved. At the same time, the foundation is similar to the double-layered soil foundation with upper hard layer and lower soft layer, which spreads the footing load to a wider area. Binquet and Lee [7] first found the stress dispersion effect of reinforcement materials through laboratory model tests.

3. Experimental study

Most studies on the performance of geosynthetic-reinforced foundations and the factors affecting them have primarily relied on laboratory-scale model tests. Additionally, some researchers have conducted field tests and large-scale model experiments to analyze the load-settlement behavior of reinforced foundations under more realistic stress conditions. Laboratory-scale model tests have become the primary method for studying geosynthetic-reinforced soil foundations due to their cost-effectiveness and time efficiency. The main equipment used for plate load tests includes a test box, loading device, rigid footing, and sensors such as load cells and displacement meters. Fig. 2 illustrates a typical setup for conducting model tests on reinforced foundations.

Through small-scale model tests, the effects of various factors on the bearing capacity and settlement of reinforced foundations have been thoroughly examined. These factors primarily include the arrangement and properties of the reinforcement, the shape and size of the footing, the type of loading, and the characteristics of the foundation soil. Researchers have mainly assessed the impact of these factors on the foundation's bearing behavior by comparing load-settlement curves of reinforced and unreinforced foundations. Typically, the bearing capacity ratio (BCR) and the percentage reduction in settlement (PRS) are used as dimensionless parameters to evaluate the effectiveness of geosynthetic reinforcement.

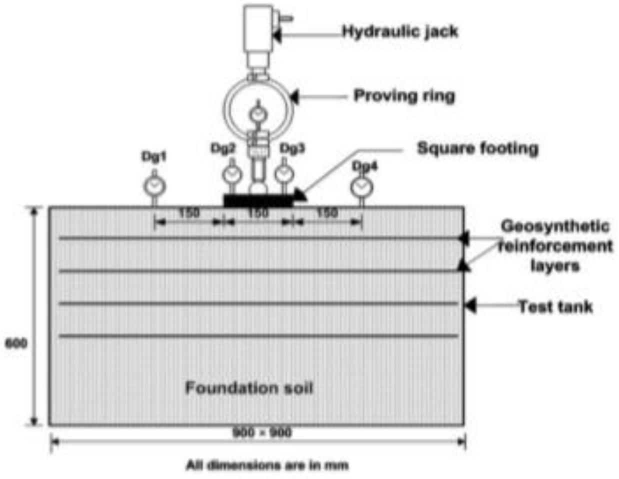

Fig. 2 Schematic view of equipment for performing plate load tests on reinforced foundations[15]

The bearing capacity ratio (BCR) is defined as follows:

$$BCR = \frac{q_r}{q_u}$$

where q_r is the bearing capacity of reinforced foundation; q_u is the bearing capacity of unreinforced foundation. The percentage reduction in settlement (PRS) is defined as follows:

$$PRS = \frac{s_u - s_r}{s_u} * 100$$

where s_r is the footing settlement in reinforced foundation and s_u is the footing settlement in unreinforced foundation.

3.1 Reinforcement layout

The arrangement parameters of reinforcement materials in a geosynthetic reinforced foundation include the distance from the top reinforcement layer to the bottom of the footing (u), the spacing between reinforcement layers (h), the reinforcement length (L), the number of reinforcement layers (N), and the depth of the reinforced zone (dr). Figure 3 illustrates the schematic representation of a geosynthetic-reinforced soil foundation [15].

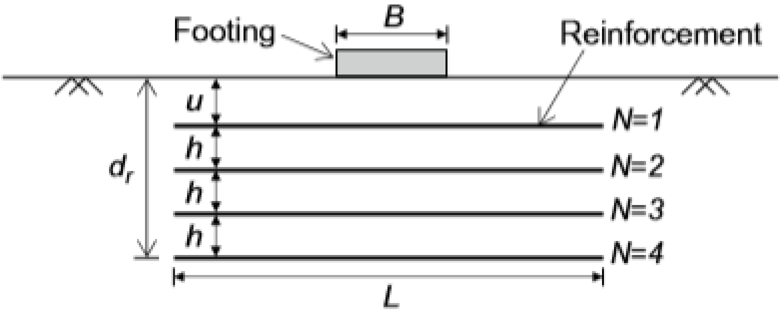

Fig. 3 Schematic view of geosynthetic reinforced foundation [15]

The model plate load tests were performed on different grades of geogrid to study the variation in bearing capacity and plastic deformation of footing in terms of BCR and SRF, respectively, due to the varying end conditions. Different end conditions were created by using three different layouts of geogrid layers, viz. planar layout, wave layout and looped layout [4], as shown in Fig. 4

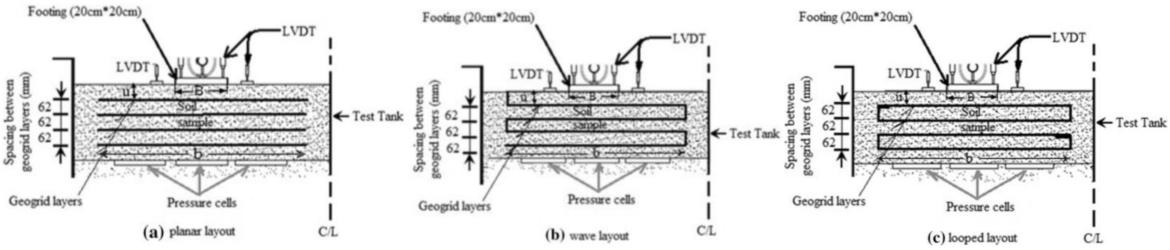

Fig. 4 Different layouts of geogrid to create different end conditions [4]

In case of planar layout, all the geogrid layers were laid in horizontal layers with free ends, as shown in Fig. 2(a)[4]. The BCR and SRF were improved due to the membrane effect and confinement effect provided by the geogrid [7, 8]. This may be attributed due the fact that the soil grains around the reinforcement surface are restricted to move laterally due to the frictional interaction and bearing resistance with the surface of reinforcement and the lateral sides of geogrid ribs, respectively [4]. However, in case of planar layout with free end geogrid layers, the central part of soil sandwiched between footing and geogrid layer in the top spacing and also between two geogrid layers may not play their role in the improvement in BCR and SRF because of the inadequate restriction against the lateral deformation. That may decrease the efficiency of geogrid layers. It was also noticed from various tests that the slip of geogrid occurs in planar layouts at large plastic deformations, i.e. beyond the ultimate deformation of 25 mm. Thus, geosynthetic reinforcement with wrap-around ends has been recently investigated to improve the effectiveness of reinforced foundation [4].

In case of wave layout, a single geogrid layer was laid with one end wrapped with the height of the wrap equal to the distance between the two geogrid layers thus restricting its lateral slip in the direction of the foundation settlement (plastic deformation) as shown in Fig. 2(b). The BCR and SRF were increased from 30 to 50% and 31–45%, respectively. Besides the reinforcing effect provided by the horizontal part, the more lateral confinement was provided by the wraps. During the vertical pressure from the plate loads, the elastic deformation will occur in the horizontal geogrid layers, which tend to move vertically downwards. As the layers are fixed with each other through the wraps around, the wrap ends will also try to move towards the footing because of the resultant pull. Thus, the soil was provided with the additional confinement effects from the wraps around. This process was a kind of wrapping geogrid around the soil layers by hand pull only thus providing a small amount of prestress to the geogrid layers also. So the whole system was acting as a single monolithic structure. This helped in reducing the plastic deformation at small settlements [5].

In case of looped layout, two layers of geogrid were laid with both ends wrapped and connected thus restricting lateral slip on both sides as shown in Fig. 2(c). An additional confinement is provided to the soil layer due to the wraps on both sides of the geogrid. The BCR and SRF were improved from 35 to 55% and 33–50%, respectively [4]. Similar results were reported by various researchers [11,15]. The looped layout was more efficient than the other two layouts due to more restriction to the lateral deformation of the sandwiched soil. The ends of the two geogrid layers were tied using thread by sewing technique. The thread had the non-elongating property against the tensile pull [4]. Makker et al. [20] have reported that BCR and SRF can be further improved by using three-dimensional geogrid reinforcement. Similar results of deformation behavior have been reported by Moraci and Cardile [23].

3.2 Materials

3.2.1 Sand

Disturbed and undisturbed soil samples were obtained. The disturbed samples were collected in large plastic bags, while the undisturbed samples were extracted using core cutters and carefully sealed to prevent moisture loss. The disturbed soil samples were thoroughly pulverized, dried, and subjected to various laboratory tests to determine their physical, index, and engineering properties [4].

3.2.2 Geogrid

Although geosynthetics possess strong mechanical properties, they may not be adequate under challenging conditions. To endure extreme loading scenarios, they are often combined with other materials [18].

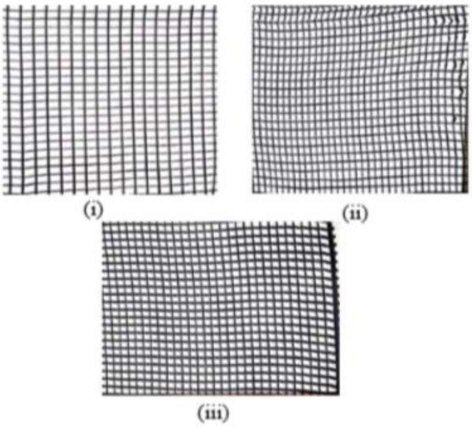
(i) (ii) (iii)

Fig. 4 Different grades of bitumen-coated geogrid [4]

Bitumen coating, a highly refined and solvent-extracted crystalline form of bitumen, creates a rough surface texture, improving the frictional characteristics of the grid. Three types of Stratagrid™ Biaxial geogrids—BX-40, BX-60, and BX-80—were used in the study, as shown in Fig. 4. Each type has different tensile strengths and varying aperture sizes. The physical and mechanical properties of the geogrid, provided by the manufacturer, are listed in Table 1 [4].

Table 1 Properties of Bitumen Coated Geogrid [4]

Sl. No.	Properties of Geogrid		Unit	BX40	BX60	BX80
1	Mechanical properties (ASTM D6673-Method A)					
	i)	Tensile strength in machine direction (MD)	kN/m	40	60	80
	ii)	Tensile strength in cross-machine direction (CMD)	kN/m	40	60	80
	iii)	Creep limited strength in machine direction (MD)	kN/m	27.2	40.8	54.4
	iv)	Creep limited strength in cross-machine direction (CMD)	kN/m	27.2	40.8	54.4
	v)	Creep reduction factor		1.47	1.47	1.47
	vi)	Partial factor installation damage in clay, silt or sand		1.07	1.07	1.07
2	Molecular properties					
	i)	Molecular weight (ASTM D 4603/GRI GG8)	gm/mol	min. 25000		
	ii)	Carboxyl End Group (ASTM D 7409/GRI GG7)	nmol/kg	max. 30		
3	Physical properties					
	i)	Aperture size	mm	23	20	20
	ii)	Rib width	mm	4.5	5	6
	iii)	Product weight	g/sq.m	300	419	558

3.3 Experimental procedure

The surface of the foundation bed was carefully leveled, and the square footing was positioned at the center of the leveled area, aligning with the center of the top geogrid layer. A series of model plate load tests were carried out to examine the load-settlement behavior of a shallow foundation on a bitumen-coated geogrid reinforced silt clay soil bed, with varying end conditions in a double-layered soil system, following the standard codal procedure [17]. The applied load was recorded using a proving ring positioned at the center of the footing [4].

3.4 Test results

To enable a consistent comparison of different influencing factors, all the above parameters, except for N, are expressed in a dimensionless form by normalizing them with the footing width (B), resulting in u/B, h/B, L/B, and d_r/B [15]. Table 2 provides a summary of key small-scale model tests performed on geosynthetic-reinforced foundations, along with the corresponding optimal layout parameters.

Table 2 Summary of the model tests conducted on geosynthetic-reinforced soil foundations.

Researchers	Footing	Soil	Reinforcement	Optimum reinforcement parameters					BCR_{max}
				u	h	L	N	d_r	
Abu-Farsakh et al. [1]	Square	Sand	Geogrid/Geotextile	0.33B	-	6B	-	1.25B	1.6
Omar et al. [24]	Square	Sand	Biaxial geogrid	0.4B	-	4.5B	-	1.4B	2-3
Shrigondekar et al. [28]	Square	Sand	Biaxial geogrid	0.25B	0.25B	-	4	-	6.87
Akbar et al. [4]	Square	Silty clay	Bitumen coated biaxial geogrid	0.62B	0.62B	-	4	-	1.54
Ghosh et al. [13]	Square	Pond ash	Jute-geotextile	0.3125B	0.3125B	5-7B	5-6	1.75B	3.54
Yetimoglu et al. [31]	Rectangular	Sand	Uniaxial geogrid	0.3B	0.2B	4.5B	4	1.5B	3.63
Guido et al. [14]	Square	Sand	Geogrid/Geotextile	0.25B	0.25B	3B	3	0.75B	2.8
Basudhar et al. [12]	Circular	Sand	Woven geotextile	0.25D	1D	3.5D	3	2.25D	5.5

Latha et al. [19]	Square	Sand	Geogrid	-	0.4B	4B	-	2B	2.5
Das et al. [10]	Strip	Sand	Biaxial geogrid	0.3B	-	8B	-	2B	5
Shin et al. [27]	Strip	Clay	Biaxial geogrid	0.4B	0.4B	4.5-5B	5	2B	1.4
Akbar et al. [3]	Square	Silty clay	Bitumen coated biaxial geogrid	0.62B	0.62B	-	2	-	2.81
Ahmad et al. [2]	Strip	Sand	Geogrid	0.6B	-	5B	2	-	2.8

Based on published literature and the results from Table 1, the optimal layout parameters for reinforced foundations can be summarized as follows: For the top reinforcement layer, the ideal embedment depth (u/B) typically ranges between 0.3 and 0.4. If u/B is too small, the overlying soil cannot effectively anchor the reinforcement. Conversely, if u/B is too large, a shallow shear failure may occur above the top reinforcement layer, which negatively impacts the foundation’s bearing capacity [13]. There is an optimal vertical spacing for reinforcement (h/B). Within the effective reinforced depth, the bearing capacity improves as h/B decreases but starts to decline slightly when h/B falls below a critical value [31].

The bearing capacity of a soil foundation increases as the reinforcement length (L/B) increases. However, once L/B surpasses a certain critical value, further extending the reinforcement length has minimal impact on the foundation’s performance. This is because when the reinforcement extends beyond the anchorage zone, the additional frictional resistance and passive force generated beyond this effective zone contribute little to enhancing the bearing capacity [10,27].

Latha [19] suggested that the optimal aperture size of geogrids should be approximately four times the median grain size of the backfill material. Beyond the properties of the reinforcement itself, the type and shape of the reinforcement also play a crucial role in influencing the load-settlement behavior of reinforced soil foundations. Geogrids outperform geotextiles in enhancing the bearing capacity of foundations [Abu, Guido], primarily due to the superior interlocking between soil particles and the geogrid. Additionally, biaxial geogrids are more effective than uniaxial geogrids in improving soil foundation performance [19,30].

In reinforced foundations, the soil consists of two parts: the fill within the reinforced zone and the underlying soil beneath it. The type, particle size, and relative density of these soils influence both the bearing capacity and settlement of the reinforced foundation. In small-scale model tests, foundation soils, including both the fill and underlying layers, are typically composed of dry sand or clay [10]. However, in some studies, the reinforced zone is filled with granular materials such as sand and gravel [9], while the soil below the reinforced zone consists of clay or other low-strength soils [26].

For a given reinforcement layout, the ultimate bearing capacity increases as soil density rises [1,7,11]. Das and Omar [11] conducted model tests on strip footings resting on geogrid-reinforced sand beds and observed that the bearing capacity ratio (BCR) decreases with increasing relative density. In contrast, Useche-Infante et al. [30] reported that BCR increases with relative density based on loading tests on circular footings. This finding aligns with the results of Durga-Prasad et al. [12], who conducted plate load tests on geogrid-reinforced foundations under square footings. The discrepancy in the relationship between BCR and relative density may be attributed to differences in footing shape, requiring further investigation.

In recent years, Huang [16] has conducted extensive testing to evaluate the ultimate bearing capacity of saturated reinforced sand foundations. The results indicate that foundation saturation significantly affects settlement at peak load, leading to greater settlement compared to dry conditions. This increased settlement in saturated soil foundations is linked to negative excess pore pressure during loading.

Compared to BCR, the percentage reduction in settlement (PRS) due to reinforcement is less frequently considered in experimental studies. However, some research has demonstrated that geosynthetics can effectively reduce footing settlement. Mandal and Sah [21] conducted plate load tests on geogrid-reinforced clay beds and found that the maximum PRS achieved using geogrid was approximately 45%. Alawaji [5] performed model tests on geogrid-reinforced sand foundations, revealing that PRS could reach up to 95%. Moghaddas Tafreshi and Dawson [22] reported a PRS of around 64% when using geotextile in sand foundations.

The bearing capacity of reinforced sand foundations is significantly higher than that of clay foundations [11]. This is primarily due to the increased stiffness beneath the footing, frictional resistance at the soil-geogrid interface, and passive forces generated along the edges of the geogrid ribs. The magnitude of passive force depends on the soil's friction angle [11], which is higher in sand than in clay, leading to greater passive resistance. Additionally, the relative density of sand has a considerable impact on the overall performance of the soil foundation.

4. Conclusion

This paper begins by outlining the reinforcement mechanisms of strengthened materials, followed by a comprehensive review of geosynthetic-reinforced foundations through experimental studies. After analyzing and discussing the existing literature, the key conclusions can be summarized as follows: The load-bearing capacity of a footing on a sand bed increases with the addition of more reinforcement layers. Also, wraparound ends consistently enhance the load-bearing capacity of a reinforced sand bed under all loading conditions. The greatest benefit from reinforcement is achieved when it is positioned within the zone of influence of the applied load. Using a full-wraparound geogrid sheet to support strip footings significantly enhances the carrying capacity compared to using a planar geogrid sheet. The bearing capacity also depends on the u/B ratio; higher u/B ratios lead to greater bearing capacity. Both Bearing Capacity Ratio (BCR) and Settlement Reduction Factor (SRF) increased with the number of reinforcement layers (N) up to 3 or 4 layers; however, adding more than 4 layers did not further improve the BCR. Among the three geogrid layouts tested planar, wave, and looped, the looped layout proved to be the most effective. It significantly reduced lateral slip of the geogrid layer toward the center of the reinforcement bed. For the same reinforcement layout, the ultimate bearing capacity of a reinforced sand foundation is significantly higher than that of a clay foundation. Additionally, the relative density of sand plays a crucial role in the performance of the soil foundation, with higher relative density leading to an increase in bearing capacity.

5. Conflict of Interest

The authors state that they have no conflict of interest.

References

[1] Abu-Farsakh M, Chen QM, Sharma R, Zhang X (2008) Large scale model footing tests on geogrid reinforced foundation and marginal embankment soil. Geotech Test J 31(5):413–423

[2]Ahmad, H., Sheble, A. (2024), "Effects of including fully wraparound geogrid layers on the load-bearing capacity and settlement of a strip footing resting on sandy soil", Discover Applied Sciences (2024) 6:82 https://doi.org/10.1007/s42452-024-05711-w.

[3] Akbar, A., Bhat, J.A., Mir , B.A. (2023), "Laboratory study on pressure settlement behavior of shallow foundation on bitumen coated geogrid reinforced soil bed with varying percentage of prestress". International journal of pavement and research technology (volume 16).

[4] Akbar, A., Bhat, J.A., Mir , B.A. (2021), "Plate load tests for investigation of the load–settlement behaviour of shallow foundation on bitumen-coated geogrid reinforced soil bed", Innovative Infrastructure Solutions (2021) 6:80 https://doi.org/10.1007/s41062-020-00397-6.

[5] Alawaji HA (2001) Settlement and bearing capacity of geogrid reinforced sand over collapsible soil. Geotext Geomembr 19(2):75–88

[6] Badrawi, E. (2024), "Influence of Geogrid-Axial Stiffness on Bearing Capacity of Geogrid-Reinforced Fine Sand", Faculty of Engineering - Port Said University Volume 28 No. 2 pp: 41 : 49, DOI: 10.21608/PSERJ.2024.253870.1298.

[7] Basudhar PK, Dixit PM, Gharpure A, Deb K (2008) Finite element analysis of geotextile-reinforced sand-bed subjected to strip loading. Geotext Geomembr 26(1):91–99

[8] Binquet J, Lee KL (1975) Bearing capacity analysis of reinforced earth slabs. J Geotech Geoenviron Eng 101(ASCE# 11793 Proceeding)

[9] Binquet J, Lee KL (1975a) Bearing capacity tests on reinforced earth slabs. J Geotech Eng Div ASCE 101(GT12):1241–1255

[10] Chen QM, Abu-Farsakh M (2015) Ultimate bearing capacity analysis of strip footings on reinforced soil foundation. Soils Found 55(1):74–85

[11] Das BM, Omar MT (1994) The effects of foundation width on model tests for the bearing capacity of sand with geogrid reinforcement. Geotech Geol Eng 12(3):133–141

[12] Durga-Prasad B, Hariprasad C, Umashankar B (2016) Loadsettlement response of square footing on geogrid reinforced layered granular beds. Int J of Geosynth and Ground Eng 2(36):1–10

[13] Ghosh A, Ghosh A, Bera AK (2005) Bearing capacity of square footing on pond ash reinforced with jute–geotextile. Geotext Geomembr 23:144–173

[14] Guido VA, Chang DK, Sweeney MA (1986) Comparison of geogrid and geotextile reinforced earth slabs. Can Geotech J 23:435–440

[15] Guo X, Zhang H, Liu L (2020) Planar geosynthetic-reinforced soil foundations. SN Applied Sciences (2020) 2:2074 https://doi.org/10.1007/s42452-020-03930-5

[16] Huang CC, Tatsuoka F (1990) Bearing capacity reinforced horizontal sandy ground. Geotext Geomembr 9:51–82

[17] IS: 1888 (1982) Method of test for soils: determination of bearing capacity of soils by plate load test. Bureau of Indian Standards, New Delhi

[18] Jiniraj, R.B., Joy, S., Jayasree, P.K., Chanthu, R., Peter, L., Anusha, S.P. (2020), "Application of Latex Backed Jute Geotextiles in Flexible Pavements: A Macroscale Study". JOURNAL OF NATURAL FIBERS. https://doi.org/10.1080/15440478.2020.1848728.

[19] Latha GM, Somwanshi A, Reddy KH (2013) A multiple regression equation for prediction of bearing capacity of geosynthetic reinforced sand beds. Indian Geotech J 43(4):331–343

[20] Makkar, F.M., Chandrakaran, S., Sankar, N. (2016), "Settlement and Surface Heave characteristics of Geogrid Reinforced Cohesionless Soil", Indian Geotechnical Conference IGC2016. https://www.researchgate.net/publication/317739222.

[21] Mandal JN, Sah HS (1992) Bearing capacity tests on geogrid reinforced clay. Geotext Geomembr 11(3):327–333

[22] Moghaddas Tafreshi SN, Dawson AR (2010) Comparison of bearing capacity of a strip footing on sand with geocell and with planar forms of geotextile reinforcement. Geotext Geomembr 28(1):72–84

[23] Moraci N, Cardile G (2012) Deformative behaviour of different geogrids embedded in a granular soil under monotonic and cyclic pullout loads. Geotext Geomembr 32:104–110

[24] Omar MT, Das BM, Puri VK, Yen SC (1993) Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement. Can Geotech J 30:545–549

[25] Prasad. D.B., Hariprasad, C., Umashankar, B. (2016), "Load-Settlement Response of Square Footing on Geogrid Reinforced Layered Granular Beds", Int. J. of Geosynth. and Ground Eng. (2016) 2:36, DOI 10.1007/s40891-016-070-6.

[26]Saha Roy S, Deb K (2019) Interference Effect of Closely Spaced Footings Resting on Granular Fill over Soft Clay. Int J Geomech 19(1):04018181

[27] Shin EC, Das BM, Puri VK, Yen SC, Cook EE (1993) Bearing capacity of strip foundation on geogrid reinforced clay. Geotech Test J ASTM 16(4):534–541

[28] Shrigondekar, A., Ullagaddi, P. (2020), "Bearing Capacity Analysis of a Square Footing Supported on Geogrid Reinforced Sand", International Journal on Emerging Technologies 11(3): 169-176(2020).

[29] Tavakoli Mehrjardi GT, Khazaei M (2017) Scale effect on the behaviour of geogrid-reinforced soil under repeated loads. Geotext Geomembr 45:603–615

[30] Useche-Infante D, Aiassa Martinez G, Arrúa P, Eberhardt M (2019) Experimental study of behaviour of circular footing on geogrid-reinforced sand. Geomech Geoeng 1–19

[31] Yetimoglu T, Wu JTH, Aaglamer A (1994) Bearing capacity of rectangular footings on geogrid–reinforced sand. J Geotech Eng 120(12):2083–2099