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Evaluation of Surface Deformation in Geocell Reinforced and Unreinforced Bases over Weak Subgrade

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Abstract. Geocell, a type of geo-synthetic material widely used as reinforcement, has encouraged the civil engineers to build roads over weak subgrades. Major concerns in pavement construction are lack of good constructions sites and inadequate base course structural strength. Pavement undergoes two types of failures viz. rutting and distress. Geocell plays a vital role in reduction of surface deformations by providing a three dimensional cellular confinement. Static plate load tests were conducted on unreinforced and geocell reinforced bases to study the effect on surface deformations. Geocell with three different heights (100 mm, 125 mm and 150 mm) were used to reinforce base course. This paper contributes to understanding how geocell reinforcement lowers the surface deformations in pavements. Thickness of base plays a crucial role in stability of pavement, the effect of varying base course thickness was also investigated, it was observed that with increase in base thickness the load distributed over a wider area thus decreasing the effects of rutting. The paper also discusses the increase in bearing capacity ratio due to geocell reinforcement. The overall findings showed that with the inclusion of geocell in base course, the surface deformations decreased.

Keywords: Geocell, Weak Subgrade, Plate load test, Pavement, Surface deformation

1 Introduction

Most of the previous research relies on laboratory experiments to study behaviour of geocell in soil and pavement. The geocell reinforcement increases the bearing capacity of the footing and embankment (Cowland and Wong 1993; Dash et al 2003; Han et al 2008; Sireesh et al 2009; Yang et al 2010; Zhang et al 2010). Previous findings showed that geocell-reinforced bases could withstand 1.5-2 times more loads depending on type and size of geocell (Pokharel et al 2009; Bathurst and Karpurapu 1993; Rajagopal et al 1999; Mengelt et al 2006; Wesseloo et al 2009). Geocell reinforcement improved the resilient modulus of granular materials from 1.4 to 3.2 % and 16.5 to 17.9 %, in case of fine-grained soils. To evaluate the bearing capacity, laboratory model tests have been conducted on sand bed-confined with geocell reinforcement. The test findings showed an increase in bearing capacity by up to 8 times that of the unreinforced section (Dash et al 2001). The geocell-reinforced sandy soil under static and cyclic loading showed 40 % improvement in the bearing capacity of sandy soil as well as an increasing trend with the increase in the height of the geocell (Chang et al 2007; Chang et al 2008). The researchers found that the geocell height and width effectively decreased the footing settlement (Tafreshi et al 2011). Geocell undergoes the slab or beam effect which can be observed by the strain produced within geocell due to vertical load (Rajagopal et al. 1999; Dash et al. 2004; Zhou and Wen 2008). The geocell has higher tensile strength than the infill material, the deformed geocell reinforced base exerts upward reaction and reduces net vertical stress on top of subgrade. The geocell reinforcement increases the bearing capacity of unpaved test section by 1.25 times than that of unreinforced base (Sheikh & Shah 2020a).

The experimental findings illustrated that the strength, stiffness and size of the geocell effect the efficiency of the reinforced-sand base bed (Dash 2011). Most of the research so far has concentrated on circular or box-shaped geocells. Nevertheless, geocells are laid in a curved or circular form by and by these days (Rea and Mitchell 1978). The geocell with circular shape had no significant change and showed stiffer and strong response as compared to the elliptical geocell (Pokharel et al 2010). The researchers found that the geocell height and width effectively decrease the footing settlement (Tafreshi et al 2011). The geocell material characteristics influenced the stiffness and bearing capacity of the geocell-reinforced base, thus decreasing the deformation and differential settlement of pavements built over weak subgrade (Bathurst and Jarrett 1988; Al Qadi and Hughes 2000). Plate load experiments concluded that as a consequence of lateral expansion, the unconfined geocell had a reduced stiffness but higher bearing capacity compared to confined geocell (Pokharel et al 2009).

The objective of this study is to evaluate the use of geocell reinforcement for limestone aggregate base course. Experimental investigation was conducted on geocell reinforced and unreinforced base under static loading. A series of static and repeated loading were conducted (Pokharel et al. 2009, Pokharel et al. 2010). The results show positive benefits of geocell reinforcement by increasing the bearing capacity of unpaved test section.

2 Material Properties

2.1 Geocell and Geotextile

The high density polyethylene (HDPE) manufactured by strata geosystems Pvt Ltd was used to reinforce base course material. The geocell with three different heights 100mm, 125mm and 150mm was used in this study (as shown in Figure 1). The tensile strength of geocell were 1.77 kN/m^2, geocell walls was rough to prevent the uplifting of infill material. The geocell confines the base course material in lateral and vertical direction. The non-woven geotextile of 350 GSM was used as a separator between base and subgrade. It prevents the penetration of aggregates into weak subgrade thus lowers the rut depth of base course.

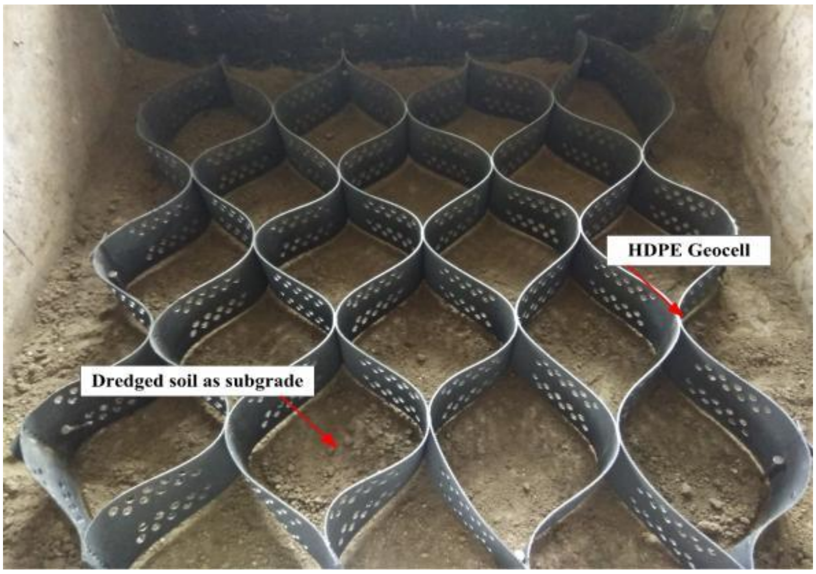

Fig. 1. Shows geocell reinforced placed on top of weak subgrade.

2.2 Subgrade

Subgrade in this study was dredged sediments extracted from Shalimar basin of Dal lake Srinagar (34.143196N, 74.861621E). The dredging process leads to accumulation of huge of quantity of dredged sediments, which needs to be disposed so as to preserve environment. The study aims to present the reuse of dredged soil as an alternative material for subgrade construction. Table 1 is showing the engineering properties of dredged soil. Based on the properties, dredged soil needs improvement. Thus in this study the stresses transferred on top of subgrade are decreased by inclusion of geosynthetics in base course. The gradation curve of subgrade is shown in fig. 2. Material similar to such properties was also used by researchers for improvement (Wani and Mir 2019, 2020).

Table 1. Properties of dredged soil used as subgrade.

Properties	Description (Value)
Liquid Limit (%)	42
Plastic Limit (%)	29
Plasticity Index (%)	13
Classification	MI
Maximum dry unit weight (kN/m^3)	16
OMC (%)	19
CBR	5

2.3 Base Course

The base course used in study was limestone aggregates collected from a local stone crusher in Srinagar (34.0167° N, 74.7989° E). The study aims to present the performance of limestone aggregates as infill material in base course. Parametric study consists of varying base course thickness and geocell height, it was observed that the limestone aggregates undergo large deformation. The deformation on the surface of base course is due to penetration of aggregates into weak subgrade, which leads to the excessive rut depth. In order to restrict the lateral and vertical deformation of limestone aggregate base, geocell reinforcement provides the confinement to the infill material thus decreasing the deformation of the pavement. Three different base course thicknesses were used in this study (120mm, 150mm and 200mm). The specific gravity of aggregates was 2.74 while as water absorption was 1%. Grain size distribution curve is shown in Fig. 2.

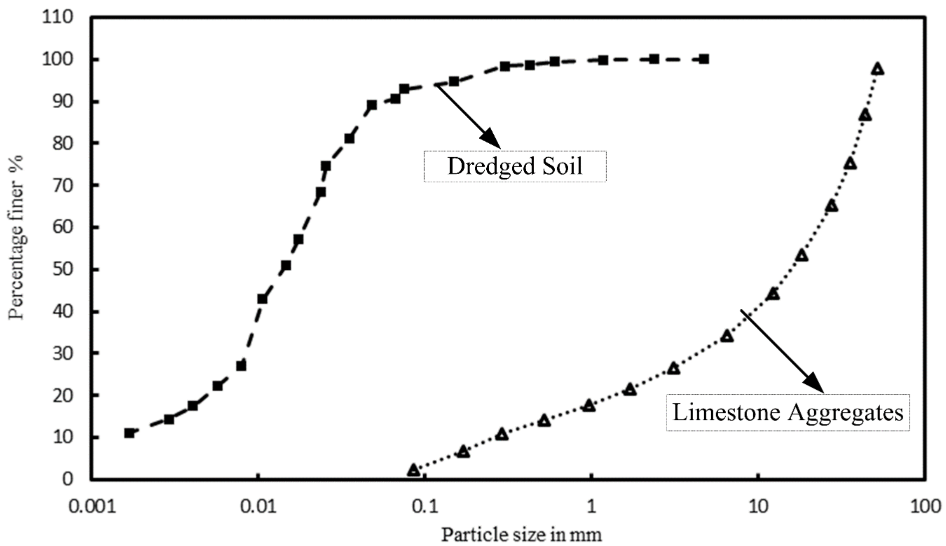

Fig. 2. Shows gradation curve of dredged soil and limestone aggregates.

3 Test Section Preparation

Thirteen unreinforced and reinforced test section were prepared in a test tank of volume 1 m^3. Three unreinforced and ten reinforced sections were evaluated under static loading. The unpaved test section comprised of two layers subgrade of 0.45 m thickness and the base course of 120, 150 and 200 mm thickness. The subgrade was compacted at 19 % OMC to obtain target CBR value of 5 %. After the preparation of subgrade, the linear differential transducers were installed on top of the footing. In this study, 100, 125, 150 mm high geocell were used to reinforced base course material. A layer of geotextile acts as a separator between weak subgrade and base course to decrease rutting. The test setup used in this study is shown in Fig. 3. The authors have previously worked on the same setup as this work is related to the PhD work of the first author (Sheikh & Shah 2020).

4 Instrumentation

The study was performed in test tank of $1m^3$, fabricated at Geotechnical Laboratory, National Institute of Technology Srinagar. The loading frame consists of a loading jack of 150 kN capacity, with a steel footing of 30cm×30cm. For each load increment the deformation is recorded on top of footing using LVDT (linear differential transducer). The LVDT's are connected to the data logger manufactured by Tokyo Sokki Kenkyujo Japan. The software used to collect data was static measurement software (TDS-7130v2).

5 Test Results and Discussion

5.1 Improvement in bearing capacity

The bearing capacity of various test sections was calculated at 25 mm deformation from load versus deformation plot obtained by performing static plate load test on various unreinforced and reinforced test sections. It was observed that being structurally weak the limestone aggregate base undergoes large deformations. The excessive deformation leads to lowering the bearing capacity of unpaved test section. The geosynthetics reinforcement lowers the excessive deformation, thus increases the bearing capacity of unpaved test section. The variables used in the study of the pressure-deformation as shown in Figures. In these Figures, "B" with number is showing the base course thickness, G with number is showing geocell height, "GT" is showing geotextile reinforcement at the interface of base and subgrade. Indexes "UR" represent unreinforced base. It is clear from fig. 3 the bearing capacity of geocell reinforced base is more as compared to unreinforced base of same thickness. The bearing capacity increases from 280 kPa to 375 kPa. It was observed that the bearing capacity of 120 mm thick geocell and geotextile reinforced base increased to 400 kPa. The increase of 25 kPa of bearing capacity is attributed to the separation provided by the geotextile that prevents the penetration of aggregates into weak subgrade.

The unreinforced 150mm base as shown in fig. 4 shows a bearing capacity of 430 kPa, Similarly after inclusion of 100mm high geocell the bearing capacity increases to 510 kPa. When non-woven geotextile was placed between the base and subgrade the bearing capacity increases by 700 kPa which is higher as compared to geocell reinforced base of same thickness. As the geocell height increases from 100mm to 125mm in same base, the bearing capacity of 125mm high geocell reinforced limestone aggregate base increases to 775 kPa. The increase in the bearing capacity is attributed to the confinement provided by geocell reinforcement. The increase in the height of geocell decreases the lateral and vertical deformation of base course. The combined use of 125 mm high geocell and non-woven geotextile increases the bearing capacity to 810 kPa.

The unreinforced base of 200 mm base shows a bearing capacity of 550 kPa, which is lesser as compared to geosynthetic reinforced base of lesser thickness. Thus the bearing capacity of geocell reinforced as shown in fig. 5 increases to 870 kPa. The 125 mm high geocell and non-woven geotextile reinforcement increases the bearing capacity by 30 kPa as compared to geocell reinforced base of same thickness. Similarly, by varying the geocell height from 125mm to 150mm in 200mm thick base, it was observed that the bearing capacity further increases by providing extra confinement to the infill material. It was also observed that the bearing capacity increases to 940 kPa. Further the separation provided by geotextile and confinement provided by 150 mm geocell increases bearing capacity to 960 kPa. The above results are in good agreement with the findings obtained by various researchers (Sheikh and Shah 2020, Arias and Tandon 2020, Isik and Gurbuz 2020, Siabil and Dawson 2020). The test results are summarized in table 2.

Table 2. Summarizes the test results obtained from plate load test.

Infill material	At 25 mm deformation		
Test Section	Bearing Capacity (kPa)	Ultimate Bearing Capacity Ratio (BCR_u)	Improvement Factor (I_{UBC})
UR 120	280	NA	NA
B120G100	375	1.34	0.34
B120G100+GT	400	1.43	0.43
UR 150	430	NA	NA
B150G100	510	1.18	0.18
B150G100+ GT	700	1.63	0.63
B150G125	775	1.81	0.80
B150G125+GT	810	1.88	0.88
UR 200	550	NA	NA
B200G125	870	1.58	0.58
B200G125+GT	900	1.64	0.64
B200G150	940	1.71	0.71
B200G150+GT	960	1.75	0.75

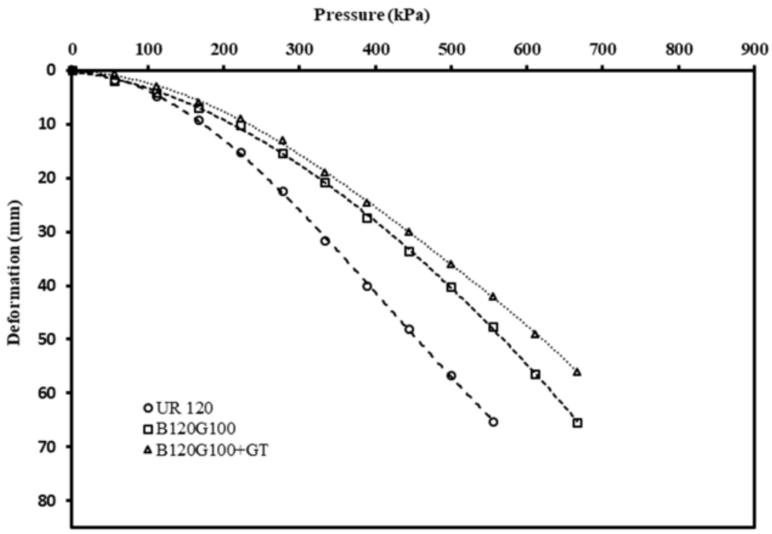

Fig. 1. Pressure vs. deformation of 120mm limestone aggregate base reinforced with geocell and geotextile.

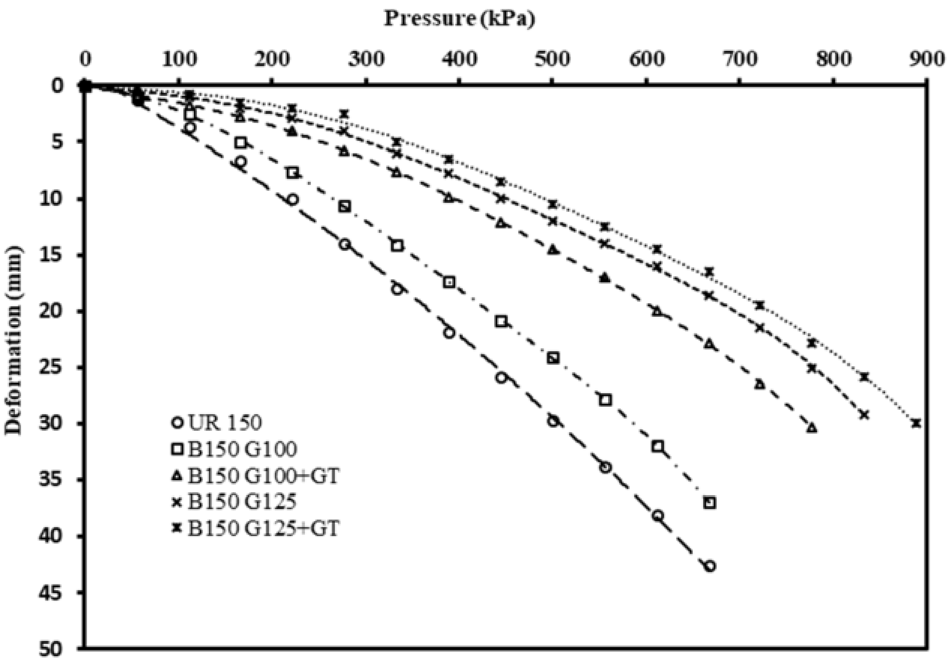

Fig. 2. Pressure vs. deformation of 150mm limestone aggregate base reinforced with geocell and geotextile.

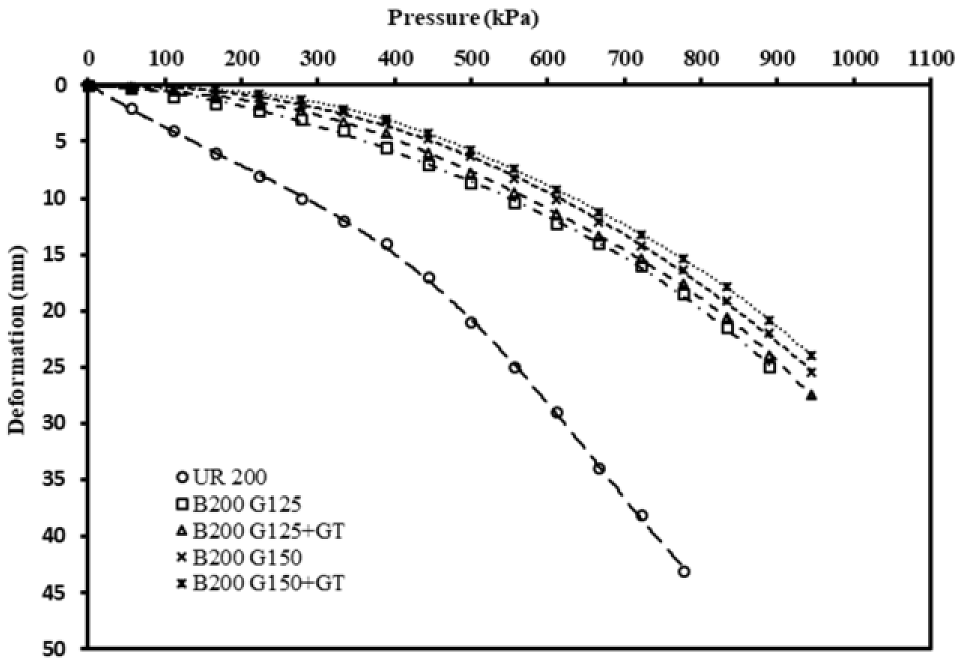

Fig. 3. Pressure vs. deformation of 200mm limestone aggregate base reinforced with geocell and geotextile.

6 Conclusions

Based on the results, following conclusion can be drawn:

1. The average bearing capacity improvement factor for 120 mm, 150 mm and 200 mm base reinforced with geocell and geotextile were found to be 38%, 62% and 68% respectively.
2. For each 25mm of addition of geocell height the average bearing capacity increases by 167 kPa. Maximum bearing capacity were obtained for 200 mm thick base. The increase in bearing capacity from 280 to 960 kPa is attributed to the geosynthetic reinforcement.
3. The above results proved that geosynthetics distribute the load over a wider spread, thus increases the bearing capacity of unpaved test sections.
4. The dredged soil used in this study proved to be more sustainable solution and environmental efficient.

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