REINFORCEMENT OF POOR SANDY SUBGRADE SOIL WITH GEOGRID

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Abstract

The type of materials such as subgrade, subbase and base has a great effect on the quality and life of pavement. The nature of subgrade soil has the most important effect among other materials. There is a real concern in construction flexible pavements over a weak subgrade and the California bearing ratio (CBR) is very low for such soils. Therefore, the constructed pavements for such cases require more thickness. In fact, there is a need to look for economic methods in order to replace the lack of suitable construction materials for pavements such as subbase and base materials. This work studies the effect of geogrid reinforcement on CBR of subgrade soil and total pavement thickness. The soft sand soil from Al-Najaf city and one type of geogrid have been selected. It has been found that there is a significant improvement in CBR of subgrade resulting from geogrid reinforcement. The results indicated that the value of CBR was about 2.14% without using geogrid whereas this value was 12.84% in case of putting geogrid at 0.2H from the top of the specimen. Also, the reinforcement of subgrade with geogrid at 0.2 from the subgrade layer thickness will reduce the total pavement thickness by (30-40) %. Then, the same case study has been modeled using Plaxis (3D) software which is a finite element package. This package is equipped with specific features to deal with different complex cases and structures to simulate a realistic of case under study. The encouraging results have been obtained.

Keywords: California bearing ratio, geogrid reinforcement, 3D Plaxis and soft soil.

تسليح التربة الرملية الضعيفة باستخدام الجيوكرد

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الخلاصة

ان نوع مادة الترشة وطبقة تحت الاساس وطبقة الاساس لها تاثير كبير على نوعيه وطول مدة الطريق. ان نوع ونوعيه الترشة لها التاثير الاهم منشين المواد الاخرى. هناك قلق حقيقي عندما يتم انشاء الطريق الاسفلتي على ترشة ضعيفة وذات مشاكل. ان معامل CBR لتلك الترب هو جدا واطى. النقص في المواد ما تحت الاساس وطبقة الاساس يؤدي الى البحث عن طرق اقتصاديه لتحويل تلك الترب ذات المشاكل الى ترب ملائمه للانشاء. العمل الحالي يدرس تاثير التسليحشاستخدام Geogrid على معامل CBR للترشه وعلى السمك الكلي للطريق. الترشه الرمليه من مدينة النجف ونوع معين من ال Geogrid قد تم اختيارهم للدراسة. لقد

وجدشان هناك تحسين معتبر في CBR للترشهشسب وجود ال Geogrid . في حالة عدم استخدام ال Geogrid فان قيمة ال CBR المغمورشالماء هي ٢,١٤% وعند وضع ال Geogrid في 0.2H من قمة العينة فان الCBR تزداد الى ١٢,٨٤%. كذلك فان تسليح الترشةشاستخدام الGeogrid على 0.2 من سمك طبقة الترشة سوف يقلل من سمك التبليطشحوالي (٣٠-٤٠)%. شعد ذلك نفس الحالة الدراسية تم نمذجتهاشاستخدامشرنامج ال Plaxis والذي هوشرنامج يعتمد على العناصر المحدده. هذا البرنامج مزودشوسائل خاصه للتعامل مع حالات وتراكيب معقده مختلفة لمحاكاة الحالة الواقعيه قيد الدراسة. نتائج مشجعة تم الحصول عليها من البرنامج.

1. Introduction

The type of materials such as subgrade, subbase and base has a great effect on the quality and life of pavement. The nature of subgrade soil has the most important effect among other materials. There is a real concern in construction flexible pavements over a weak subgrade and the California bearing ratio (CBR) is very low for such soils. Therefore, the constructed pavements for such cases require more thickness (Nyakarura, 2009). To understand the behavior of subgrade, different factors may be considered such as high compressive and shear strength, the complexity of interrelationship of texture, moisture content, density, and strength of subgrade materials (Nagrale et al., 2010). Recently, several researchers have found that reinforced soil is one of the solutions to improve the problematic soil characteristics (Nagrale et al., 2010, Tiwari, 2011, Sun, 2015). Improving the engineering soil properties by replacing the soil from remote locations might not be a practical solution. Therefore, suitable stabilizer may be more effective way to improve the soil properties such as geogrid materials.

Geogrid has been playing an important role in solving geotechnical problems such as paved/unpaved roads constructed on weak subgrade. A lot of geotechnical problems, for paved/unpaved roads constructed on weak subgrade, have been solved by geogrid (Sun, 2015). Geogrid provides lateral confinement to resist the lateral movement of aggregates by the interlocking effect that happens between geogrid openings and surrounding aggregates. The presence of geogrid affects the resilient behavior of stabilized bases and benefits the stabilized bases by reducing permanent deformations (i.e. rutting) (Sun, 2015).

The current study focuses on improving sand soil using geogrid and determining the optimum location for the geogrid. Then, Plaxis 3D model has been adopted to model the current case. Using such model to represent geogrid in pavement is considered as the first step as indicated in the previous literature in the next section.

2. Geogrid and its usage

According to the literature, the most mentioned definition of a geogrid could be described as geosynthetic material utilized to reinforce soils and other similar materials. Geosynthetics, manufactured from polymeric materials, have been adopted to stabilize subgrade and base to construct unpaved structures for more than four decades (Giroud and Han, 2004) in addition to that, they have been playing a significant role in solving geotechnical problems (Qian et al., 2013; Wang et al., 2014). Generally, the materials used to manufacture geogrid consist of polypropylene, high density polypropylene, and high-tenacity polyester. Geogrid can be an uniaxial, biaxial, or triaxial regular network of integrally connected tensile elements. **Figure 1** indicates the three types of geogrid.

The thought of reinforcement is widely used starting from the early civilizations where they mixed straw or other fiber with soil to get better properties. The reinforcement materials used in pavement and subgrade mainly differ in their forms (sheets, strips or fibers), relative stiffness (polymeric fabrics and steel) and texture (smooth or rough) (Donald, and Harukazu, 1983).

Haas (1985) indicated that using reinforced flexible pavements with the polymer geogrid saves the asphalt thickness from 5cm to 10cm and increases the ability to 2 or 3 times traffic loads for same thickness. The use of geogrid in the granular base of a flexible pavement placed on sand was examined by Nejad and Small (1996). They noticed that a significant reduction in the value of the permanent deformation by 40% to 70%.

On the other hand, putting geogrid over sand subgrade and below gravel base course demonstrated that the increment in CBR of subgrade and decrement in the value of vertical settlement under loading (Montanelli et. al., 1997). Moreover, the authors also found from their work that is the value of CBR for reinforced sample is much higher than corresponding value of CBR for unreinforced sample and the settlement amount in reinforced sample with 3cm base course is less than unreinforced sample with 4cm base course.

According to Ling and Liu (2001), the influence of conducting some static and dynamic experiments on model sections containing geosynthetic reinforcement on the stiffness and strength of asphalt pavements indicated that the settlement for reinforced pavement over the loading area was higher when comparing with unreinforced pavement. The geogrid layer was placed above the subgrade and the asphalt layer was put on.

Overall, the best location of geogride layer is at 30 % of thickness measured from CBR mold as reported by Naeini and Moayed (2009). The merits of using geogrid with flexible pavement in terms of elongated service life and reducing its thickness have been reported by several studies (Haas, 1984; Love, 1984; Haas et al., 1988; Kinney et al., 1998; Perkins, 1999; Al-Qadi et al., 2008; Henry et al., 2009). The main aim of using geogrid in a flexible pavement is to reduce the permanent deformation by providing lateral restraint to the surrounding unbound pavement materials. Several attempts have been made to identify and correlate important characteristics of geogrids with reinforced pavement performance. However, no clear and quantifiable information on geogrids, specifically in relation to performance, is available; although, there are some indications that stiffness, junction strength, and aperture stability of geogrids have significant roles in strengthening effectiveness for pavements (Webster, 1993; Kinney and Yuan, 1995 and Tang, 2011).

Sun (2015) conducted a study to test cyclic and static plate loading on test sections of geogrid stabilized bases over subgrade under various loading intensities. The author also studied the vertical and horizontal pressures along the interface. Permanent and resilient deformations were observed by the researchers. The results demonstrate that both the vertical and horizontal stresses were redistributed due to the inclusion of geogrids. Vertical stresses were distributed to a wider area, while horizontal stresses were confined to a smaller area close to the loading plate. The presence of geogrids reduced permanent deformations but increased resilient deformations.

Rostami and Ghazavi(2015) determined the ultimate bearing capacity of surface strip footing on a sand slope reinforced with geogrid layers using an analytical method and they compared their results with experimental and numerical results. Parametric studies have also been performed to show the effects of contributing parameters such as number of geogrid layers, positions of reinforcement layers, soil properties and the slope angle on the bearing capacity of strip foundations placing on the reinforced sand. The authors figure out that the magnitude of bearing capacity for strip footings on the sand slope can be considerably increased using geogrid layers.

3- California Bearing Ratio (CBR) Test

Many pavement design methodologies incorporate California Bearing Ratio (CBR) values into the formulation of pavement sections. The test typically performed to determine the CBR value is outlined in the ASTM standards.

The CBR value represents the relative resistance to shear and penetration of a soil mass as compared to a standard material. A CBR test was originally developed by the California Department of Transportation before World War II and has been adopted after several modifications by the U.S. Department of Defense. The CBR of a soil mass has been standardized and is obtained from either laboratory tests following the ASTM D1883-05 standard conducted on samples obtained from representative soil samples of the area where the pavement will be constructed or, from in-situ field CBR tests following the ASTM D4429-09a standard. The CBR test was developed to measure the bearing capacity of subgrades used for roadways and airfields (Gonzalez, 2015).

4. Experimental work

I. Material

The properties of selected soil used in this study were illustrated in **Table 1.** These properties are physical and chemical.

The two cubic meter of Al-Najaf sand passing through sieve No.10 (2.0 mm) openings was air dried and stored in barrels. The chemical and physical properties are summarized in **Table 1**. The tests have been performed on medium dense sand with max. and min. dry unit weights of the sand obtained as stated in the D4253 and D4254 (ASTM, 2007) specifications, respectively. The specific gravity test was conducted in line with (ASTM D854-05, 2007), and the grain size distribution was performed just as in D422-63 (ASTM, 2007) specifications. The chemical tests of the sand performed according to the D422-63 (ASTM, 2007). The sand was classified as SP type according to the Unified Soil Classification System (USCS). AASHTO classification is A-6. One type of Iranian geogride (SQ12) was used to reinforce the subgrade soil as indicated in **Figure 2**. According to BS 812 (1988) and ASTM (D1388-96, D1505-03, D1777-96, D1910 and D6637-01) (2007), several properties of geogrid were considered for this work are indicated in **Table 2.**

II. Experimental Test Results

CBR tests were conducted in accordance of standard method 1883 (ASTM, 2007) on unreinforced and reinforced soil, with a single geogrid layer as it is illustrated in **Figure 3**. To reinforce a specimen, the geogrid was located in a single layer at various positions starting from the top surface: 0H, 0.2H, 0.40H, 0.60H and 0.80H. The sample was cut in a circular disc of diameter somewhat less than that of the sample to avoid separation in the sample by the strengthening layer. Then, the mold was filled with the required dry weight which was calculated depending on the maximum dry density (MDD) and corresponding optimum moisture content was conducted according to the standard proctor test. A total of 5 specimens of unreinforced and reinforced were tested after immersing in water for 4 days. The load penetration curve was drawn for the soil specimens with geogrid at different locations and the CBR values were determined from these curves. **Table 1** demonstrates the results of CBR tests under various test conditions. Also, **Figure 4** indicates the loading versus penetration values for various soil samples.

Table 3 indicates the results of CBR tests for both soaked and unsoaked conditions. It is obvious that a significant increment in the CBR of reinforced soil. The value of CBR in case of reinforced is 9.4% but this value is 2.9% for unreinforced case. Moreover, the table also shows how the maximum value of CBR corresponds to the 0.2H of geogrid position according to different tested depths of the geogrid in the sample.

III. Influence of geogride position on pavement structure depth

Initially an equivalent 80 KN (18 Kip) single axle load (ESAL) with dual tires was adopted. Traffic loading is assumed to be fifteen million ESAL during fifteen years of pavement service life. The use of ESAL is based on the results of experiments that have been shown that the effect of any load on the performance of a pavement can be represented in terms of the number of single applications of (ESAL). SN value is structural number which will be used in determining the thickness of each layer and according to the equation (AASHTO, 1993):

$$SN=a_1*D_1 +a2 *D_2\, m_2+a_3*D_3*m_3 \qquad \text{………………. (1)}$$

Where a_1, a_2 and a_3 are the layers coefficients for surface (asphalt concrete surface course =0.44 and asphalt concrete binder course =0.38), base (asphalt concrete base course =0.34) and subbase (gravel sand soil subbase course =0.14) respectively. D_1, D_2 and D_3 are the thickness for the same layers in inches. The drainage factor value of base and subbase (m_2 and m_3) is 1.0. Roadbed soil resilient modulus is calculated from [AASHTO,1993]:

$$Mr= 1500\ CBR \qquad \text{………………. (2)}$$

$$Mr = 3{,}000 \times CBR^{0.65} \qquad \text{………………. (3)}$$

Table 4 indicates the effect of geogride position on total pavement structure depth by using Excel software to find the structural number and thickness values of flexible pavement courses.

It can be noticed from table above the reinforcement of subgrade with geogride at 0.2 subgrade layer thickness from subgrade top will reduce the total pavement thickness by 30-40% in comparison of without reinforcement.

5. Modeling using Plaxis

The flexible pavement system used in 3-D PLAXIS software version 2013 consisted of asphalt concrete (AC) surface layer, granular subbase layer and subgrade layer as well as reinforced with geogrid layer subjected to static loading. This software has already verified to be used in representing different cases such as asphalt pavement (Al-Jumaili, 2016). The unreinforced and geogrid reinforced pavement response was evaluated under a uniform applied contact pressure of 600 kPa acting on a circular area of 15cm radius. The two asphalt concrete layers and geogrid were modeled as a linear elastic isotropic material while the Mohr-Coulomb model was used to model granular subbase and subgrade materials. An axisymmetric model was utilized in the analysis using 45900-noded structural solid elements with medium refinement. The model dimensions are 10m width, 8m depth and 10m in perpendicular direction on screen. Alex (2000) mentioned that the strains of nodal radial were mainly assumed to be neglected at approximately ten times radius of the loaded area from the area of applied wheel load. The nodal stresses and displacements were also assumed to be negligible at 20 times radius of contact area below the pavement surface. Therefore, the length, width and depth of the model were set as 10, 5 and 8m respectively. **Figures 5** to **14** indicate the outputs of 3D Plaxis program.

The modulus of elasticity for asphalt concrete layer was calculated from the equation developed by Timm and Newcomb (1999) as following:

$$E_{AC}=16693.4\, e^{\left\{\frac{(T+26.2)^2}{-1459.7}\right\}} \quad \text{……………….(4)}$$

Where;

EAC= Asphalt concrete modulus, MPa

T=Asphalt concrete surface temperature, ^{o}C

For mean temperature of 35^{o}C the elastic modulus will be 1280 MPa. Since the resilient modulus test equipment is currently not present in many laboratories, researchers have developed correlations to converting CBR values to approximate M_R values. The correlation was considered reasonable for fine grained soils with a soaked CBR of 10 or less or more (AASHTO, 1993):

For various CBR soaked values obtained from several positions of geogrid (0.0 H, 0.2H, 0.4H, 0.6H and 0.8H) from top of final subgrade layer (30 cm) depth. These values have been adopted in determining M_R as demonstrated in **Table 5**. Claessen et al., (1977) established the relation between subbase resilient modulus and subgrade resilient modulus according to the following relationship:

$$M_R= 0.2 * h^{0.45} * M_R\ (\text{subgrade}) \quad \text{………….. (5)}$$

Where;

h= the thickness of subbase layer in mm.

In this study, the thickness of subbase layer has been assumed as 400mm and M_R for the subbase is calculated depending on resilient modulus of subgrade value. Material parameters and constitutive models used are shown in **Table (5).**

The Plaxis software outputs are mainly principle effective stress and maximum displacement at top of subgrade layer. These were obtained by entering the pavement structure properties. It is important to mention the Plaxis results are used to be compared among various geogride positions. Figure 5 through Figure 10 present the Plaxis software output for three cases only which are unreinforced, 0.2 H and 0.8 H of final 30 cm subgrade soil layer respectively

The results obtained from the above figures could be summarized in **Table 6**. This table points out just the compressive stress and displacement cases. It is clear that case of reinforced soil with geogrid at 0.2H represents the lowest stress and vertical displacement among other cases obtained from unreinforced and reinforced cases.

6. Conclusions

The overarching aim of this paper has been to identify and understand how geogrid could improve the local weak soil. The importance and expected contribution of this work has been highlighted; using local soil and modeling with Plaxis 3D have been mentioned as in the text. The main outcomes from this study could be summarized as:

1. The value of CBR for the tested soil increases by 2 to 5 times when it is strengthened with a single layer of geogrid. The type of soil and position of geogrid mainly determine the amount of improvement.
2. The value of CBR for the soaked subgrade soil is 2.14% without reinforcement. This value has been increased to 12.84% when geogrid was placed at 0.2H from the top.
3. There is a significant improvement in the stress-strain behavior of subgrade soils under static load condition when putting geogrid at optimum position.
4. It was found that the use of geogride layer at 0.2 from the subgrade layer thickness decreases the pavement thickness by 30-40%.
5. The results obtained from 3D Plaxis model indicate putting geogrid at 0.2H is the optimum location at which the strength for stress increases and the vertical displacement decreases.

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Table 1 Physical and chemical properties of the tested soil

Chemical properties	
SO_3	3.6 %
T.S.S	0.75 %
Gypsum content	7.76%
Physical properties	
Dry density (gm/cc)	1.73
Optimum moisture content, O.M.C. (%)	9.52
Specific gravity	2.61
Plasticity index	N.P.

Table 2 Physical and mechanical properties of SQ 12 geogride product.

Physical properties		
Property	Result	
Mesh type	Square	
Standard color	Green	
Polymer type	High Density Polyethylene	
Packaging	Rolls	
Dimensional properties		
Property	Unit	Result
Aperture size	mm	12*12
Mass per unit area	g/m^2	318
Rib thickness	mm	1.7
Junction thickness	mm	1.6
Rib width	mm	1.3/1.6
Roll width	m	1.2
Roll length	m	30
Mechanical properties		
Peak tensile resistance	kN/m	1.1
Elastic modules	GPa	0.28
Tensile strength	MPa	2.5
Percentage elongation at maximum load	%	2.7

Table 3 CBR test results for different positions of geogrids.

Position of geogride from top	Unsoaked CBR (%)	Soaked CBR (%)
No geogride	3.56	2.14
0.0H	11.79	8.49
0.2 H	18.46	12.84
0.4 H	15.1	9.06
0.6 H	10.94	6.57
0.8 H	7.98	4.12

Table 4 Effect of geogride position on total pavement structure depth

	Position of geogride					
Factor	No geogride	0.0H	0.20H	0.4H	0.6 H	0.80 H
Initial Serviceability, Po	4.2					
Terminal Serviceability, Pt	2.5					
Reliability Level, R	95%					
Overall Standard Deviation, S_o	0.45					
Performance Period (years)	15					
Un soaking condition						
SN required	5.82	4.25	3.82	4.00	4.29	4.54
Asphalt concrete surface course thickness (cm)	5					
Asphalt concrete binder course thickness(cm)	8	7	4	6	5	7
Asphalt concrete base course thickness (cm)	10	10	10	10	10	10
Subbase course thickness (cm)	40	35	35	35	40	40
SN available	5.83	4.31	3.87	4.02	4.29	4.59
Total pavement structure depth	63	52	49	51	55	57
Soaking condition						
SN required	6.82	4.49	4.14	4.36	4.84	5.61
Asphalt concrete surface course thickness (cm)	5					
Asphalt concrete binder course thickness(cm)	10	7	6	6	7	8
Asphalt concrete base course thickness (cm)	15	10	10	10	10	15
Subbase course thickness (cm)	45	40	35	40	45	45
SN available	6.85	4.59	4.17	4.43	4.87	5.68
Total pavement structure depth(cm)	75	57	51	56	62	68

Table 5 Pavement materials properties

Course	**Asphalt concrete**	**Gravel , sand and soil subbase**						**Fine sand soil**					
Thickness(m)	**0.10**	**0.40**						**7.5**					
Geogride position								**N/P**	**0.0H**	**0.2H**	**0.4H**	**0.6 H**	**0.8H**
Model	**Linear elastic**	**Mohr-Coulomb**						**Mohr-Coulomb**					
Resilient modulus(Mpa)	**1280**	**65**	**250**	**320**	**280**	**200**	**125**	**20**	**85**	**110**	**90**	**68**	**40**
Poisson's ratio	**0.35**	**0.40**						**0.45**					
Dry density (kN/m^3)	**23**	**20**						**17.2**					
Saturated density (kN/m^3)	**---**	**22**						**20.8**					
Cohesion (kN/m^2)	**---**	**0**						**0**					
Friction angle (degree)		**40**						**35**					

Table 6 Comparison of unreinforced and reinforced soil results.

Cases	The maximum value of principal stress (KN/m^2)	The maximum value of vertical displacement (m) $\times 10^{-3}$
Unreinforced soil	529.3	4.367
Reinforced soil (0.0 H)	461.2	2.197
Reinforced soil (0.2 H)	304.2	1.773
Reinforced soil (0.4 H)	336.7	2.424
Reinforced soil (0.6 H)	392.7	2.635
Reinforced soil (0.8 H)	403.9	4.06

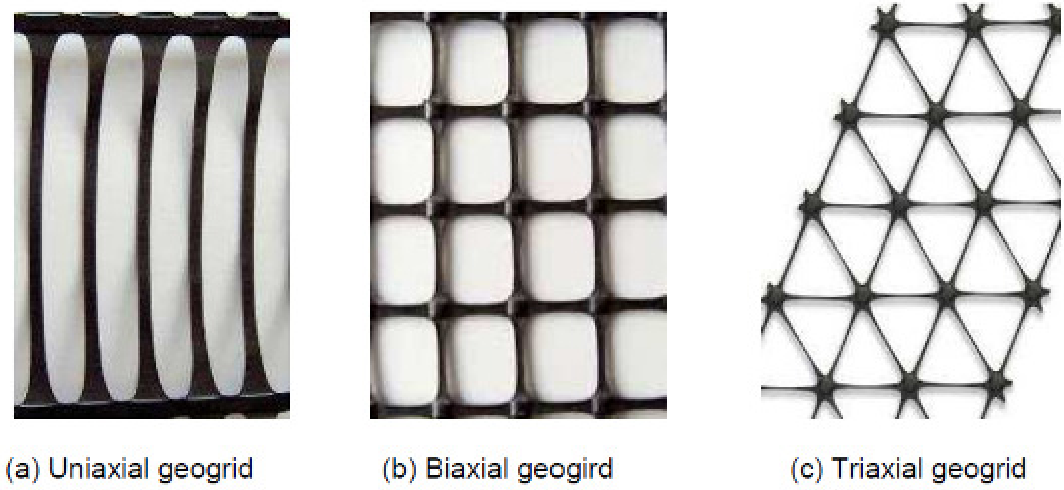

Figure 1 Geogrids with different shapes of openings (Sun, 2015).

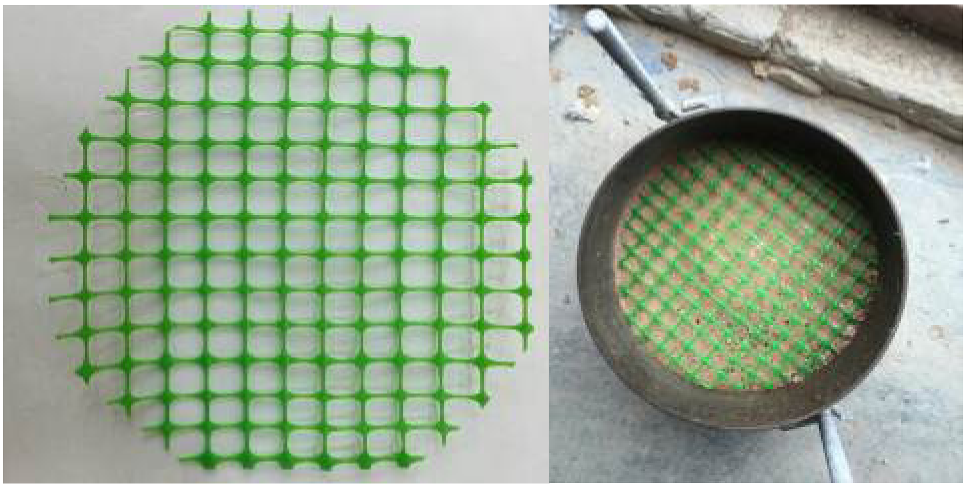

Figure 2 Chinese geogrid used in this study.

Figure 3 CBR test device.

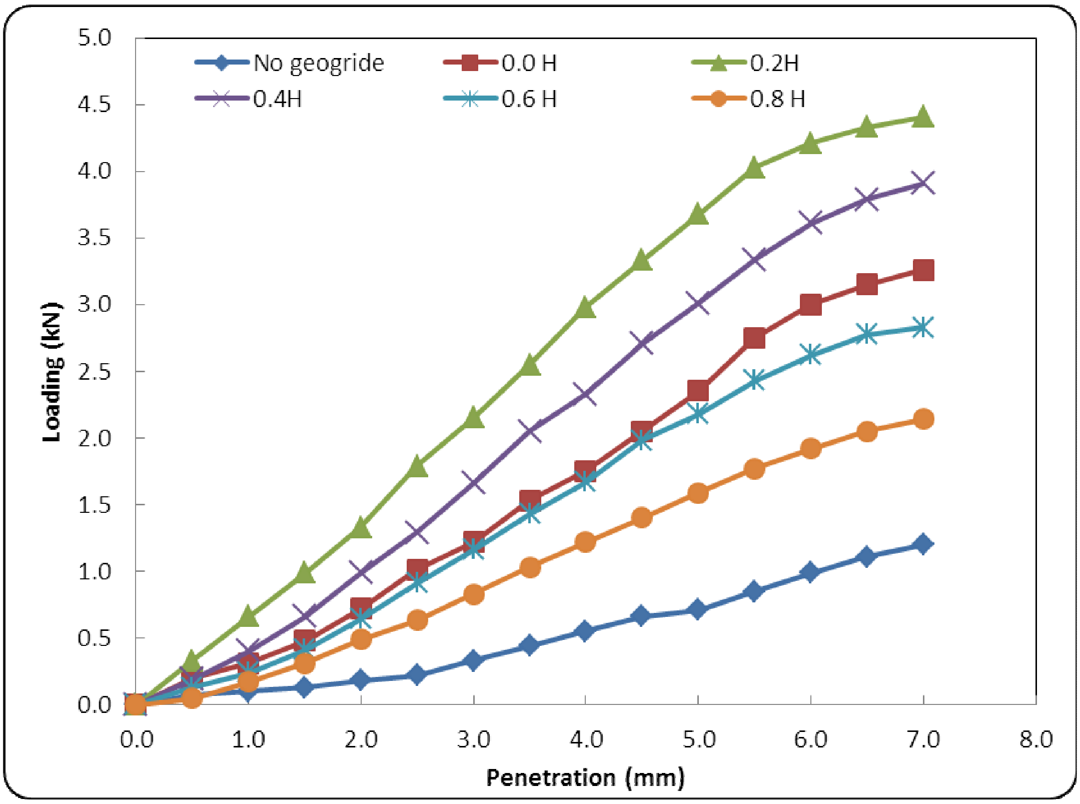

Figure 4 Loading versus penetration values for various un-soaking soil samples.

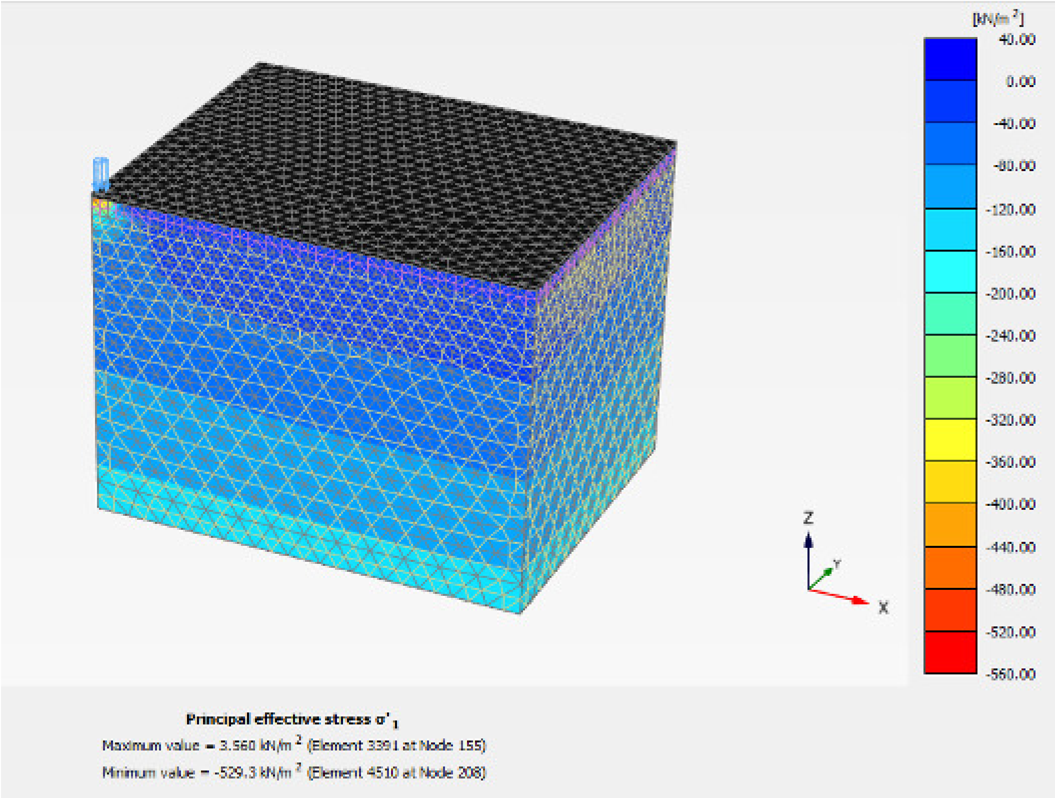

Figure 5 Principle effective stresses for unreinforced pavement case.

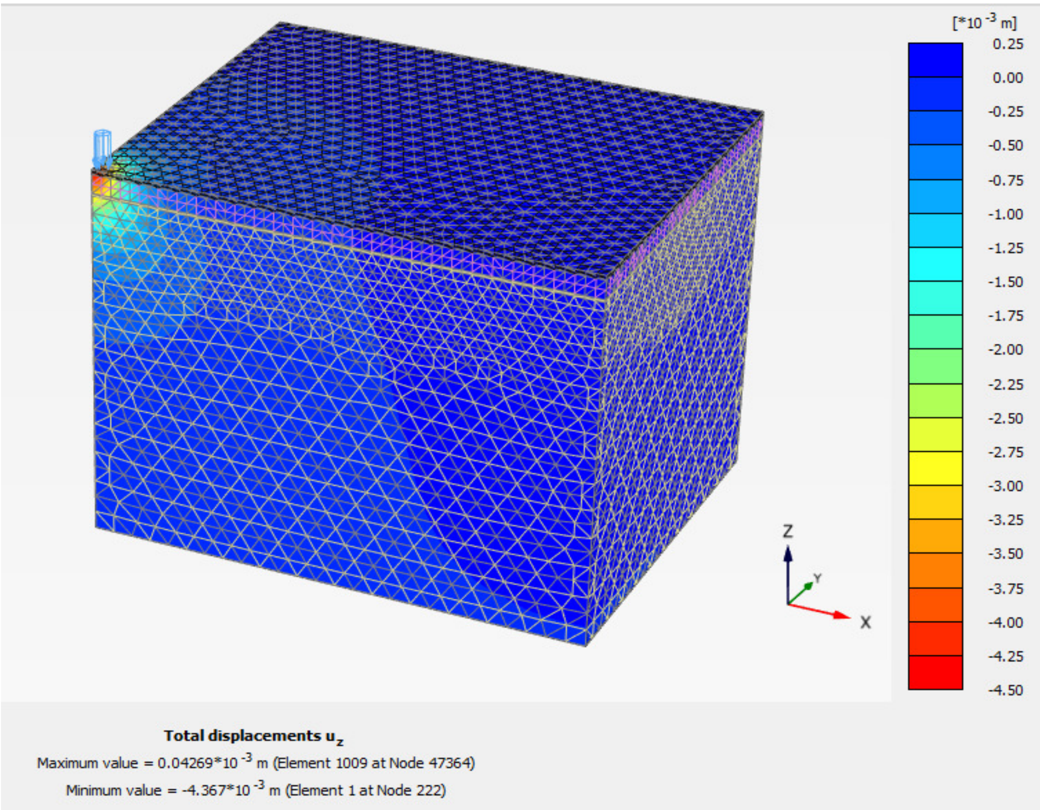

Figure 6 Maximum vertical displacements for unreinforced pavement case

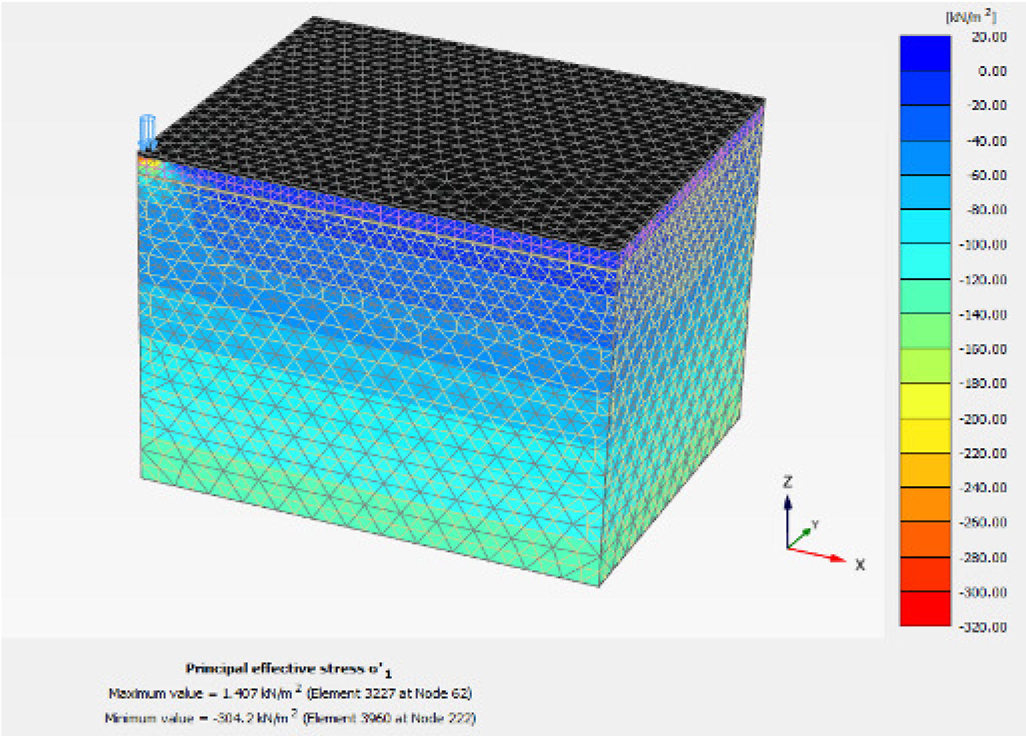

Figure 7 Principle effective stress for reinforced pavement at 0.20 of final 30 cm subgrade soil layer.

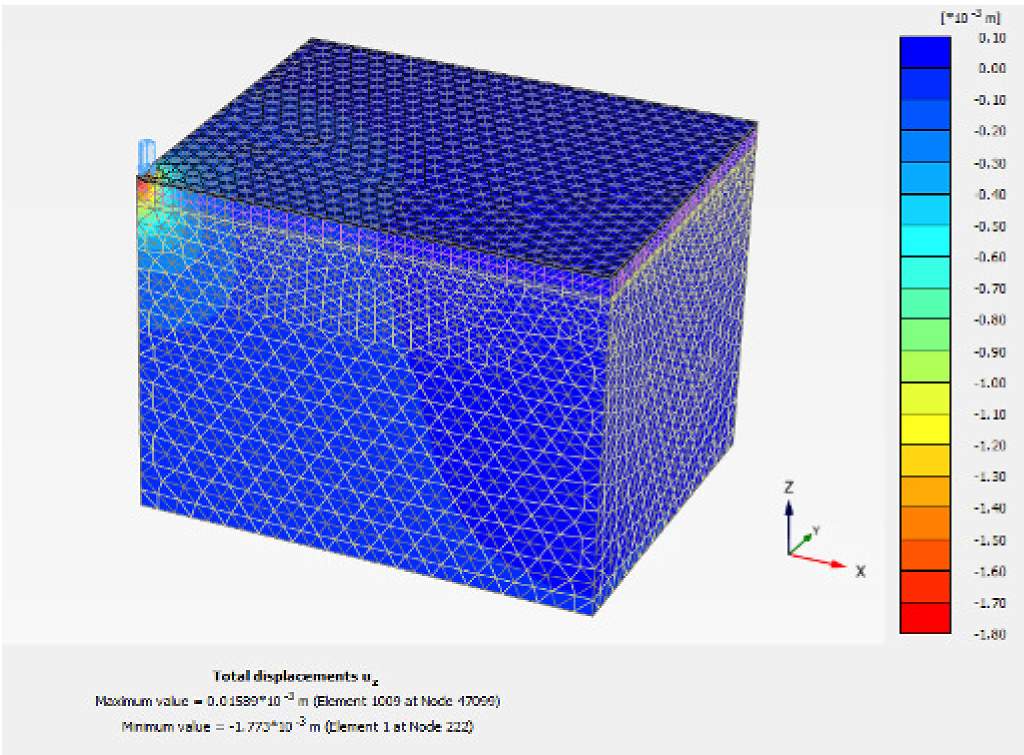

Figure 8 Maximum vertical displacement for reinforced pavement with geogrid at 0.20 of final 30 cm subgrade soil layer.

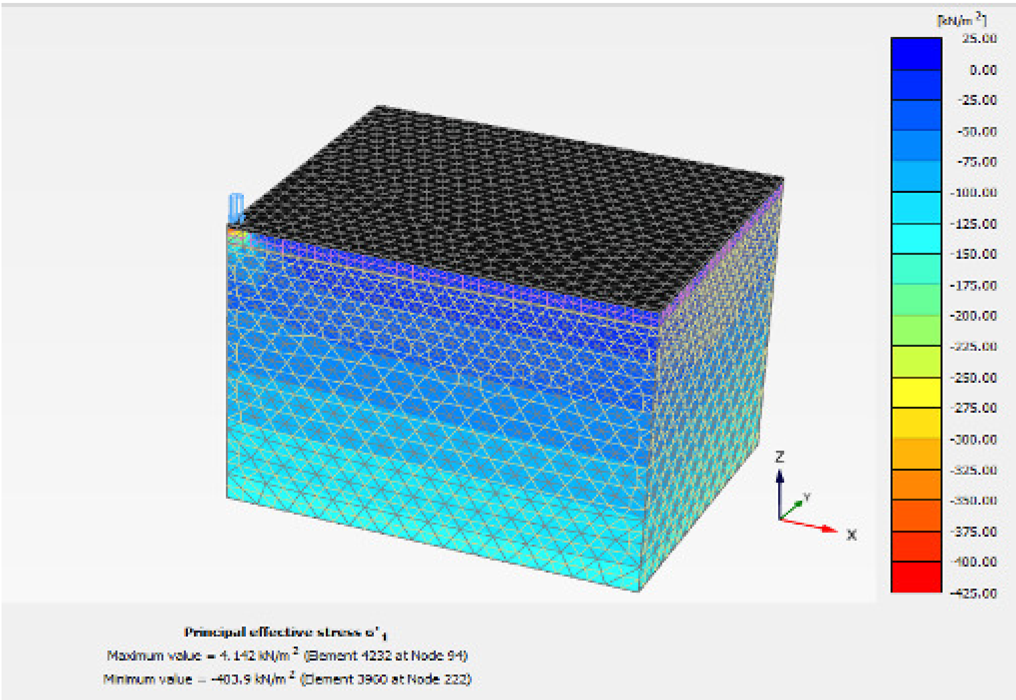

Figure 9 Principle effective stress for reinforced pavement at 0.80 of final 30 cm subgrade soil layer

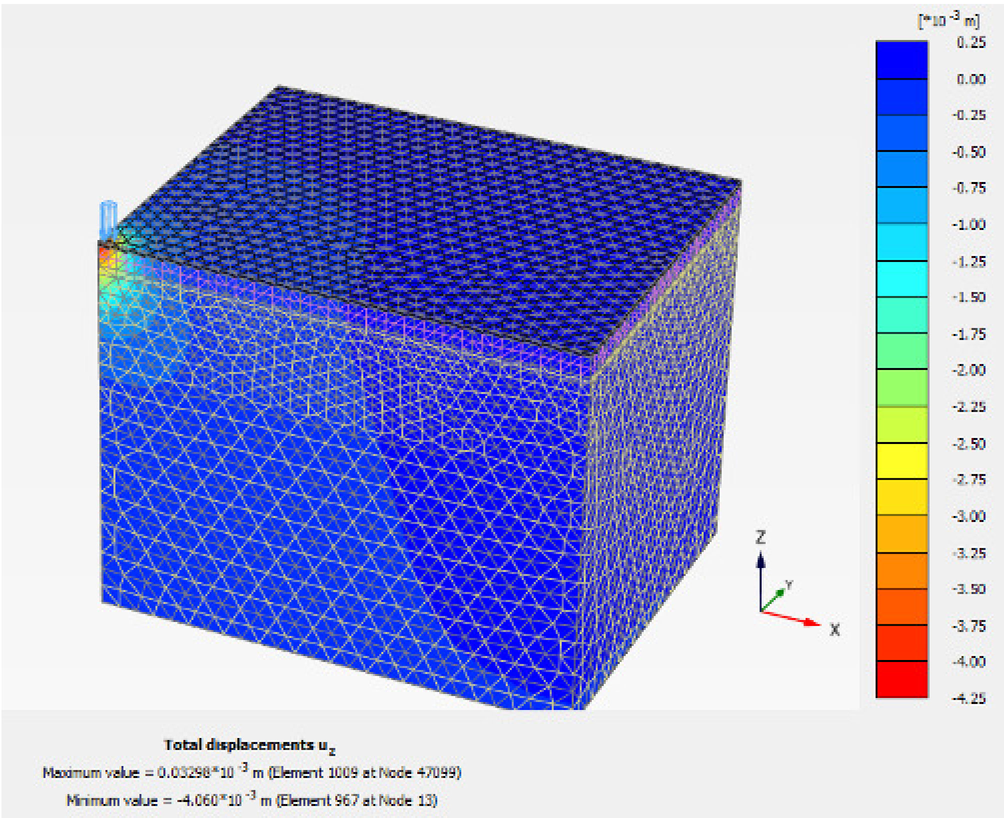

Figure 10 Maximum vertical displacement for reinforced pavement with geogrid at 0.80 of final 30 cm subgrade soil layer