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Numerical Studies on Rutting Criteria of Geotextile Reinforced Flexible Pavement

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Abstract. Flexible type of pavement is the most common type of pavement in India. During the last few years excessive damages are observed in flexible pavements throughout the country mostly due to various factors such as subgrade conditions, traffic loading, environmental conditions, aging etc. All these factors cause an equally wide variety of distress in the form of fatigue, rutting, differential settlement and reflective cracks in pavements. In order to reduce the rutting in the pavements and to increase the service life in poor subgrade soil new techniques of construction are adopted. The use of geosynthetics is widely used to stabilize poor subgrade soils. In this study the benefits of using coir geotextile in reducing rutting in pavements is analyzed using a finite element software PLAXIS 3D. Coir geotextile placed at the interface between the subgrade and sub base layer shows the maximum value of 18 % in reducing settlement of flexible pavement. Also, the geosynthetic reinforcement potential for reducing the rutting and surface deflection is much more pronounced when using it in subgrade subbase interface as maximum surface deflection of 17% is obtained at this position. From the numerical modeling, the best placement location for the coir geotextile is at the subgrade subbase considering the surface deflection in pavements. It was found that pavement reinforced with coir geotextile has reduced rutting when compared to other pavement section.

Keywords: Flexible Pavement, Rutting, Geotextile.

1 Introduction

A well-developed road network system is very important for the development of a country. It is important to provide link between different places of importance. The main objective of transportation system is to upgrade into a higher level both in terms of length and quality in order to meet the needs of the country. But the rapid growth in road traffic in terms of number of vehicles, frequency, magnitude of loading etc., possess challenges to the engineers. Due to this increasing rapid growth in traffic each year, the roads maybe subjected to both structural and functional failures. The road users are concerned with the functional condition of the road so that they can reach their destination comfortably and safely in less time. The challenges in road construction have to be met with proper design, construction, operation and maintenance of sustainable road infrastructure using alternative methods duly considering the life cycle cost.

Based on the structural behavior, the road pavements are generally classified into two types, flexible and rigid pavements. Flexible pavements are those, which have low or negligible flexural strength and are flexible under the loads whereas rigid pavements are those which possess flexural rigidity. The top most layer consists of the surface course followed by base course and subbase course. The bottom layer is subgrade soil having the lowest stability among the all four layers.

During the last few years excessive damages are observed in flexible pavements throughout the country mostly due to various factors such as subgrade conditions, traffic loading, environmental conditions, aging etc. All these factors cause an equally wide variety of distress in the form of fatigue, rutting, differential settlement and reflective cracks in pavements. Rutting is considered as a predominant distress in pavements due to high severity and density levels and their high effects upon the pavement condition. The increased rutting is considered as a shortcoming in the flexible pavement and thus need to be minimized.

In order to reduce rutting in the pavements and to increase the service life in poor subgrade soil, new techniques of construction are adopted. In the recent years, utilization of geosynthetics for various civil engineering projects, especially road construction is gaining importance. Geotextiles, one among geosynthetics like geogrids, geonet, geomats, geocomposites, etc., are progressively performing in road construction applications as an alternative, economically viable material. Geotextile are made of synthetic or natural fibers. Synthetic products are much durable and have longer life but is non-biodegradable creating environmental problems (Haowu et al., 2020). With concerns towards the environment, use of biodegradable natural materials has its popularity. Among natural fibers, coir which has been used as a geotextile has already proved it is worth in its applications.

Coir geotextile is strong and degrades slowly due to its high lignin content. Due to the wide application of the technique, many experimental and analytical studies have been conducted to assess and potentially quantify the improvements associated with coir geotextile reinforcement of roadways.

The finite element method (FEM) is one of the most powerful techniques used to simulate the behavior response for different structural engineering problems. FEM analysis has gained significance over these years due to its accuracy and ease with which one can work on it. PLAXIS 3D is one such software used in analyzing the pavements. Finite element methods have been conveniently implemented in software's such as PLAXIS, FLAC, SNAIL, etc. This study investigates the benefits of using coir geotextiles in minimizing rutting characteristics of flexible pavements using PLAXIS 3D software.

2 Methodology

The methodology adopted for the study is detailed as follows. The flowchart showing methodology is shown in figure1. An extensive literature study was carried out in order to study the existing methods for reinforcing the paved roads to reduce rutting in flexible pavements and the applications of coir geotextile. A detailed study of available journal and research papers sort out the need and features exhibited by geotextiles in improving the strength and stability of pavements.

The finite element method enables development of a design model that can be used to conduct the stress-strain analysis by construction stages, taking into account the relevant geotechnical properties of the environment. Finite element analysis has become the more acceptable tool for the studies. It has been applied extensively for the design and analysis of pavement structures.

PLAXIS 3D is a geotechnical software that can be used to stimulate field conditions and obtain required results. It is equipped with features to deal with various aspects of complex geotechnical structures. It is user friendly, efficient and accurate software

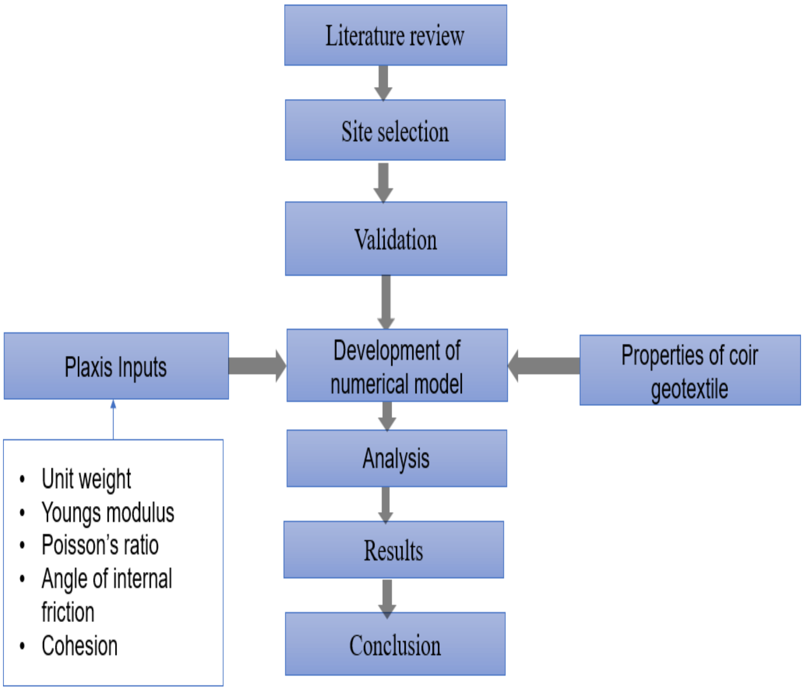

Fig. 1. Methodology flowchart

3 Analysis of Flexible Pavement

The performance of the unreinforced and coir geotextile reinforced pavements was analyzed to assess the effect of reinforcement on the pavement responses in terms of rutting of the pavement. The density, elastic modulus, Poisson's ratio along with the other parameters are kept constant for all the variable data set respectively in all stages of the analysis.

In this research, the soil layers are modeled with 10-noded tetrahedral elements and geogrids are composed of 6 nodded surface elements. This type of elements provides a second order interpolation of displacements. The only drawback of using this element is, it leads to relatively high memory consumption and relatively slow calculation and operation performance.

Table 1 Material properties of subgrade (Cochin Geotechnical Laboratory Report)

Properties	Soil Model	Drainage type	Young's modulus (MPa)	Unit weight, γ (kN/m^3)	Cohesion (kN/m^2)	Angle of internal friction (degree)	Poisson's ratio
Subgrade	Mohr-Coulomb	Drained	5.76	15.63	1.96	12	0.35

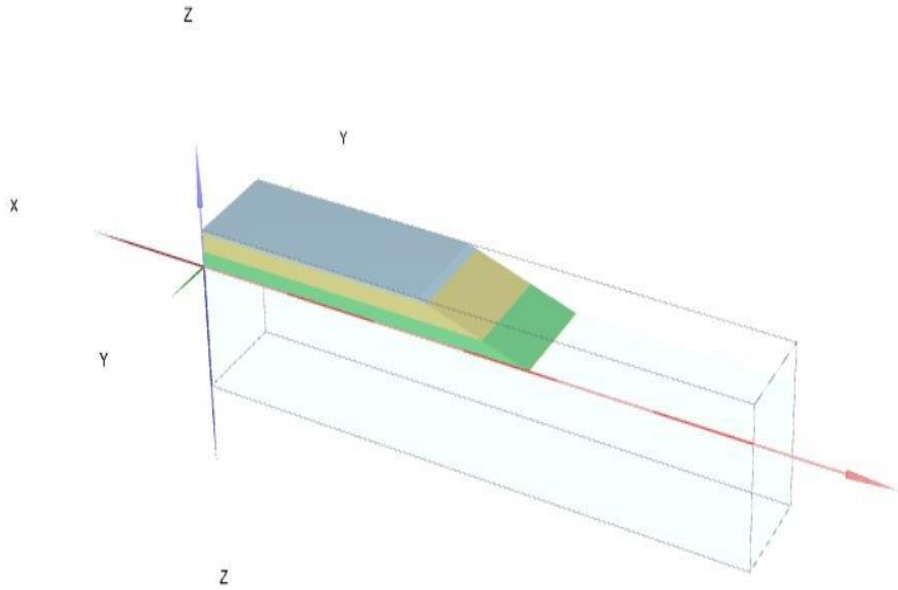

Fig. 2. Geometry of soil model

The finite element modeling was conducted using PLAXIS 3D. The model has a length of 6 m, depth of 1.3 m and a width of 1m. The subgrade layer below the pavement structure consists of clayey sand up to a depth of 1m. The base and sub-base course thickness of the pavement are 150 mm and 125 mm respectively. Asphalt layer of 25 mm thickness is provided. The geometry model of the pavement is shown in figure 2.

Table 2. Soil properties of the pavement (Anusudha et al., 2020).

Properties	**Subbase**	**Base**	**Asphalt**
Soil Model	Mohr-Coulomb model	Linear elastic	Linear elastic
Drainage type	Drained	Drained	Drained
Young's modulus (MPa)	85	154	3000
Unit weight, γ (kN/m3)	18.5	19	20
Cohesion (kN/m2)	5	NA	NA
Angle of internal friction (degree)	27	NA	NA
Poisson's ratio	0.35	0.35	0.35

The three cases of coir geotextile reinforcement were studied. In the first case the geotextile was placed between subgrade and sub-base as shown in figure 3. In the second case the geotextile is placed between sub-base and base and in the third case the geotextile is placed in base and asphalt layer interface as shown in figure 4 and 5 respectively. The properties of coir geotextile are given in table 3. The geotextiles are modelled in geogrid elements as this can represent any geosynthetic planar product. These elements are composed of 6 node triangular surface elements. Element stiffness matrices are based on the properties as defined in the material data set given in Table 1 and 2. Figure 6 shows the final staged construction model of the pavement after all materials activated, meshing and loading.

Table 3. Properties of coir geotextiles

Properties	Values
Elastic stiffness (kN/m)	500
Mass per unit area (g/m^2)	1286.56
Tensile strength weft (kN/m)	20.7
Tensile strength warp (kN/m)	36

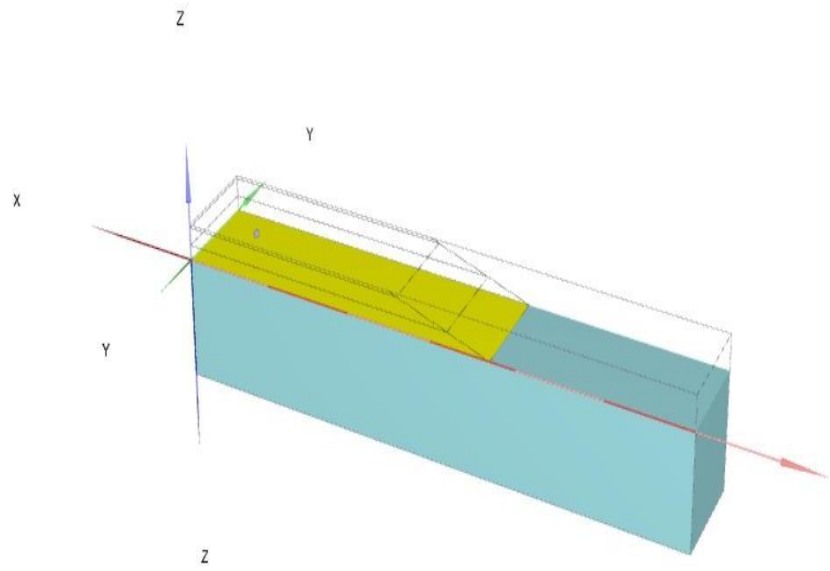

Fig. 3. Geotextile reinforcement between subgrade and sub-base interface

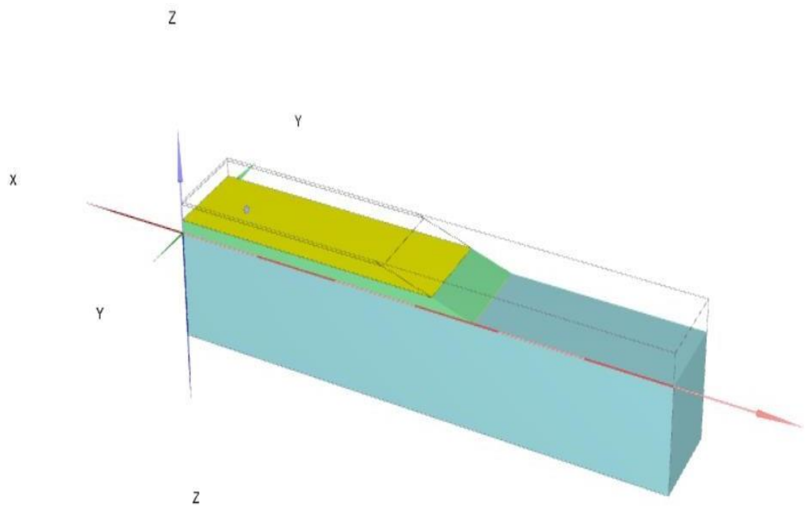

Fig. 4. Coir geotextile reinforcement between sub-base and base interface

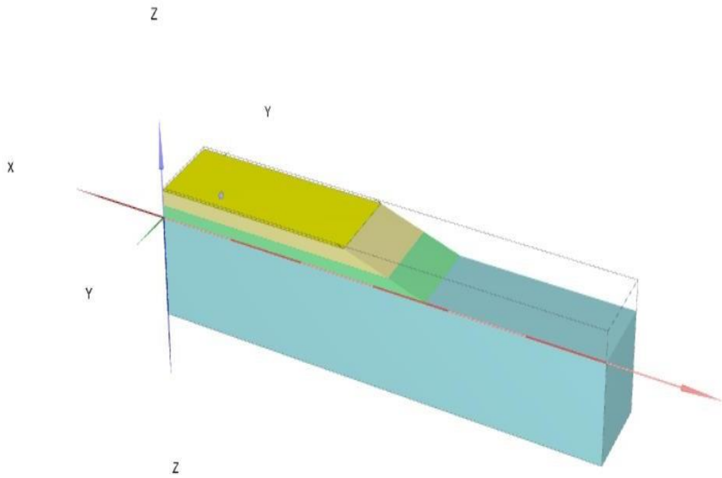

Fig. 5. Geotextile reinforcement between asphalt and base interface

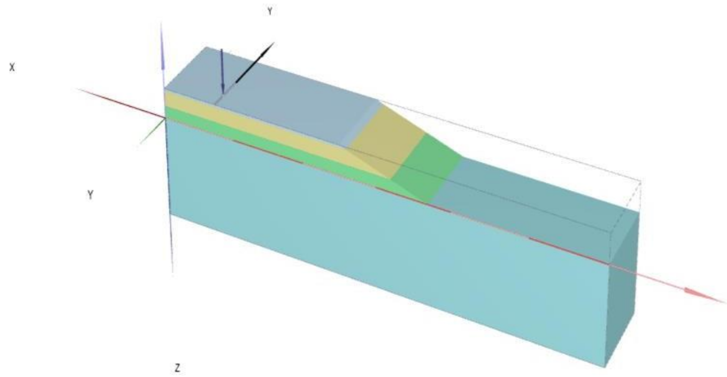

Fig. 6. Staged construction model.

In this study, conventional boundary conditions were adopted. Roller support is provided for all the vertical boundaries and at the bottom boundary both the horizontal and vertical displacements were fixed. Such boundary conditions are used in the work reported by Saad et al., 2006. The meshing sizes adopted were fine for all the models. As the loading on the pavement surface is localized, finest mesh is required near the loaded area therefore in line path of the load refined mesh is used. PLAXIS provides an automatic mesh generation system in which the model is discretized into standard elements.

A consolidation analysis in PLAXIS is driven by the dissipation of excess pore pressures and the soil will transition from an undrained state to a drained state as a function of the drainage path, loading time, and hydraulic conductivity of the soil. Whereas in a drained plastic analysis, the soil remains in a drained state, and the stiffness of water will not have an influence on the stiffness or strength behavior of the soil. The effective stress path of the soil will be different in a consolidation analysis compared to a drained plastic analysis. In the consolidation analysis, more plasticity is developed compared to a drained analysis.

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. The FEM assumed that the pressure of the vehicle wheel had a uniform distribution on the pavement. The standard axle, with one of the dual tyres of 40 kN, was used to simulate the various traffic loads moving on the pavement. The load is considered to be at a distance 0.75m away from the edge of the road Centre. Due to the double symmetry of the geometry, boundary conditions, and load about the horizontal x and y axis, only a quarter model is considered and pavement response to only a single wheel load is investigated in the study.

The dynamic load sample pulse of duration time = 0.05 s and velocity 10 m/s was provided. In the staged construction mode, each process of construction is taken as a single phase. After activation of all the phase the model is calculated to obtain the desired results.

4 Results

Moving load was simulated for both reinforced and unreinforced section. The applied pressure was 40 kN and the analysis was carried out by placing geotextile at different interfaces i.e. subgrade sub-base interface, sub-base base interface and base asphalt concrete interface. Critical pavement responses, total displacement and strains, of unreinforced and geotextile reinforced pavements are determined.

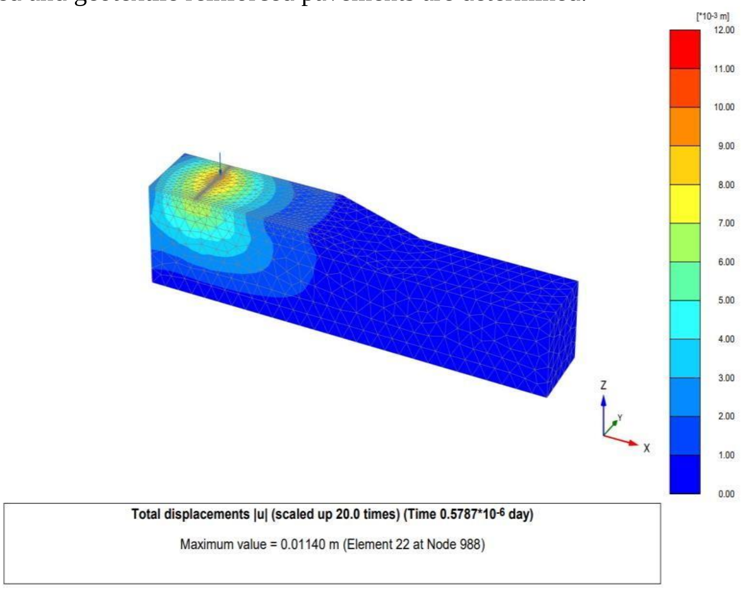

Fig. 7. Total displacement diagram for unreinforced pavement.

It was observed that the maximum total displacement obtained for unreinforced pavement section is 11.4 mm as shown in figure 7 and with geotextile reinforcement the maximum reduction of total displacement changes to 9.3mm when placed between subgrade subbase interface. Figure 8 shows total displacement diagram of pavement with geotextile placed between subgrade subbase interface. Total displacement values of 9.52 and 10.29 mm was obtained while placing geotextile at base asphalt interface and subbase base interfaces as shown in figure 9 and 10 respectively.

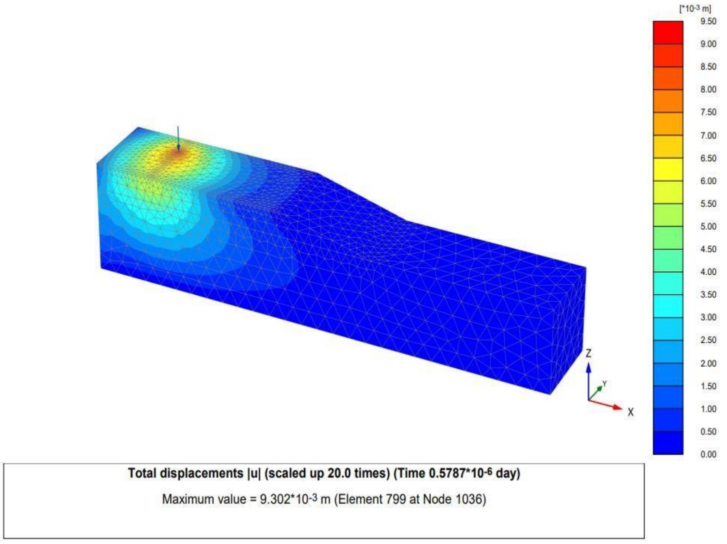

Fig. 8. Total displacement of pavement with geotextile at subgrade subbase interface

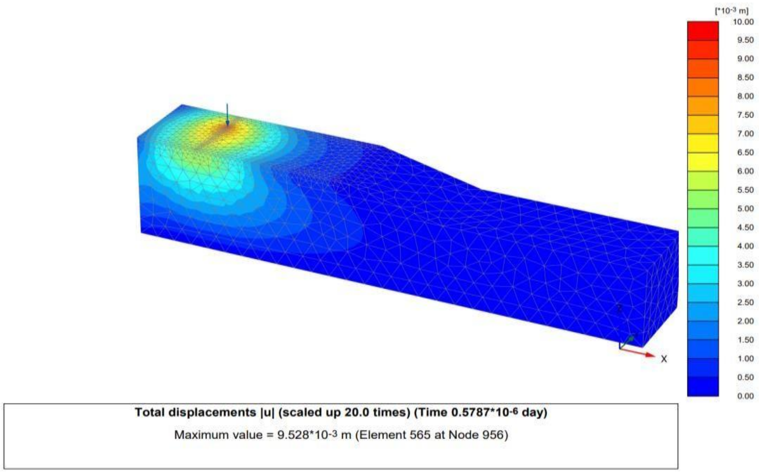

Fig. 9. Total displacement of pavement with geotextile at asphalt base interface

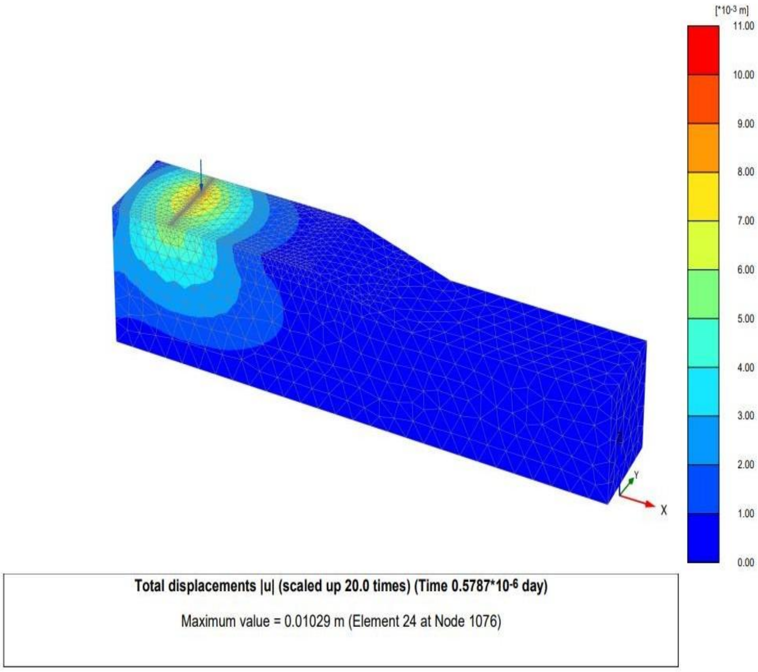

Fig. 10. Total displacement of pavement with geotextile at subbase base interface.

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, coir geotextile placed at the interface between the subgrade and sub base course shows the maximum value of 18 % where as for the geotextile placed at interface between the base subbase gives the lowest percentage reduction of 9 %. The percentage reduction for asphalt base interface is 16 %. According to the study, it is clear that considering the reduction in settlement the best position for placing the geocell is at the interface between subgrade subbase interface.

Surface deflection ($U_{z\ max}$) at the top of the pavement layer is evaluated for rutting. Rutting for both unreinforced and geotextile reinforced sections for the peak load are analyzed and compared. Table 4 represents the summary of rutting strains obtained from each section.

Table 4. Finite element predicted surface deflection

Coir Geotextile location in pavement	($U_z{}^{max}$) mm	Reduction in surface deflection (%)
Unreinforced	11.39	-
Subgrade subbase Interface	9.30	17
Subbase Base Interface	10.27	9
Asphalt Base Interface	9.40	16

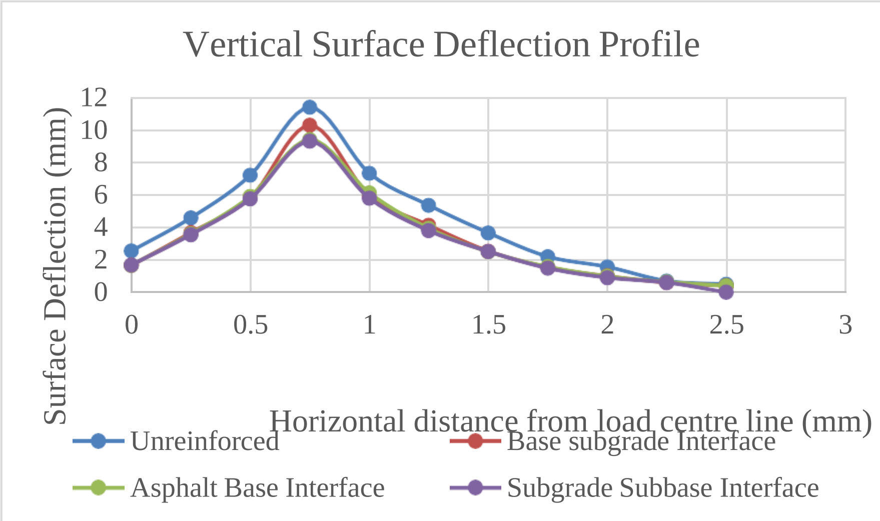

Fig. 11. Variation of surface deflection along horizontal distance

Figure 11 shows the vertical surface deflection predicted along the horizontal distance from the load center line. From the results it can be observed that the coir geotextile reinforcement at the subgrade subbase interface leads to highest reduction in surface deflection. A reduction of maximum 17 % is obtained for this section. The difference in surface deflection between the reinforced systems and unreinforced systems tends to decrease as moving away from the wheel load center until it disappears. The reduction in surface deflection for sections reinforced at subbase base interface and base asphalt interface are 9 % and 16% respectively. It can be concluded from these observations that the maximum decrease in surface deflection occurs when placing the coir geotextile at subgrade subbase interface.

5 Conclusions

The present numerical investigation aimed at evaluating the benefits of using coir geotextile in pavement. A better alternative for the extensive use of artificial geosynthetics is indeed possible by the use of natural coir geotextiles. The numerical simulations are conducted in the study to investigate the beneficial effects of coir geotextile reinforcement to reduce the rutting failures of the flexible pavement. From the numerical modeling conducted with the coir geotextile reinforcement at different positions the following conclusions can be made:

- Coir geotextile placed at the interface between the subgrade and sub base layer shows the maximum value of 18 % in reducing settlement of flexible pavement, whereas for the geotextile placed at interface between the base subbase gives the lowest percentage reduction of 9 %. The percentage reduction for asphalt base interface obtained is 16 %.

- Study confirms the capability of coir geotextile reinforcement in the reducing settlement thereby improving the pavement properties.
- The geosynthetic reinforcement potential for reducing the rutting and surface deflection is much more pronounced when using it in subgrade subbase interface as maximum surface deflection of 17% is obtained at this position.
- The reduction in surface deflection for sections reinforced at subbase base interface and base asphalt interface are 9 % and 16% respectively.
- From the numerical modeling, the best placement location for the coir geotextile is at the subgrade subbase considering the surface deflection in pavements.

The above results show the possibility of using coir geotextile for reducing rutting strains in the pavement.

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