Analysis on foundations reinforced with geocell

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Abstract - *Most residential buildings are constructed of shallow footing. If soil shows low bearing capacity, deep foundations are adopted. But it is uneconomical to construct a deep foundation for residential purpose. So, in order to reduce the construction cost and strengthen the soil, soil reinforcement methods are adopted. Geocell reinforcement is one of the effective ways to reduce the soil settlement. In this paper, the possibility and effects of providing geocell reinforcement on conical shell footing, isolated footing and strip footing are determined. A comparison on single and multilayer geocell reinforcement on these foundations are analyzed. Also, the effect of varying cohesion value of soil and friction angle value of soil on these foundations reinforced with geocell is determined.*

Key Words: **Geocell, Conical shell footing, Isolated footing, Strip footing, Settlement, Bearing capacity**

1.INTRODUCTION

Soil reinforcement techniques is the means of giving strength to the soil. If the soil is having low bearing capacity and high settlement, the only way to reduce this condition is soil reinforcement. Several soil reinforcement methods are available nowadays. In the beginning, the soil is reinforced using bamboos, straws, reeds etc. But due to the innovations in construction field and difference in construction techniques, the natural reinforcement method was unable to take heavy loads and cause higher settlement. So, the natural reinforcement technique is replaced with modern technique. One of the most commonly adopted reinforcement methods nowadays is geocell reinforcement. Geocell is a three-dimensional polymer membrane used to strengthen the weak soil. It is a mesh like structure, the pockets or cell like shape is filled with locally available soil. Mostly they are used for enhancing the strength of road, embankments, protection of slope etc. The fig below shows the geocell filled with soil.

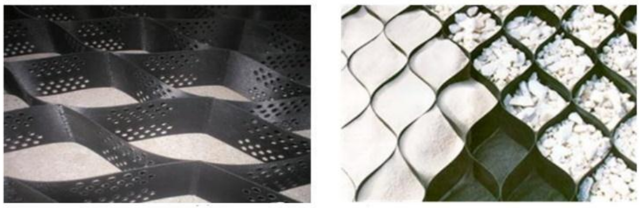

Fig -1 Geocell

The main aim and objective of this project is to analyze the settlement behavior and bearing capacity of conical shell footing reinforced with single and multiple geocell. And to compare these footing with isolated footing and strip footing. A parametric study on varying the cohesion and friction angle has been conducted to find the effect of these footings on different soil and to determine their settlement and bearing capacity.

1.1 Geocell reinforcement

Geocell reinforcement is one of the soil reinforcement techniques used to strengthen the weak soil. Several reinforcement methods are available nowadays. But this technique is unique is because they are very cost effective and can even be used for foundation purpose. Geocells are three-dimensional in shape and cells or the pockets of geocell are filled with sand, gravel or locally available materials. Due to its mesh like, the pockets encase the soil and provide enrich support to weak soil. This will help in spreading the vertical forces to a much wider area. This is developed by U. S. Army to strengthen the weak soil material. Providing multilayers of geocell give additional strength to the soil. Providing multilayers of geocell to the soil give additional strength to the soil.

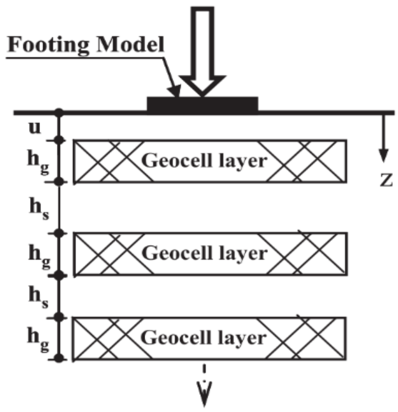

Fig -2 Multilayer geocell reinforcement

Where u is the height of the soil from the footing base to the top of the geocell, h_g is the height of the geocell and h_s is the height of the soil layer between the geocells. Multilayers of geocells helps in reducing the stress developed inside the soil to a great extent. Therefore, the settlement or the deformation thereby reduces.

2. NON-LINEAR ANALYSIS OF CONICAL SHELL FOOTING REINFORCED WITH SINGLE AND MULTILAYER GEOCELL

Non-linear analysis of conical shell footing, isolated footing and strip footing reinforced with single and multilayers of geocell is done using ABAQUS CAE 2018 software.

2.1 Material properties and dimensions

Detailed dimensions and material properties of conical shell footing reinforced with single and multilayer geocell are discussed in table 1 below.

Table - 1 Material properties and dimensions

Properties	Soil bed	Core soil	Footing	Geocell
Young's modulus, E (kN/m^2)	11000	11000	1.61×10^{10}	275000
Poissons ratio, ν	0.3	0.3	0.25	0.45
Cohesion, c (kPa)	0.35	0.35	-	
Friction angle, ϕ (◦)	37	37	-	30
Unit weight, γ (kN/m^3)	17.6	17.6	-	-
Dimension	0.8 m x 0.8 m x 0.64 m	-	-	-
Cell size (mm)	-	-	-	240 x 210 x 150

2.2 Loading and boundary conditions of one-layer geocell reinforced conical shell footing

The base of the footing is provided with fixed support condition and all the other four sides are provided with rotation or displacement. A contact tie is given to the footing and soil bed in order to provide smooth flow of load to the foundation soil.

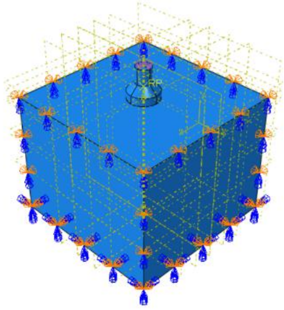

Fig -3 Loading and boundary conditions

An applied pressure of 600kPa is applied at the top surface of the conical shell footing. The assembled model and section view of conical shell footing reinforced with one-layer geocell is given below;

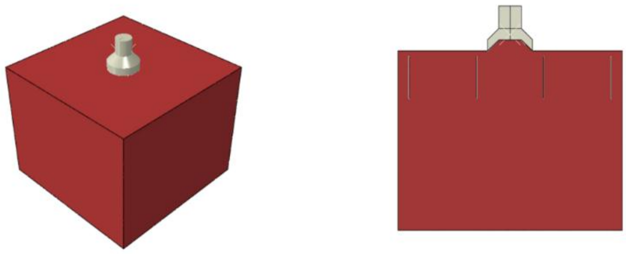

Fig -4 Assembled model and section view of geocell reinforced conical shell footing

2.3 Analysis result of one-layer geocell reinforced conical shell footing

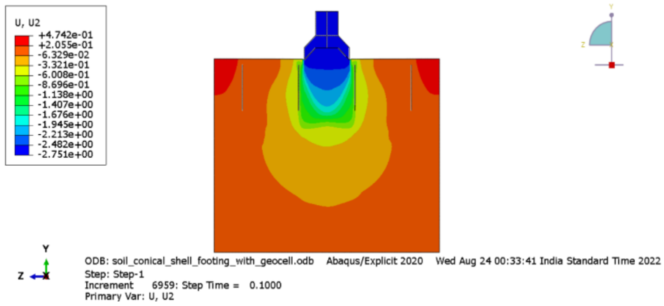

Fig -5 Settlement analysis result of one-layer geocell reinforced conical shell footing

The analysis result shows that by applying one-layer geocell to the conical shell footing give an ultimate settlement value of 2.75mm and an upward soft lift of -4.742mm. this result shows that, when an applied pressure is applied to the footing only a small settlement is noticed while comparing with unreinforced conical shell footing.

2.4 Two-layer geocell reinforced conical shell footing

The geocells are placed in two layers. The height of the soil is taken as 0.32m, ie; 2D (2 x 0.16). Same applied pressure, meshing and boundary conditions are provided with this.

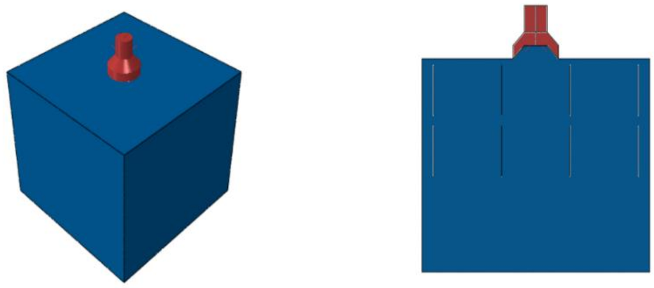

Fig -6 Assembled view and section

The figure shows the assembled view and section view of two-layer geocell reinforced conical shell footing.

2.5 Analysis result of two-layer geocell reinforced conical shell footing

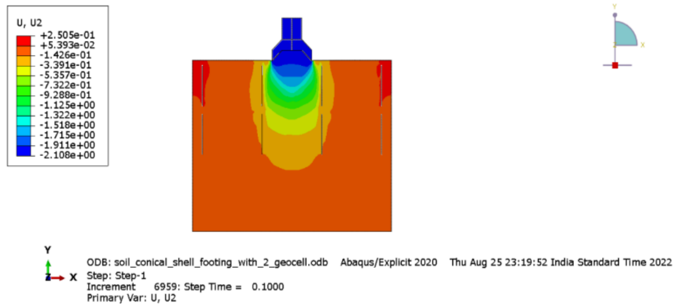

Fig - 7 Settlement analysis result of one-layer geocell reinforced conical shell footing

The analysis result shows that the two-layer geocell reinforced conical shell footing on applied pressure shows an ultimate maximum settlement of 2.108mm and an upward soil lift of -0.250mm. this shows that on increasing the number of layers of geocell, the settlement of the footing reduced to a noticeable limit.

2.6 Two-layer geocell reinforced conical shell footing

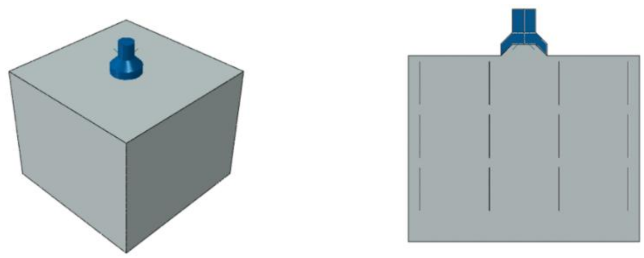

Fig -8 Assembled model and section view

Fig 8 shows the assembled model and section view of single layer geocell reinforced conical shell footing.

2.7 Analysis result of three-layer geocell reinforced conical shell footing

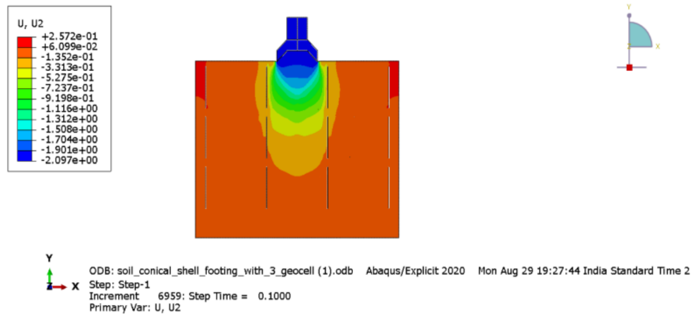

Fig - 9 Settlement analysis result of three-layer geocell reinforced conical shell footing

The settlement result concluded that, there shows an ultimate minimum settlement of 2.09mm and minimum soil uplift of -0.257mm. thus, when soil settlement is reducing on increasing number of layers, the bearing capacity can be increased.

2.8 Comparison of single and multilayer geocell reinforced conical shell footing

Table – 2 Comparison result of one-layer, two-layer and three-layer geocell reinforced conical shell footing

Geocell layer	Umax (mm)	Umin (mm)
One layer	2.75	-0.474
Two layers	2.10	-0.250
Three layers	2.09	-0.257

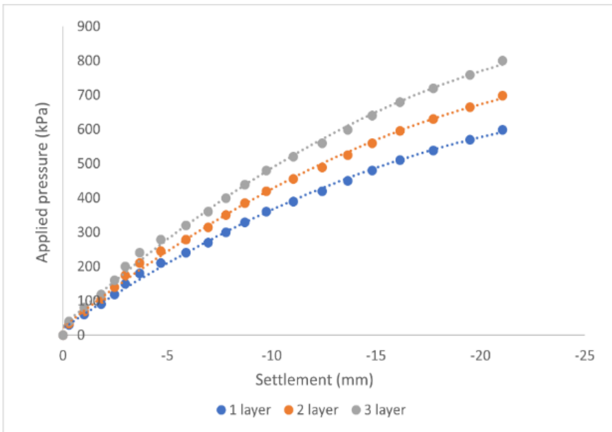

Chart - 1 Comparison result on the bearing capacity of multilayer geocell reinforced conical shell footing

The analysis result concluded that, three-layer geocell reinforced conical shell footing offers good minimum settlement result. Thus, three-layer geocell below footing helps in reducing the settlement and bearing capacity of footing can be reduced.

3. NON-LINEAR ANALYSIS OF ISOLATED FOOTING REINFORCED WITH SINGLE AND MULTILAYER GEOCELL

In this section, geocell reinforced in single and multilayer geocell is applied to the isolated footing. One of the most commonly adopted shallow footing is isolated footing. This directly transfer heavy loads to the foil in a much wider area. This footing is provided with same pressure, boundary conditions and soil material properties same as the conical shell footing. The fig 10 shows the detailed dimensions of isolated footing, where H1 is 40cm, H2 is 20cm and size is 170cm x 110cm.

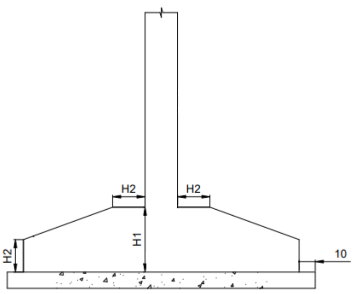

Fig – 10 Isolated footing

3.1 One-layer geocell reinforced isolated footing

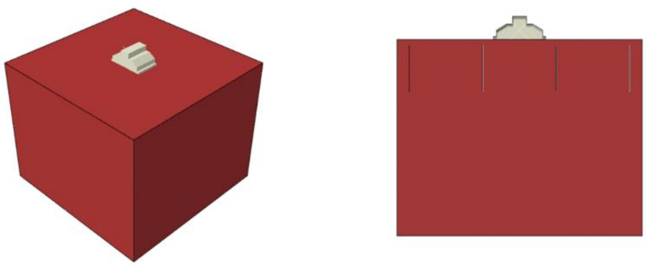

Fig -11 Assembled model and section view

Fig 11 shows the assembled model and section view of isolated footing reinforced with one-layer geocell. Footing is provided with same applied pressure same given to the conical shell footing.

3.2 Analysis result of one-layer geocell reinforced isolated footing

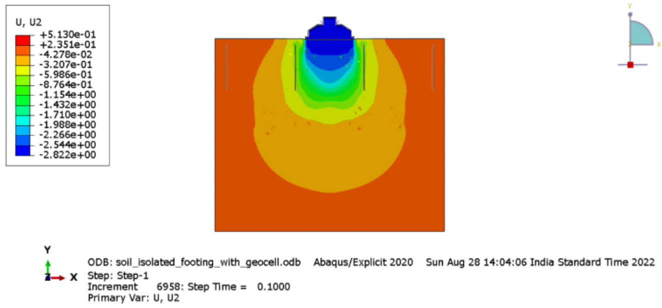

Fig - 12 Settlement analysis result of one-layer geocell reinforced isolated footing

Fig 12 shows the settlement analysis result of on-layer geocell reinforced isolated footing. From the analysis result, the maximum ultimate settlement occurred due to the applied pressure is 2.822mm and minimum upward soil lift of -0.513mm

3.3 Two-layer geocell reinforced isolated footing

Fig 13 shows the assembled model and section view of geocell reinforced on two layers isolated footing. Providing two-layers of geocell helps in reducing the settlement compared to one-layer geocell. this is an effective way to reduce the settlement due to heavy loads.

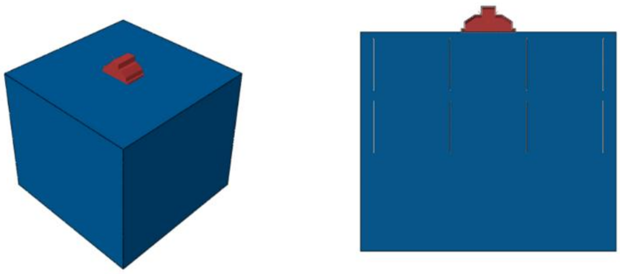

Fig -13 Assembled model and section view

3.4 Analysis result of two-layer geocell reinforced isolated footing

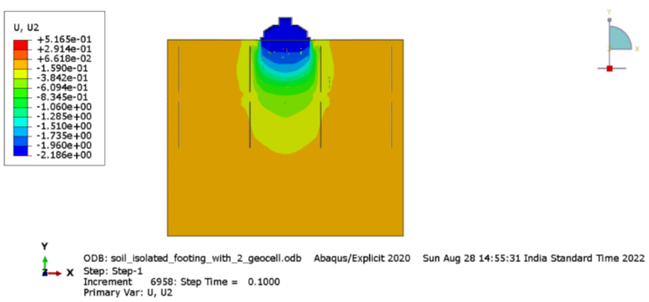

Fig - 14 Settlement analysis result of two-layer geocell reinforced isolated footing

Settlement result of two-layer geocell reinforced isolated footing is shown in fig 14. The analysis results concluded that, there shows an ultimate maximum settlement of 2.186mm and minimum soft uplift of -0.516mm is noted.

3.5 Three-layer geocell reinforced isolated footing

Geocells are placed on three layers as shown in fig 15. This gives additional strength to the weak soil. Same pressure, boundary conditions are applied to this soil bed.

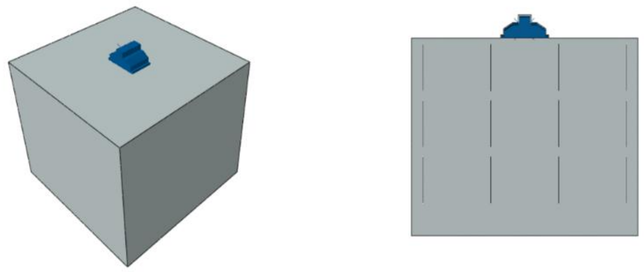

Fig -15 Assembled model and section view

3.6 Analysis result of three-layer geocell reinforced isolated footing

The analysis result shows that, there occurred a maximum ultimate settlement of 2.163mm and minimum soil uplift of -0.509mm.

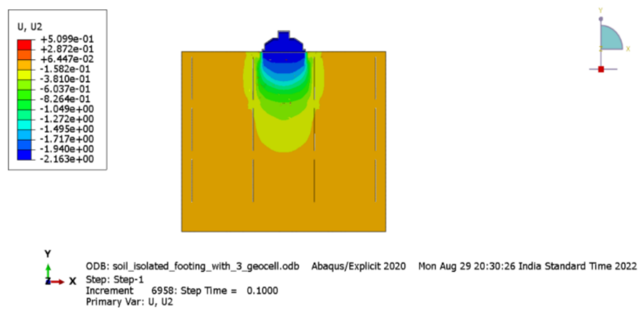

Fig - 16 Settlement analysis result of three-layer geocell reinforced isolated footing

2.8 Comparison of single and multilayer geocell reinforced isolated footing

Table – 3 Comparison result of one-layer, two-layer and three-layer geocell reinforced isolated footing

Geocell layer	Umax (mm)	Umin (mm)
One layer	2.822	-0.513
Two layers	2.186	-0.516
Three layers	2.163	-0.509

On comparing the results, three layers of geocell give minimum settlement on comparing with one-layer and two-layer geocell. And this shows only a minimum uplift value. Thus, the bearing capacity of the soil is increased.

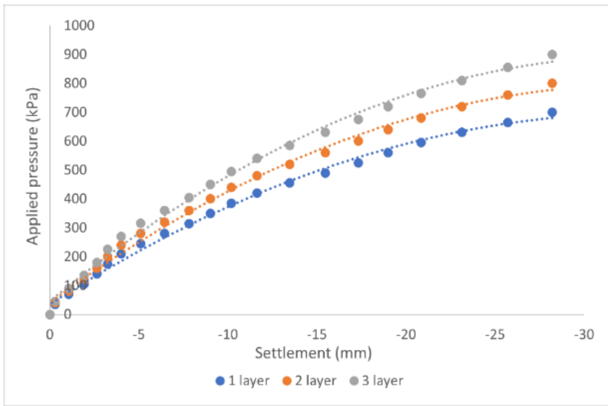

Chart – 2 Comparison result on the bearing capacity of multilayer geocell reinforced isolated footing

4. NON-LINEAR ANALYSIS OF STRIP FOOTING REINFORCED WITH SINGLE AND MULTILAYER GEOCELL

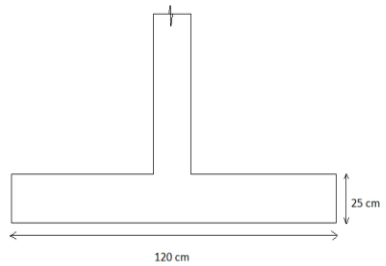

Fig - 17 Strip footing

One of the most commonly adopted shallow footing is strip footing. This footing helps in directly transferring the heavy loads through the walls to the footing to the soil.

4.1 One-layer geocell reinforced strip footing

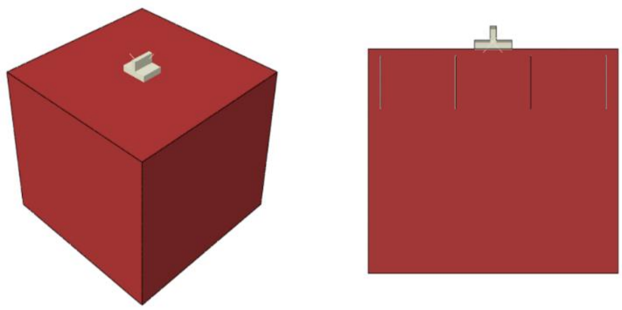

Fig -18 Assembled model and section view

Fig 18 shows the assembled model and section view of strip footing reinforced in one-layer.

4.2 Analysis result of one-layer geocell reinforced strip footing

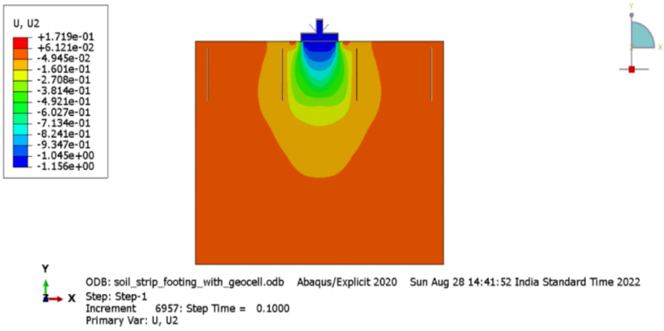

Fig - 19 Settlement analysis result of one-layer geocell reinforced strip footing

The analysis result concluded that, there shows a maximum ultimate settlement of 1.156mm and minimum soil uplift of -0.171mm.

4.3 Two-layer geocell reinforced strip footing

The geocell layers are placed on two layers below the footing. This way, the settlement can be reduced for a weak soil base.

Fig -20 Assembled model and section view

4.4 Analysis result of two-layer geocell reinforced strip footing

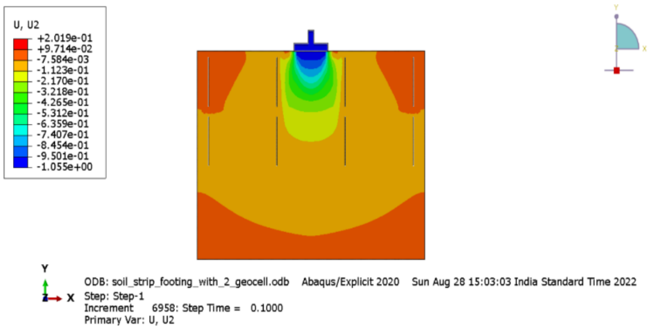

Fig - 21 Settlement analysis result of two-layer geocell reinforced strip footing

The settlement analysis result shoes that, the ultimate maximum settlement of 1.055mm and minimum upward soil lift of -0.201mm was noticed. Compared to one-layer geocell two-layer geocell reinforced strip footings show better settlement reduction.

4.5 Three-layer geocell reinforced strip footing

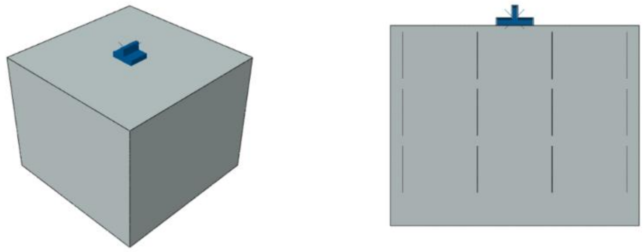

Fig -22 Assembled model and section view

Fig 22 shows the assembled model and section view of three-layer geocell reinforced strip footing. Geocells are placed in three-layers below the footing.

4.6 Analysis result of three-layer geocell reinforced strip footing

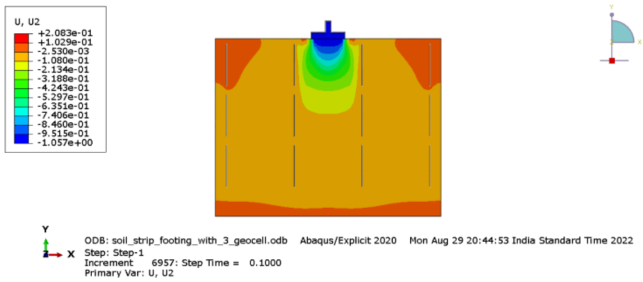

Fig - 23 Settlement analysis result of three-layer geocell reinforced strip footing

The result of the analysis shows, the ultimate maximum settlement observed is 1.057mm and minimum upward soil lift is -0.208mm.

4.7 Comparison of single and multilayer geocell reinforced strip footing

Table – 4 Comparison result of one-layer, two-layer and three-layer geocell reinforced strip footing

Geocell layer	Umax (mm)	Umin (mm)
One layer	1.156	-0.171
Two layers	1.055	-0.201
Three layers	1.057	-0.208

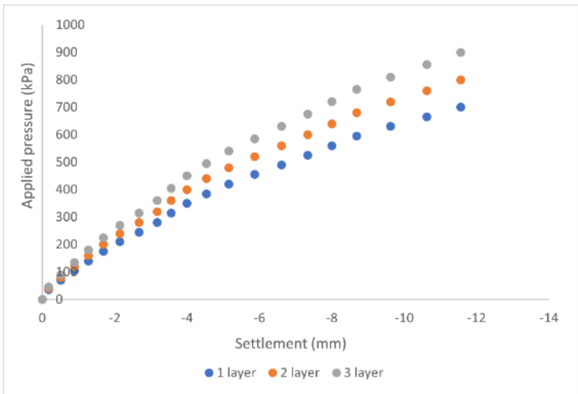

Chart – 3 Comparison result on the bearing capacity of multilayer geocell reinforced strip footing

On comparing the results of one-layer, two-layer and three later geocell reinforced strip footing, three-layer geocell reinforced strip footing offers better settlement reduction. Thus, by reducing the settlement, the bearing capacity of the soil is increased.

5. EFFECT OF COHESION AND FRICTION ANGLE OF CONICAL SHELL FOOTING, ISOLATED FOOTING AND STRIP FOOTING REINFORCED WITH ONE-LAYER GEOCELL

On varying the value of cohesion and friction angle of conical shell footing, isolated footing and strip footing reinforced with single layer geocell, we can find whether this is feasible for construction or not on different soil conditions.

Table – 5 Effect of varying cohesion and friction angle value on conical shell footing reinforced in one-layer

	Umax (mm)	Umin (mm)
Cohesion		
3kPa	1.480	-0.023
5kPa	1.303	0
7kPa	1.198	0
9kPa	1.133	0
Friction angle		
35°	3.560	-0.718
39°	2.151	-0.296
41°	1.783	-0.180
43°	1.481	-0.109

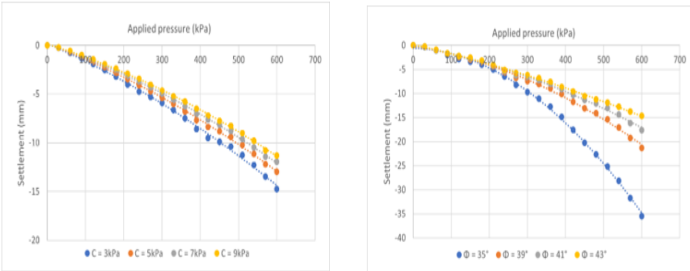

Chart – 4 Effect of variation of cohesion and friction angle on bearing capacity of conical shell footing reinforced in one-layer

Table – 6 Effect of varying cohesion and friction angle value on isolated footing reinforced in one-layer

	Umax (mm)	Umin (mm)
Cohesion		
3kPa	1.568	-0.320
5kPa	1.334	-0.248
7kPa	1.225	-0.197
9kPa	1.148	-0.159
Friction angle		
35°	3.509	-0.704
39°	2.281	-0.393
41°	1.849	-0.267
43°	1.555	-0.211

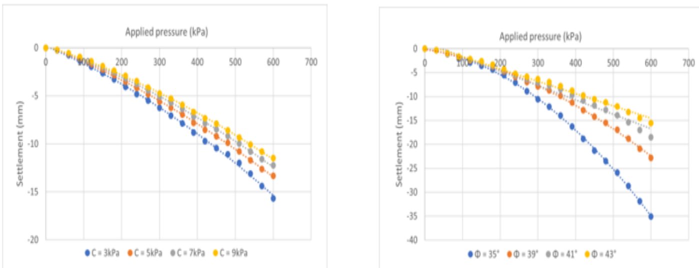

Chart – 5 Effect of variation of cohesion and friction angle on bearing capacity of isolated footing reinforced in one-layer

Table – 7 Effect of varying cohesion and friction angle value on strip footing reinforced in one-layer

	Umax (mm)	Umin (mm)
Cohesion		
3kPa	0.758	-0.031
5kPa	0.661	0
7kPa	0.593	0
9kPa	0.533	0
Friction angle		
35°	1.483	-0.371
39°	0.933	-0.067
41°	0.820	-0.015
43°	0.738	0.005

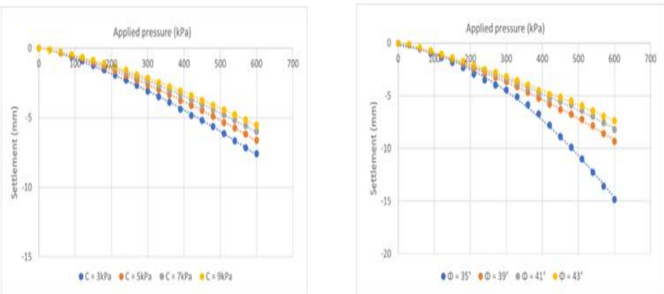

Chart – 6 Effect of variation of cohesion and friction angle on bearing capacity of strip footing reinforced in one-layer

6. CONCLUSIONS

Geocell helps in reducing the settlement in a much effective way. On providing geocell to the weak soil base, the soil become much stiffer, stronger and thereby bearing capacity of the soil can be increased. Providing geocell in multilayers helps in increasing the bearing capacity of soil compared to single later geocell reinforcement, thus, the settlement can be reduced in an effective way. On comparing one-layer, two-layer and three-layer geocell to a soil base, three-layer geocell reinforcement offers a reduction in settlement for conical shell footing, isolated footing and strip footing systems. On increasing the value of cohesion and friction angle of soil, the shear strength of the soil can be increased, thus the bearing capacity of soil increases and settlement reduces.

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