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Square footing on geocell reinforced cohesionless soils

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Abstract. Ground improvement with use of geosynthetic products is globally accepted now. The present paper discusses the improvement in bearing capacity of square footing placed at surface of cohesionless soil reinforced with geocell. Mohr-Coulomb failure criterion has been used in the observations. To study effects of geocell with respect to planar geogrid, model tests were conducted on planar reinforcement also. A comparative study of unreinforced soil and soil reinforced with plane geogrid and geocell has also been made. Numerical analysis results obtained by PLaxis have been compared with those obtained from model tests and were found to be in good agreement. A parametric study revealed the role of length of reinforcement, spacing between layers, placement of reinforcement from top surface etc. on bearing capacity. A design example given in paper illustrates the savings in cost of construction of footing on reinforced sand. The study shows that there is improvement in bearing capacity with respect to unreinforced soil which is of the order of 86%. Similarly settlement reduction is 13.07% for single layer of geocell which for double layers of geocell is 693% and 86.48% respectively. The cost reduction in case of reinforced soil is 35% as compared to unreinforced soil.

Keywords: settlement reduction; geocell; cohesionless soil; bearing capacity improvement; economical design

1. Introduction

Ground improvement techniques are used to increase the bearing capacity of the soil and reduce the settlement to a considerable extent. In last three decades, many techniques have been developed, besides emergence of new materials. People of third century BC used even timbers for construction of roads over peat and water logged grounds (Dewar 1962). Ground improvement in weak soils and in difficult site conditions becomes necessary in view of heavy loads imposed by roads and pavements, embankments, industrial structures, buildings etc. Methods like soil replacement, pre loading without or with sand-drain, dynamic compaction have been adopted successfully in road and pavement construction projects (Jones 1996, Jian *et al.* 2006). Another form of ground improvement is reinforcing the soil by the inclusion of tension bearing elements. Numerous soil reinforcing materials are available like steel strips, polymers geotextiles, and jute geotextiles (Chauhan *et al.* 2008, Mittal 2013). Geosynthetics have been increasingly used in various geotechnical and environmental engineering related projects for the last four decades. Over the years, these products have helped designers and developers to solve several types of

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engineering problems where the conventional construction material is considerably more expensive. The ground improvement technique using geosynthetics was initiated during early eighties of twentieth Century. Since then polymeric fabrics (i.e., geotextiles) and geogrids are being extensively used all over the world in foundations, walls, roads in order to improve their performance (Binquet and Lee 1975, Guido *et al.* 1986, Khing *et al.*1993, Hatami *et al.* 2001, Léonard *et al.* 2002, Dash *et al.* 2007, 2012, Moghaddas *et al.* 2014, Chen 2013, Khalaj *et al.* 2015, Hegde and Sitharam 2015) through interface friction and membrane effect. Polymers strip type reinforcements and composite-type geogrids show excellent long-term performance. An examination of the existing literature indicates that the bearing capacity is considerable improved with planar reinforcement (geogrid). The works available in literature for 3D reinforcement (geocell) are very scanty. Literature is available highlighting the bearing-capacity improvement of sand beds due to planar reinforcement (Binquet and Lee 1975, Akinmusru and Akinbolande 1981, Fragaszy and Lawton 1984). Some studies have been done for soil reinforcement by Bathurst and Jarrett (1989), Bush *et al.* (1990), Cowland and Wong (1993), Krishnaswamy and Rajagopal (2001). Dash *et al.* (2001a, 2004 and 2007), Sitharam *et al.* (2005), Zhou and Wen (2008), Pokharel *et al.* (2010), Madhavi Latha and Somwanshi (2013), Moghaddas (2013), Ngo *et al.* (2016). Sitharam and Hegde (2013) conducted model footing tests on geocell reinforced soil and found that interconnected geocells increase load carrying capacity and reduce settlement significantly through increased rigidity of geocell layer by confinement of foundation soils. The geocell reinforcement arrests the lateral spreading of the in-fill soil and creates a stiffened mat to support the foundation, thereby giving rise to higher load-carrying capacity.

Hence in order to have a better understanding and add information to existing data base, an attempt has been made to carryout experimental study to understand behavior of cohesionless soil reinforced with geocell subjected to axially loaded square footing. The tests have been done in plain strain conditions. To understand the difference between planar and 3D reinforcement, tests were conducted on uniaxial geogrid and geocell laid in different layers. The results obtained from model tests had been verified by PLAXIS software also.

2. Model test

2.1 Properties of sand used

Table 1 Properties of sand used in the study

Property	Value
Soil Classification	SP
Effective Size (D_{10}) mm	0.16
Uniformity Coefficient (C_u)	2.07
Coefficient of Curvature (C_c)	1.21
Mean Specific Gravity (G)	2.65
Maximum Dry Density (kN/m^3)	16.67
Minimum Dry Density (kN/m^3)	15.1
Relative Density (D_r)	60%
Unit Weight of Sand (kN/m^3)	16
Shear Parameters	$c=0$, $Ø=32^0$

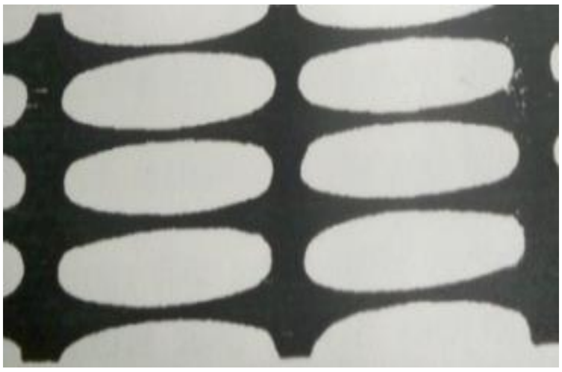

Fig. 1(a) Geogrid used in the study

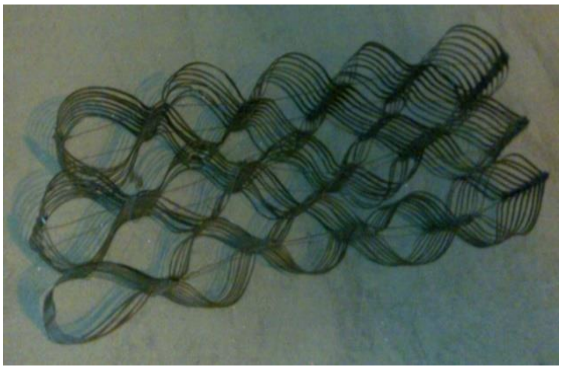

Fig. 1(b) Geocell used in the study

Table 2 Properties of geogrid

Properties of geogrid	Value
Polymer	HDPE
Minimum Carbon Black (%)	2
Roll width (m)	1.3
Roll length (m)	50
Unit weight(N/m^2)	6.5
Roll Weight (N)	450
Ultimate strength (kN/m)	88.7
Typical strain at T_{ult} (%)	11.50

The soil used in the present investigation was collected locally from Solani river sand. The various properties of soil are presented in Table 1 (Mittal and Shukla 2007).

2.2 Reinforcement

Two types of reinforcement i.e., planar geogrid and 3D geocell were used. The geocell were made by made by using uniaxial geogrid (Fig. 1(a)). The properties of uniaxial geogrid are shown in Table 2. The geocell used in the present study had pocket size of 200 mm with diamond pattern and 200 mm height. The diamond pattern geocell were made by cutting the planar geogrid in required width and joining them using thin wire (Fig. 1(b)).

2.3 Test tank

A rigid square steel tank of size 1130 mm×1130 mm×800 mm (depth) was used in the laboratory model test (Fig. 2). The sand was filled in the tank in layers by compacting a flat wooden block size 100 mm×200 mm weighing about 2 kg in equal layers till the desired height was reached. Through a series of trials, required height of fall and number of blows of the wooden block in order to achieve the desired density of the sand bed was determined beforehand. The sand was filled up to the required depth in pre-marked layers and in between geogrid or geocell (as the case may be) was placed at different depths (Fig. 3). Geocell pockets were filled with a sand and were compacted uniformly using a tamping rod of 20 mm diameter. After placing the geogrids or geocell at specified depth, sand was filled again and compacted and then next geogrids or geocells was placed (in case of double layers).

In the present investigation a rigid mild steel plate of size 200 mm×200 mm×10 mm was used as a footing on the top of the test tank for applying the load. The loads on the footing were applied by means of hydraulic jack of 200 kN capacity acting through a calibrated proving ring. The intensity of the pressure was increased gradually. Load was applied in increments as per the provisions of Indian Standard code IS 1888-1982, each incremental load was applied when the deformations under any particular load reached a steady state value. Four dial gauges were fixed to measure the settlements of footing. During each test, the dial gauges readings were taken after each load increment. This process is continued till the footing failure. After every test, the soil was completely scooped out and freshly prepared for the next experiment. Some tests were repeated to ensure the uniformity of test conditions. The typical results of 5 tests conducted are illustrated in Fig. 4.

Fig. 2 A view of test set up

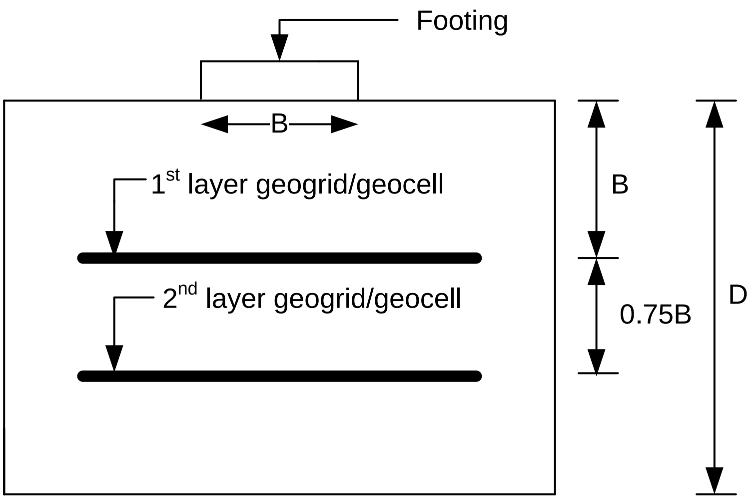

Fig. 3 Typical placement of reinforcement

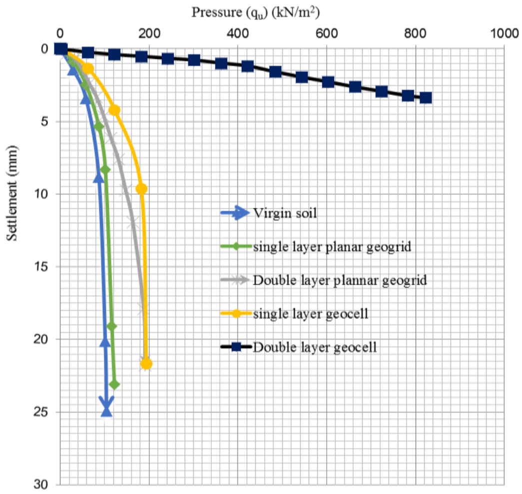

Fig. 4 Pressure v/s settlement curves for unreinforced soil and reinforced soil

Table 3 Properties of soil used in PLAXIS analysis

Parameter	Type
Material model	Mohr-Coloumb
Type of behaviour	Undrained
Soil unit weight (kN/m^3)	16
Modulus of Elasticity (kN/m^2)	150 (virgin soil), 325 (soil+geogrid),500 (soil +geocell)
Poisson’s ratio	0.25
Cohesion (kN/m^2)	0.0
Friction angle 32^0 (virgin soil), 35.5^0 (reinf. with geogrid) and 40^0 (reinf. with geocell)	

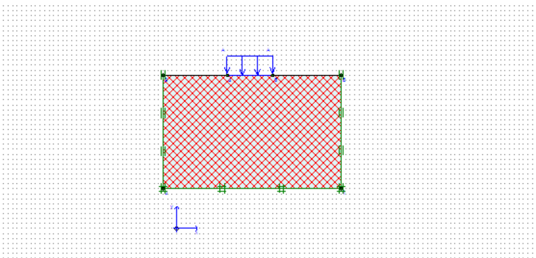

Fig. 5(a) PLAXIS model for virgin soil

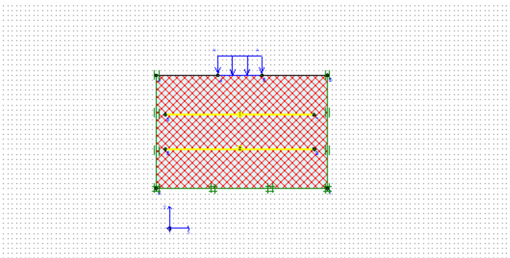

Fig. 5(b) Model for double layers of geocell

3. Numerical analysis

To verify the results obtained by model tests by numerical analysis was done using PLAXIS 2D Software. It is a finite element package that has been developed for the analysis of deformation and stability in Geotechnical Engineering problems. A linearly elastic perfectly plastic model with Mohr-Coulomb failure criteria was adopted to simulate the behavior of equare footing foundation Distributed load was applied at the top of the footing. Values of soil parameters used in the investigation are shown in Table 3. The soil properties were determined from Triaxial tests for virgin soil as well as soil with planar reinforcement material. These values were used for numerical model also. Here, the value of Ø is changed for virgin soil, soil reinforced with geogrid and 3D geocell. This value of Ø was obtained by conducting large size (300 mm×300 mm×200 mm) direct shear tests in laboratory. The geometry of model for virgin soil, as adopted for analysis by PLAXIS is given in Figs. 5(a) and 5(b). In PLAXIS soil/structure interface behaviour may be modeled using parameters generated using an interaction coefficient, Ri, defined as the ratio between the shear strength of soil/structure interface and the corresponding shear strength of the soil. In this study, fully rough interface conditions with Ri=1, was assumed. A typical soil deformation diagram as obtained by analysis are given in Fig. 6(a) (virgin soil) and Fig. 6(b) (double layers of geocell). The results obtained by model tests were compared with those obtained by PLAXIS software. The comparison of both results is given in Fig. 7(a) (virgin soil) and Fig. 7(b) (double layers of geocell). It is evident from Fig. 7(a) that for 10% strain (i.e., 10% of footing dimension), the loading intensity values obtained by model tests and numerical analysis are same as 100 kN/m^2. Though for other strains, the values differ within a range of 10-17% which seems to be reasonable.

4. Parametric study

The laboratory tests are always useful tests for solution of any real life problems. But laboratory tests are time consuming and expensive. Sometimes there are also limitations of availability of testing facilities.

In the present study, five model tests were conducted, the results of which were compared with numerical analysis conducted by PLAXIS software. Since the results obtained by both methods were comparable, hence in order to save time from model tests, following parametric study was done with PLAXIS software. The results of which are presented elsewhere (Biswas 2010). The parametric study is given in Table 4.

On the basis of results obtained by parametric study and the laboratory model tests, a design example is given below for design of footing on reinforced soil.

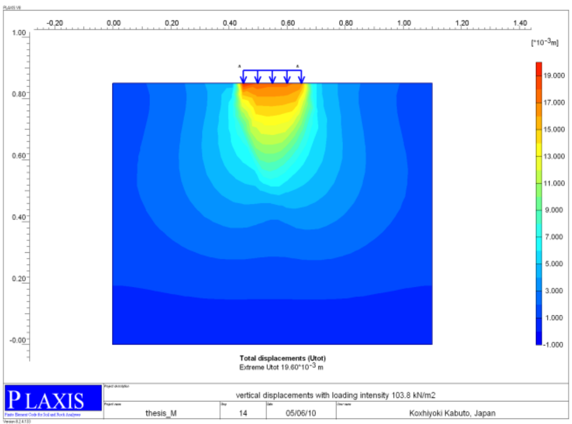

Fig. 6(a) PLAXIS deformation contour for virgin soil

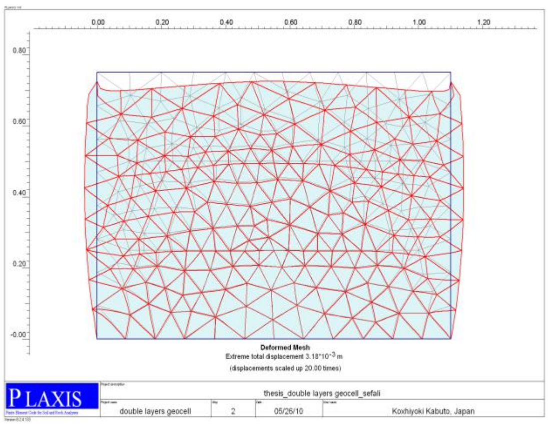

Fig. 6(b) PLAXIS deformation for double layers of geocell

Table 4 Parametric study for numerical analysis

Parameter	Value
Length of geogrid	2B, 2.5B, 3B, 3.5B, 4B, 4.5B, 5B, 6B
Depth of single layer reinforcement from top surface of soil	0.5B, 1B, 1.5B, 2B, 2.5B
Depth of first layer of reinforcement from top surface for two layers of reinforcement	0.5B, 1B, 1.5B, 2B, 2.5B
Centre to centre distance between two layers of reinforcement	0.5B, 0.75B, 1B, 1.5B

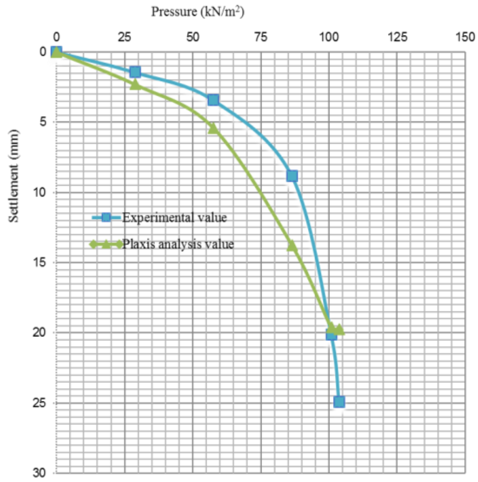

Fig. 7(a) Pressure v/s settlement for virgin soil

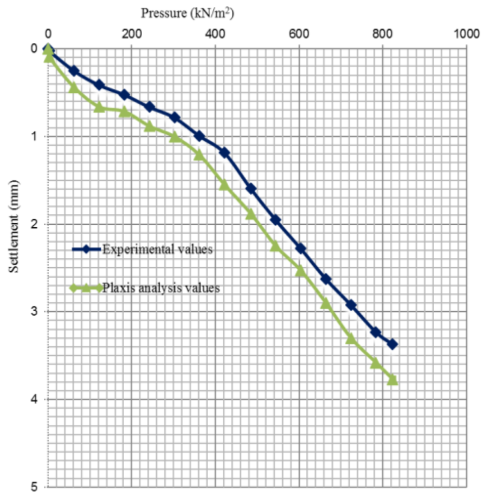

Fig. 7(b) Pressure v/s settlement for double layers of geocell

5. Design example

The cost comparison was done for a virtual problem of a RCC column of size 400 mm×400 mm, proposed to cater a load of 1000 kN (including self-weight), the foundation of which was proposed either on unreinforced soil or soil reinforced with geocell (Structural design done as per IS 456:2000).

5.1 Design data

Factored load on foundation, P_u = 1.5×1000 kN, Pedestal size: 650 mm×650 mm. The other data are as below.

The same is explained in following table (rates as per current prevailing rates in Indian market). The same is explained in Table 5.

Sl. No.	Item	Value
1	Grade of Concrete	M 25
2	Grade of Steel	Fe 500
3	B.C. from model test for virgin soil	22.5 kN/sqm (for 2 mm settlement), Fig.7(a)
4	B.C. from model test with double layer of geocell	505 kN/sqm (for 2 mm settlement), Fig.7(b)

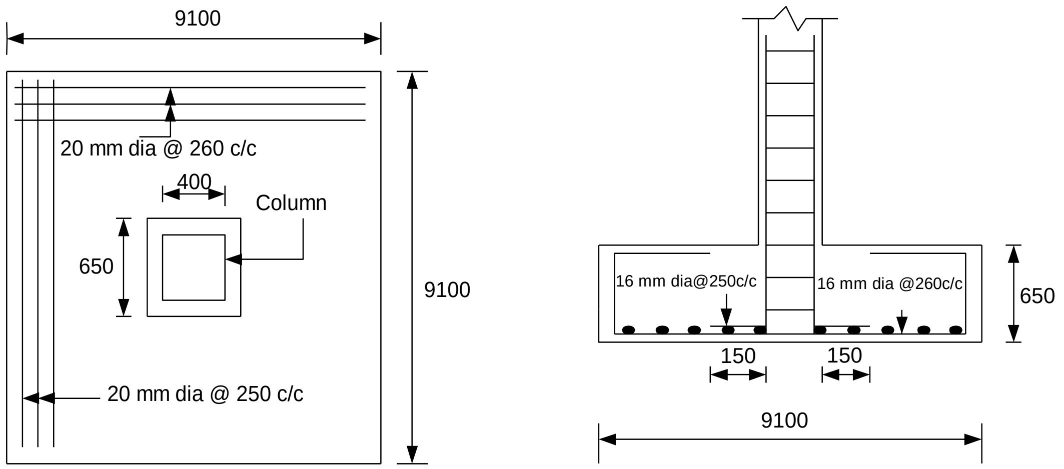

Fig. 8 Placement & Elevation of reinforcement for footing without geocell

Table 5 Design costs valuesyer of geocell for unreinforced soil and reinforced with double la

Items	Unreinforced Soil	Soil reinforced with double layers of geocell
Bearing capacity	22.5 kN/m^2	505 kN/m^2
Foundation size	9100 mm×9100 mm	2100 mm×2100 mm
Depth of footing	650 mm	650 mm
Steel	1908 Kg	133 Kg
Geocell cost	-	Rs 47,344/-.
Present cost of Steel=Rs 43 per Kg (as per market)		
Total Cost	Rs. 82, 044/-	Rs. 53,063/-

Percentage decrease in cost of the footing due to reinforced soil=(1–53,063/82,044)×100% =35%

6. Conclusions

In the present study, model tests had been conducted on planar as well as cellular reinforcement. It is clearly evident that bearing capacity of soil increases with use of polymer reinforcement, and settlement reduces. The use of such reinforcement also does not require specialized skill and thus may be used. Such reinforcing materials are easily available in global market. These materials can also be customized according to specific requirements in field. The salient conclusions can be summarized as below:

1. The present study indicates that the planar and 3D reinforcement in soil substantially increases the bearing capacity of soil and reduces the settlements appreciably. The study discussed here on cohesionless soil indicates that improvement in bearing capacity is 16.6% for single layer of geogrid and 84.2% for double layers of planar geogrid. This improvement drastically increases to 86.7% for single layer of 3D geocell and 693.2% for double layers of 3D geocell for the test conditions as obtained in model tests.
2. The bearing capacity improvement factor (i.e., ratio of bearing capacity of reinforced soil to that of unreinforced soil for same settlement) for single layer of geocell is 1.87 and that for double layer of geocell is 7.93.
3. Similarly the percent settlement reduction (difference between reinforced soil and unreinforced soil divided by settlement for unreinforced soil) is 7.34 for single layer of planer geogrid, 12.71 for double layers of planar geogrid, 13.07 for single layer of geocell and 86.48 for double layers of 3D geocell.
4. Foundations supported on geocell reinforced soil are very economical and smaller in size as compared to those supported on soil without reinforcement. The design example shows that the cost of an isolated footing supported by geocell reinforced soil decreases by 35% as compared to that on unreinforced soil.

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References

Akinmusuru, J.O. and Akinbolade, J.A. (1981), "Stability of loaded footings on reinforced soil", *J. Geotech. Eng*., **107**(6), 819-827.

Bathurst, R.J. and Jarrett, P.M. (1989), *Large-Scale Tests of Geocomposite Mattresses over Peat Subgrades*, Transportation Research Record 1188, Transportation Research Board, Washington, U.S.A., 28-36.

Binquet, J. and Lee, K.L. (1975), "Bearing capacity tests on reinforced earth slabs", *J. Geotech. Eng. Div*., **101**(12), 1241-1255.

Biswas, S. (2010), "Study of behaviour of geocell in ground improvement", M.S. Dissertation, IIT Roorkee, Roorkee, India.

Bush, D.I., Jenner, C.G. and Bassett, R.H. (1990), "The design and construction of geocell foundation mattress supporting embankments over soft ground", *Geotext. Geomembr*., **9**(1), 83-98.

Chauhan, M.S., Mittal, S. and Mohanty, B. (2008), "Performance evaluation of silty sand subgrade reinforced with flyash and fiber", *Geotext. Geomembr*., **26**(5), 429-435.

Chen, R.H., Huang, Y.W. and Huang, F.C. (2013), “Confinement effect of geocells on sand samples under triaxial compression”, *Geotext*. *Geomembr*., **37**, 35-44.
Cowland, J.W. and Wong, S.C.K. (1993), “Performance of a road embankment on soft clay supported on a geocell mattress foundation”, *Geotext*. *Geomembr*., **12**(8), 687-705.
Dash, S.K. (2012), “Effect of geocell type on load-carrying mechanism of geocell-reinforced sand foundations”, *J. Geomech*., **12**(5), 537-548.
Dash, S.K., Krishnaswamy, N.R. and Rajagopal, K. (2001a), “Bearing capacity of strip footings supported on geocell-reinforced sand”, *Geotext*. *Geomembr*., **19**(4), 235-256.
Dash, S.K., Rajagopal, K. and Krishnaswamy, N.R. (2004), “Performance of different geosynthetic materials in sand foundations”, *Geosynth*. *Int*., **11**(1), 35-42.
Dash, S.K., Rajagopal, K. and Krishnaswamy, N.R. (2007), “Behaviour of geocell reinforced sand beds under strip loading”, *Can*. *Geotech*. *J*., **44**(7), 905-916.
Dewar, S. (1962), “The oldest roads in Britain”, *Countryman*, **59**(3), 547-555.
Fragaszy, R.J. and Lawton, E. (1984), “Bearing capacity of reinforced sand subgrades”, *J*. *Geotech*. *Eng*. *Div*., **110**(10), 1500-1507.
Guido, V.A., Chang, D.K. and Sweeny, M.A. (1986), “Comparison of geogrid and geotextile reinforced earth slabs”, *Can*. *Geotech*. *J*., **23**(4), 435-440.
Hatami, K., Bathurst, R.J. and Di Pietro, P. (2001), “Static response of reinforced soil retaining walls with non-uniform reinforcement”, *J. Geomech*., **1**(4), 477-506.
Hegde, A. and Sitharam, T.G. (2013), “Experimental and numerical studies on footings supported on geocell reinforced sand and clay beds”, *J. Geotech*. *Eng*., **7**(4), 347-354.
Hegde, A. and Sitharam, T.G. **(**2015), “3-Dimensional numerical modelling of geocell reinforced sand beds”, *Geotext*. *Geomembr*., **43**(2), 171-181
IS 456 (1978), *Design Aids for Reinforced Concrete*, Bureau of Indian Standards, New Delhi, India.
IS 456 (2000), *Plain and Reinforced Concrete Code of Practice*, Bureau of Indian Standards, New Delhi, India.
Jian, C.J., Yan, S.W. and Zheng, Y.R. (2006), “The soil improvement methods and their applications to road construction”, *Ground Imp*., **10**(3), 103-112.
Jones, C.J.F.P. (1996), *Earth Reinforcement and Soil Structure*, Thomas Telford Publication, London, U.K.
Khalaj, O., Moghaddas Tafreshi, S.N., Mask, B. and Dawson, A.R. (2015), “Improvement of pavement foundation response with multi-layers of geocell reinforcement: Cyclic plate load test”, *Geomech*. *Eng*., **9**(3), 373-395
Khing, K.H., Das, B.M., Puri, V.K., Cook, E.E. and Yen, S.C. (1993), “The bearing capacity of a strip foundation on geogrid reinforced sand”, *Geotext*. *Geomembr*., **12**(4), 351-361.
Krishnaswamy, N.R. and Rajagopal, K. (2001), “Bearing capacity of strip footings supported on geocell-reinforced sand”, *Geotext*. *Geomembr*., **19**(4), 230-246.
Léonard, D., Vanelstraete, A. and Parewyck, S. (2002), “Structural design of flexible pavements using steel netting as base reinforcement”, *J. Geomech*., **2**(3), 291-303.
Madhavi, Latha, G. and Somwanshi, A. (2013), “Effect of reinforcement form on the bearing capacity of square footing on sand”, *Geotext*. *Geomembr*., **27**(6), 409-422.
Mittal, S. and Shukla, J.P. (2007), *Soil Testing for Engineers*, Khanna Publishers, Delhi, India.
Mittal, S. (2013), *An Introduction to Ground Improvement Engineering*, Scientific International Pvt. Ltd. Publishing House, New Delhi, India.
Moghaddas Tafreshi, S.N., Khalaj, O. and Dawson, A.R. (2013), “Pilot-scale load tests of a combined multilayered geocell and rubber-reinforced foundation”, *Geosynth*. *Int*., **20**(3), 143-161.
Moghaddas Tafreshi, S.N., Khalaj, O. and Dawson, A.R. (2014), “Repeated loading of soil containing granulated rubber and multiple geocell layers”, *Geotext*. *Geomembr*., **42**(1), 25-38.
Ngo, N., Indraratna, B., Rujikiatkamjorn, C. and Mahdi Biabani, M. (2016), “Experimental and discrete element modelling of geocell-stabilized subballast subjected to cyclic loading”, *J. Geotech*. *Geoenviron*. *Eng*., **142**(4), 04015100-1-04015100-14.
Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L. and Halahmi, I. (2010), “Investigation of factors

influencing behavior of single geocell reinforced bases under static loading", *Geotext*. *Geomembr*., **28**(6), 570-578.
Sitharam, T.G, Sireesh, S. and Dash, S.K. (2005), "Model studies of a circular footing supported on geocell-reinforced clay", *Can*. *Geotech*. *J*., **42**(2), 693-703.
Zhou, H. and Wen, X. (2008), "Model studies on geogrid or geocell reinforced sand cushion on soft soil", *Geotext*. *Geomembr*., **26**(3), 231-238.

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