Numerical Studies on Rutting Criteria of Geocell Reinforced Flexible Pavement

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Abstract. Roadways play an inevitable role in providing maximum service to one and all. Mostly, flexible pavements are adopted for roadways around the globe. India, being a place of geographical diversity, consists of large varieties of soils with different strength characteristics. Areas with soil having poor bearing capacity poses a serious problem in pavement construction. Constant increase in traffic frequency and axle loads will lead to a large deformation of weak subgrade which will finally result in the failure of the paved or unpaved surface. Geosynthetics such as geotextiles, geogrids, geo-composites etc. have been increasingly used as construction materials in civil engineering projects. Recently, geocell application in pavement layers have been showing much improved performance. In this study, numerical analysis using Plaxis 3D software is carried out to evaluate the performance of areca geocell reinforced flexible pavement on rutting characteristics. It was found that pavement reinforced with areca geocell has reduced rutting when compared to other pavement section.

Keywords: Flexible pavement, Rutting, Geocell.

1 Introduction

Mostly, flexible pavements are adopted for roadways around the globe. This is because flexible pavements can be strengthened and improved in stages with the growth of traffic. In India, the roadways carry about 65% of freight and 85% of passenger traffic. The Indian Road infrastructure categorized roads as rural roads, district roads, state highways, national highways and expressways. The road network of India is recognized as one of the most extensive networks with about 58.98 lakh km length comprising National Highways, State Highways, Major District Roads, Rural Roads and Urban Roads [7].

India, being a place of geographical diversity, consists of large varieties of soils with different strength characteristics. Areas with soil having poor bearing capacity pose a serious problem in pavement construction. Constant increase in traffic frequency and axle loads will lead to a large deformation of weak subgrade which will finally result in the failure of the paved or unpaved surface. Most of the pavement structures fail well before their design life due to the poor quality of construction materials, inadequate compaction, poor strength of subgrade and overloading.

The stresses induced between the layers as a result of traffic loads will lead to crack formation which may lead to subsequent settlement of upper layers. Thus, the major concern of any flexible pavement is the phenomenon of rutting and fatigue cracking.

Loads on the surface of the pavements produces two strains: horizontal tensile strain at bottom of asphalt layer and vertical compressive strain at the top of subgrade layer, considered as critical parameters for the design of pavements. Pavement failure due to fatigue cracking is a result of development of excessive horizontal tensile strain. Whereas rutting occurs due to excessive vertical compressive strain.

As it is not always advisable to avoid construction sites with weak soil, there is a need to improve such sites. Geosynthetics such as geotextiles, geogrids, geo-composites etc. have been increasingly used as construction materials in civil engineering projects. Recently, geocell application in pavement layers have been showing much-improved performance. However, commercially available geocells are costly and hence there is a need to adopt natural cells that are sustainable and eco-friendly [6].

Areca geocell is a natural cell made of areca leaf sheath which is abundantly available in Kerala. The durability of the cells is increased by treating them chemically. The natural cells have to be protected from the natural predators such as fungi, moisture and insects for long term applications.

Many studies have been carried out experimentally and analytically to find out the behaviour of geocell reinforced flexible pavement. With the development of finite element method, analysis of structures became easier as it eliminates the need of performing field tests or large-scale laboratory tests. PLAXIS 3D is one of the software which is used to analyze pavements. PLAXIS uses an intuitive approach to analyze a wide variety of geotechnical problems. The software provides advanced material models which helps to simulate the behaviour of soils more realistically. It helps in reflecting the complex behaviour of the pavement under traffic loading without actual construction of the pavement. It also helps to analyze structures with different boundary conditions and different material properties.

2 Methodology

The project follows a well-planned methodology. The initial stage was to collect the information required for the successful completion of project. Figure 1 shows the methodology adopted in this study.

Various literatures related to flexible pavement distresses were reviewed in order to identify the research gap for the same. Initially, borehole details, to be used as input parameters in the software, of subgrade soil and infilling sand at the site in Kumbalam Toll Plaza were collected. From the data collected, both unreinforced and reinforced pavement models were developed in PLAXIS 3D by providing the material details and boundary conditions. And then the analysis of pavement sections for the evaluation of critical responses of pavement were carried out.

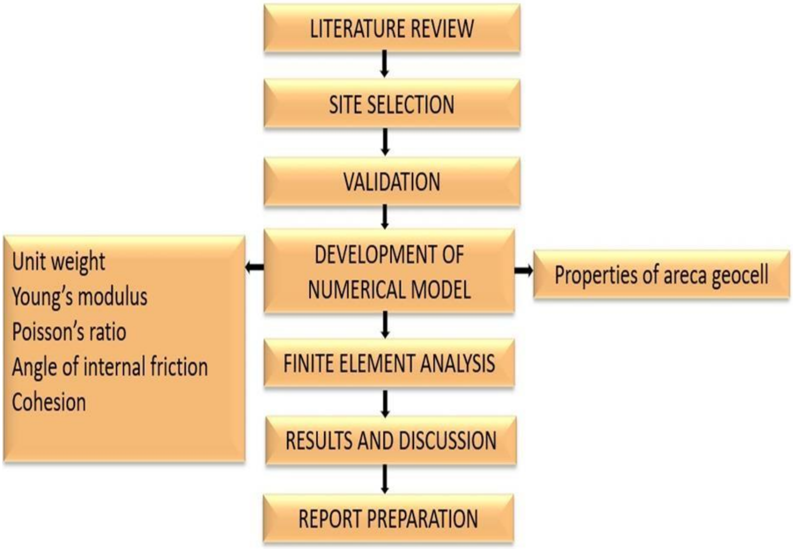

Fig. 1. Methodology Flowchart

3 Analysis of Flexible Pavement

The performance of the unreinforced and areca geocell reinforced pavement were analysed to assess the effect of reinforcement on the fatigue and rutting characteristics of the flexible pavement. The density, elastic modulus, Poisson's ratio along with other parameters of pavement layers and subgrade soil were kept constant in all the stage of analysis.

In this research, the soil elements are modelled as tetrahedral elements with 10 nodes. Pavement was modelled as a multi-layer structure subjected to dynamic loading. Due to double symmetry, only a quarter portion of the pavement was modelled so as to reduce the execution time. Geometry model of unreinforced pavement section included surface layer, base course and sub-base course founded on clayey sand subgrade. Model geometry of flexible pavement developed in PLAXIS 3D is shown in figure 2. Mohr-coulomb model with drained condition was used to model subgrade soil. The thickness and properties of pavement layers were adopted from Anusudha et al., 2020. Properties of pavement layers, soil and areca geocell are given in tables 1, 2 and 3 respectively.

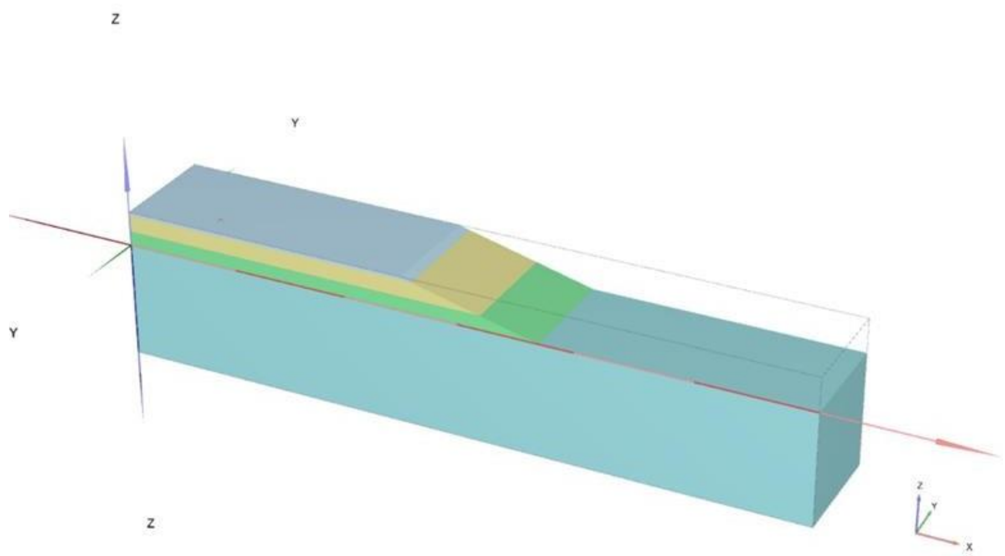

Fig. 2. Model geometry

The numerical modelling was conducted using PLAXIS 3D. The model has a length of 6 m, depth of 1 m below ground level and a width of 1 m. The meshing size adopted were fine for all the models. Default boundaries were chosen in favour of the viscous boundaries. This software provides an automatic mesh generation system in which the model is discretized into standard elements.

Table 1. Pavement layer properties

PARAMETERS	UNITS	SURFACE COURSE	BASE COURSE	SUB-BASE
Model	-	Linear elastic	Linear elastic	Mohr-Coulomb
Thickness	mm	25	150	125
Young's modu-lus	MPa	3000	154	85
Poisson's ratio	-	0.35	0.35	0.35
Dry density	kN/m³	20	19	18.5
Cohesion	kPa	-	-	5
Friction angle	o	-	-	27

Table 2. Subgrade soil and infill soil properties

PARAMETERS	UNITS	SUBGRADE SOIL	INFILL SOIL
Model	-	Mohr-Coulomb	Mohr-Coulomb
Thickness	mm	1000	75
Young's modulus	MPa	5.76	10
Poisson's ratio	-	0.35	0.35
Dry density	kN/m³	15.63	16.49
Cohesion	kPa	1.96	0
Angle of internal friction	o	12	16

Table 3. Areca geocell properties

PARAMETERS	UNITS	ARECA GEOCELL
MODEL	-	Geogrid element
AXIAL STIFFNESS	kN/m	880

The three cases of geocell reinforcement in flexible pavement were studied. In case one, the geocell was placed between subgrade and sub-base, in the second case the geocell was placed between sub-base and base and in the third case geocell was placed between base and asphalt concrete layer. Figures 3 shows the placement of geocell between clayey sand subgrade and sub-base. Figure 4 and 5 shows the placement of geocell between sub base-base and base-asphalt concrete respectively. Geocell was modelled by using geogrid option as a 6-noded element.

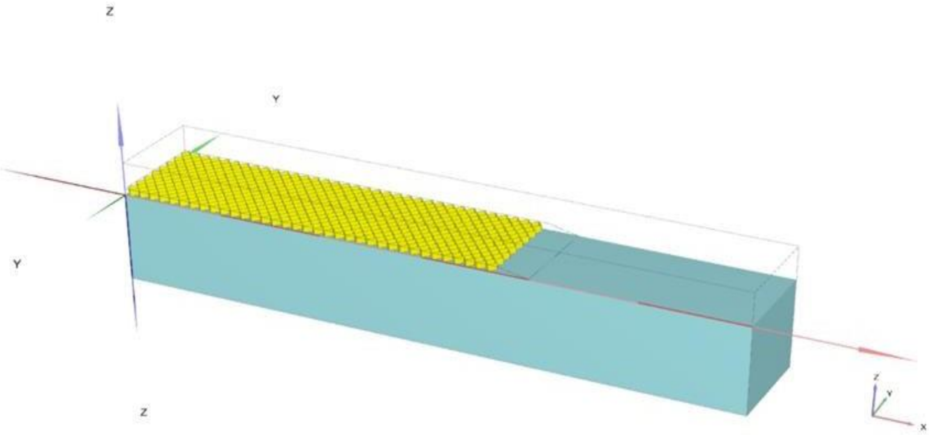

Fig. 3. Geocell placed in subgrade-sub base interphase

Mohr-Coulomb model involves mainly five parameters, namely Young's modulus, E, Poisson's ratio, ν, the cohesion, c, the friction angle, ϕ, and the dilatancy angle, ψ. The main advantage of this model is that it calculates constant average stiffness for each layer. And due to these calculations tends to be relatively fast and one obtains a first estimate of deformations.

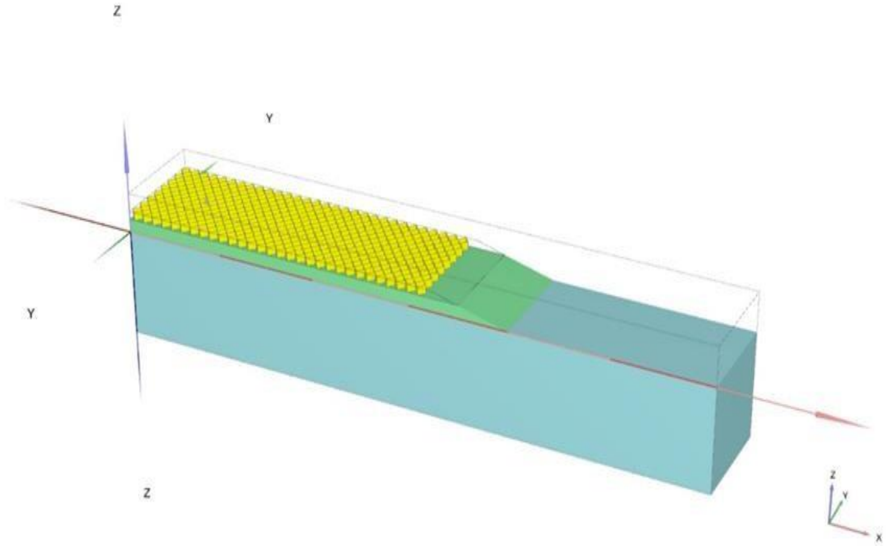

Fig. 4. Geocell placed in sub base-base interphase

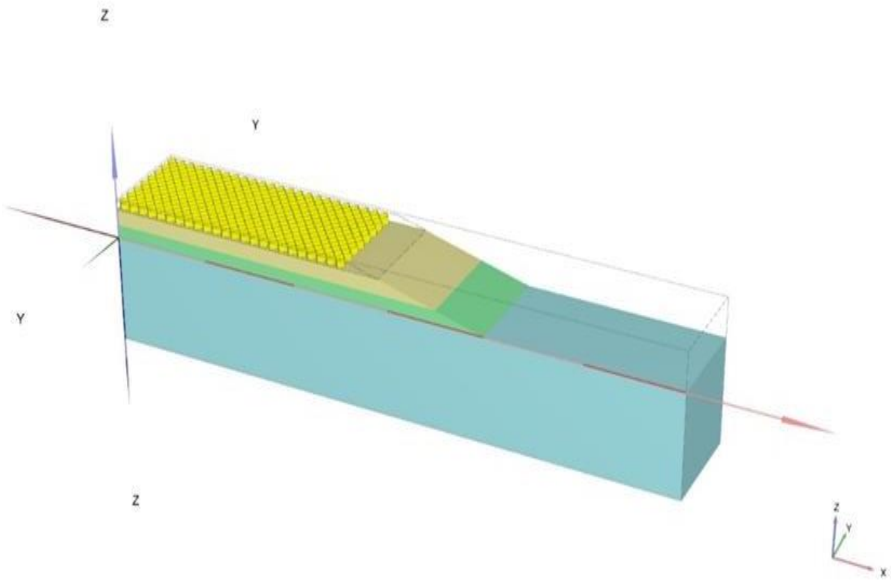

Fig. 5. Geocell placed in base-asphalt concrete interphase

Horizontal displacements were fixed on all four sides of the pavement model whereas vertical displacements were allowed simulating the effect of roller support on all four sides. At the bottom boundary both horizontal and vertical displacements were fixed simulating the effect of fixed support at the bottom.

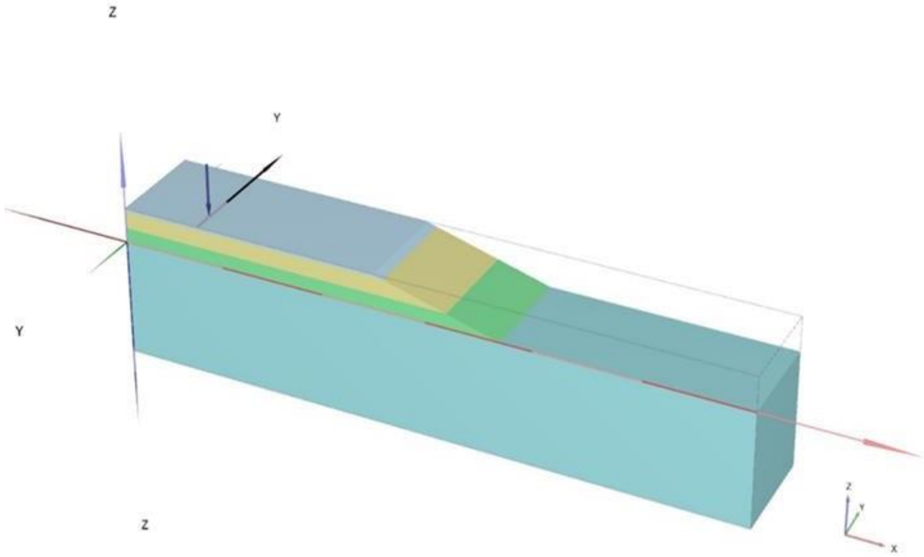

Fig. 6. Dynamic load activation on flexible pavement

Finest mesh is required near the loaded area as the loading on the pavement surface is confined. Assigning fine mesh will helps in the calculation of stress and strain more accurately. In this study fine mesh is assigned to the pavement model. Areas having large stress concentrations or large deformation gradients requires more accurate finite element mesh than other parts of the model, in such situations mesh can be refined in the needed area. In this study the mesh in the load path is refined.

The simulation process for the pavement model was based on specifying the magnitude of the applied load which represents the effect of a vehicle wheel during movement. In this method an assumption is made that the pressure of the vehicle wheel had a uniform distribution on the pavement. A linear path was made for the movement of load on the flexible pavement. A load of one of the dual tyres of 40 kN was considered as only a quarter portion of the flexible pavement is considered in this study. The dynamic load pulse of duration time 0.05 s and velocity 10m/s was provided. Figure 6 shows the activation of dynamic load on flexible pavement.

4 Results

Moving load was simulated for both unreinforced and geocell reinforced section. The applied load was 40 kN and the analysis was carried out by placing geocell at various layer interface i.e., between subgrade-sub base layer, sub base-base layer and base-asphalt concrete layer. Critical pavement responses, total displacement and strains, of unreinforced and geocell reinforced pavements were determined under moving load.

The maximum total displacement obtained for unreinforced section was found to be 11.4 mm as shown in figure 7. It was observed that maximum reduction in displacement of value 9.3 mm was obtained when geocell was placed between sub base-base interface. Figure 8 shows the total displacement diagram of flexible pavement with geocell placed between sub base-base interface. A total displacement values of 10.02 mm and 10.34 mm was obtained while placing geocell at subgrade-sub base interface and base-asphalt concrete interface as shown in figures 9 and 10 respectively.

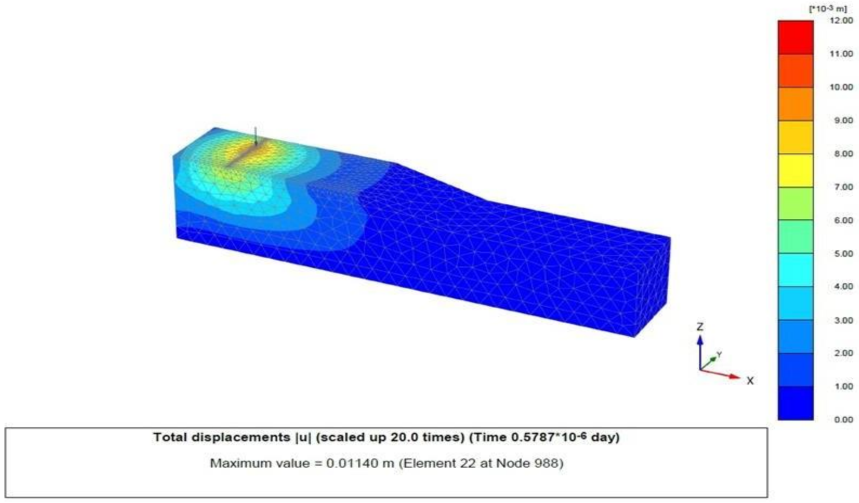

Fig.7. Total displacement of unreinforced pavement section

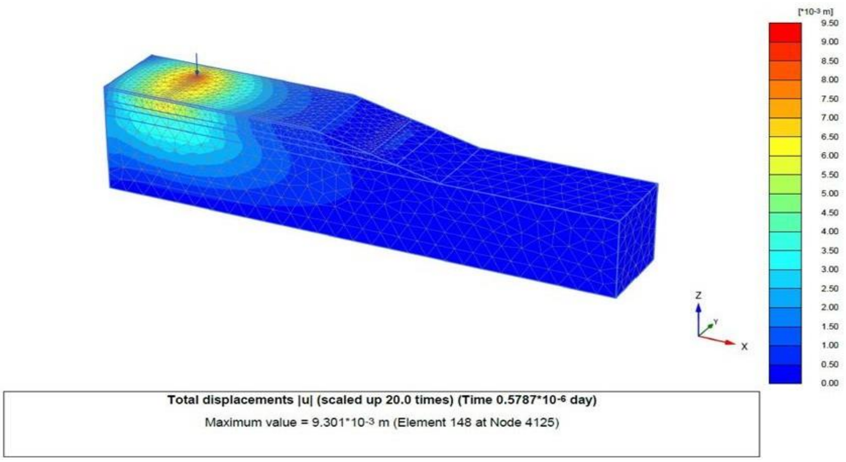

Fig.8. Total displacement of pavement with geocell at sub base-base interface

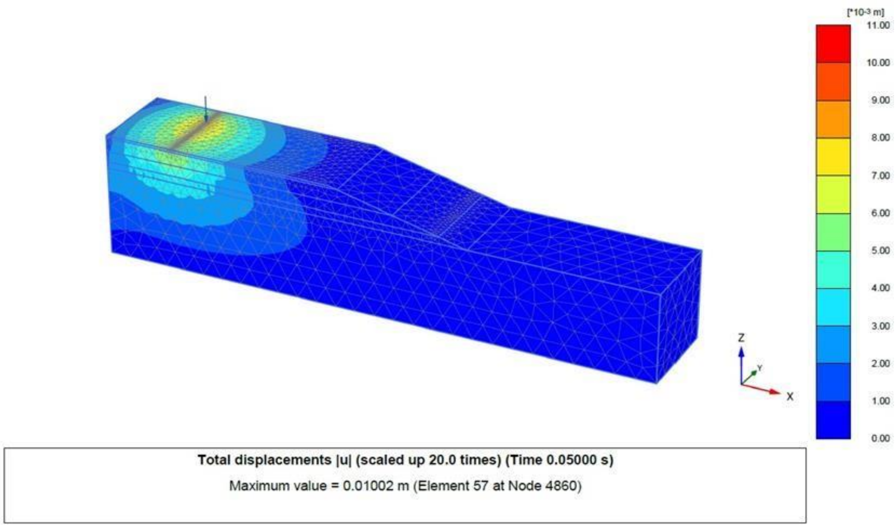

Fig.9. Total displacement of pavement with geocell at subgrade-sub base interface

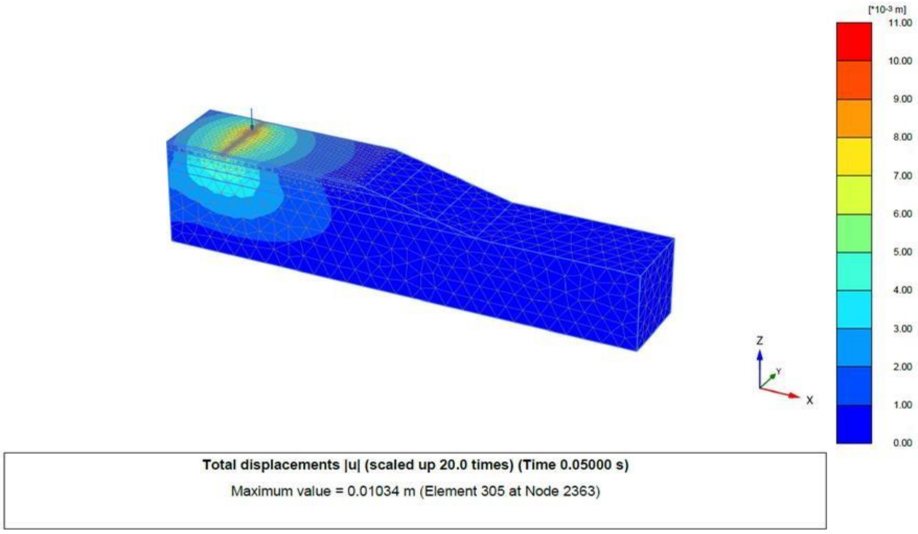

Fig.10. Total displacement of pavement with geocell at base-asphalt concrete interface

Percentage reduction in settlement is a parameter which can be used to explain the beneficial effect of the reinforcing section. When the percentage reduction in settlement is calculated areca geocell placed at the interface between the subgrade and sub base course shows a percentage improvement of 12.10% where as for the areca geocell placed at interface between the sub base and base shows the maximum of about 18.41% and a percentage reduction of only 9.29% was obtained when placed between base and asphalt concrete. According to the study therefore it is clear that the best position for placing the geocell considering total settlement is at the interface between sub base and base course.

Rutting was analyzed by evaluating the surface deflection (Uz) of the pavement layer. Rutting of both unreinforced and geocell reinforced pavement section for the peak load were analyzed. Table 4 shows the surface deflection obtained for unreinforced and reinforced section.

Table 4. Finite element results surface deflection

Location of areca geocell in pavement	U_z (mm)	Percentage reduction in surface deflection (%)
Unreinforced	11.39	-
Subgrade-sub base interface	9.76	14.31
Subbase-base interface	9.30	18.35
Base-Asphalt concrete interface	10.34	9.21

Figure 11 shows the variation of surface deflection along the horizontal distance from the centreline of wheel. The results indicated that areca geocell when placed between sub base-base layer achieved the highest reduction in horizontal tensile strain. A reduction of 18.35% was obtained for the same. It was also observed that the reduction in surface deflection diminishes as the distance from the load center-line increases. A reduction of only 14.31% and 9.21% was obtained in surface deflection when the geocell was placed between subgrade-sub base and base-asphalt concrete interface respectively. And it can be seen that there is only a small reduction in the surface deflection when the geocell was placed between subgrade-sub base and base-asphalt interface. Therefore, it can be concluded that the maximum reduction in surface deflection is obtained when the areca geocell is placed between base and sub-base interface.

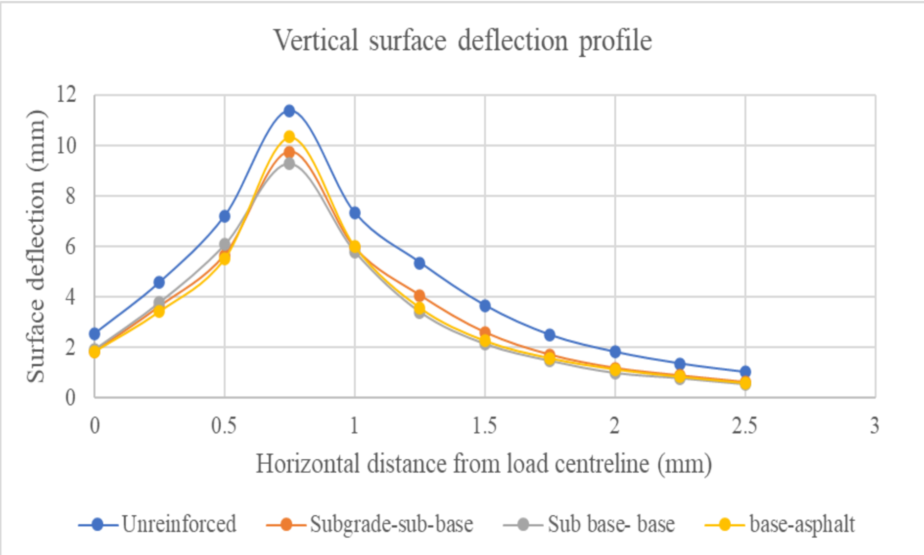

Fig.11. Variation of surface deflection along horizontal distance

5 Conclusions

The present numerical investigation aimed at finding the possibility of areca geocell in reinforcing the pavement sections. The need for the better alternative for polymer based geocells is indeed possible by the use of areca geocell. From the numerical modelling conducted with the areca geocell reinforcement at different positions the following conclusions can be made:

- Areca geocell placed at the interface between the subgrade and sub base course achieved a percentage improvement of 12.10% in reducing settlement of flexible pavement, whereas for the areca geocell placed at the interface between the sub base and base shows the maximum improvement of about 18.41% and a percentage improvement of 9.29% was obtained when placed between base and asphalt concrete.
- Study confirms the capability of areca geocell reinforcement in settlement reduction of the flexible pavement thus improving the strength characteristics of pavement.
- An improvement of 18.35% was obtained for the reduction of rutting while placing geocell in base-sub base interface.
- A reduction of only 9.21% and 14.31% was obtained for surface deflection when the geocell was placed between base-asphalt concrete and subgrade-sub base interface respectively.
- The best placement location of the reinforcement in reducing rutting was found to be between base- sub base interface.
- The above results show the possibility of areca geocell as an effective reinforcement in pavement construction.

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