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Assessing reinforced pavement performance: Influence of geogrid position, axial stiffness, and applied stress

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ABSTRACT

This study examined the performance of pavement, considering geogrid's position within the pavement layers, geogrid's axial stiffness, and applied stress through the Plaxis 2D program. Results showed that the position of the geogrid has a significant effect on the pavement performance. Using geogrid at the top of the base layer produced a deformation of 2.357 mm, and one at the top of the subbase had a deformation of 2.433 mm. Thus, the use of geogrid on the top of the base layer could provide the highest effectiveness on the pavement performance. Additionally, the geogrid's axial stiffness had a slight impact on the performance of reinforced pavement. When the axial stiffness increased 2.5 times, the deformation of the pavement decreased only about 0.061 mm. The response of the stress-strain of the reinforced pavement was found to be nonlinear for the static applied stress and to be linear for the dynamic applied stress. The results obtained in this study were theoretically extracted using finite element analysis and the discussions were based on those. Therefore, further studies for the pavement reinforced with geogrid by experiments in the laboratory and on-site should be carried out to understand the impact of geogrid on pavement performance.

1. INTRODUCTION

A typical pavement is constructed with a surface asphalt layer and a base course layer made from granular or cement-treated materials on top of a subgrade layer. The pavement itself is designed to provide the load-bearing capacity for dynamic loads from traffic and a safe riding base for the passengers (Ahirwar & Mandal, 2017; Patil & Shivananda, 2017). Furthermore, on-site, pavement is designed to prevent environmental effects such as temperature, freezing, thawing, and moisture (Alimohammadi et al., 2021). In practical utilization, to enhance the long-term use of pavement, geogrid is used widely as an environmentally friendly, effective, and economical solution (Kawalec et al., 2018; Aga, 2021). Geogrids, known as geogrid mesh or stabilization mesh, is a type of geosynthetic material. It is used to produce stabilization and reinforcement to pavement layers. It could be made from polymer plastics, typically polypropylene, polyethylene, or polyester. They consist of a series of interlocking vertical and horizontal cells that formed in a grid pattern. Generally, geogrid will be laid with a pattern of square holes, like rigid plastic netting. Fig. 1 shows the typical polymer geogrid (Sinmez, 2019).

The use of geogrid in the pavement body can help prevent distress and contamination, erosion, and root barriers. To date, several studies have been conducted to evaluate the effect of geogrid on the performance of the reinforced pavement. Sadiq et al. (2022) studied the behavior of a pavement reinforced with geogrid using the finite element analysis method. Their study used the Abaqus 2D program to model the scenario. The materials in the model were assumed to have a linear elastic behavior. The asphalt surface displacement results were compared between the unreinforced and reinforced pavement. The results showed that the reinforced pavement by geogrid had a significant improvement in deformation. In their study, the effects of position, stiffness of the geogrid, and applied stress on the performance of the reinforced pavement were not considered. In another study by Jasim et al. (2021), the finite element analysis program was used to model pavements with and without geogrid in a three-dimensional finite element model. This study highlighted that geogrids could enhance the performance of pavement. In addition, the position in which that pavement produced the highest performance was also captured. The results showed that the geogrid was the most effective in improving pavement performance when placed within the upper third of the layer. The research observed the effect of the geogrid position and recommended using geogrid to stabilize the pavement. Susanto et al. (2022) recently used the finite element analysis program Plaxis 2D to compare the performance of the unreinforced and reinforced pavement by geogrid. The results implied a remarkable improvement in pavement life when it was reinforced by geogrid. The use of geogrid in the asphalt layer can help reduce the deformation of the pavement layer. Moreover, the geogrid contributes to the long-term performance of the pavement. They figured that the optimum position for the geogrid position in the pavement was between the base and subgrade layers. However, the effects of geogrid stiffness and applied stress on the performance of reinforced pavement were not mentioned. Ahirwar & Mandal (2017) simulated the reinforced pavement by geogrid to extract the effect of axial stiffness of geogrid and thickness of the base layer. In the study, the geogrid was located between the pavement layers. Furthermore, they compared the deformation of reinforced pavement which was reinforced by geogrid having different axial stiffness. They concluded that when the geogrid was used for the reinforcement, it helped to significantly decrease the deformation of pavement. This study only discussed the effect of geogrid' axial stiffness regardless of the position and the static and dynamic applied stress.

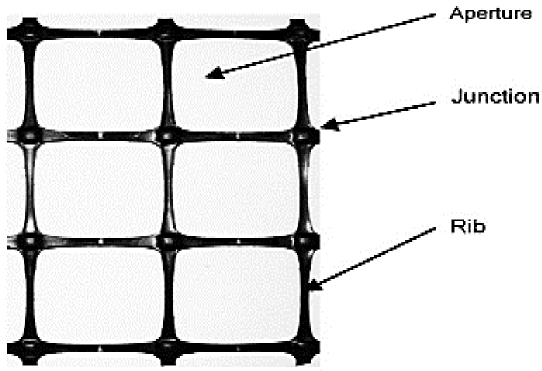


Figure 1. Typical polymer geogrid

(Sinmez, 2019)

Literature has shown that the use of geogrid in the layers of pavement could improve its mechanical performance. In addition, it could also improve the long-term performance of pavement. Geogrid was used widely to stabilize the payment layers since it was economically effective and easy to install. The performance of the reinforced pavement by geogrid strongly depends on the position, axial stiffness, and applied stress.

This study was conducted to fulfill the gaps by observing the performance of the reinforced pavement considering the position, stiffness, and applied stress. To archive the scope, the finite element analysis program Plaxis 2D was used. The reinforced pavement was initially modeled based on literature. Then, further observations were conducted. Firstly, the reinforced pavement with different geogrid positions in the pavement body was simulated to find the optimum position. Secondly, the reinforced pavement with the optimum geogrid's position was simulated with different axial stiffness values. Finally, the effect of static and dynamic stress on the deformation of the reinforced pavement was estimated.

2. FINITE ELEMENT MODEL FOR THE PAVEMENT

This study used the two-dimensional finite element analysis program Plaxis 2D 2017. The pavement model was established with the axis-symmetry model. The pavement was constructed with four layers: surface, base, subbase, and subgrade. To build the pavement model, 15-nodded structural solid elements were utilized. As mentioned above, the current study only discussed the results from the finite element analysis. After the literature review process, the model parameters and geometry in the study of Ahirwar and Mandal (2017) met the scope of the current study. In addition, that model could run well and provide suitable results. Hence, the model and parameters in this study followed those in the study of Ahirwar and Mandal (2017). Worthily, the current study fills the gaps since it will define the effect of the geogrid's position, axial stiffness, and applied stress on the performance of the reinforced pavement. Based on the analysis, the current study will figure out the optimum position for geogrid and the behavior of the reinforced pavement in the static and dynamic applied stress. Details of the pavement layers' parameters are displayed in Table 1. The pavement model in this study is illustrated in Fig. 2.

Table 1. Pavement layers' parameters (Ahirwar & Mandal, 2017)

Material	Surface (Asphalt)	Base (Copper slag)	Subbase (Sand)	Subgrade (Clay)
Model	Linear elastic	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Thickness, (mm)	100	100	380	500
Unit weight, (kN/m^3)	22.3	22.2	15.5	14.5
Saturated unit weight, (kN/m^3)	-	23.5	16.2	16.1
Cohesion, (kPa)	-	1	1	120
Internal friction angle (°)	-	43	40	5
Elastic Modulus, (MPa)	1000	20	42	10.6
Poisson ratio (μ)	0.35	0.35	0.35	0.35

The applied stress values on the pavement model followed that in the study of Ahirwar & Mandal (2017). It was a uniform loading of 575 kN/m^2, equivalent to a single wheel load of 4080 kg (Bohagr, 2013). The vertical thickness of pavement layers was 100 mm, 100 mm, 380 mm, and 500 mm for the surface, base, subbase, and subgrade, respectively. In this study, the geogrid was modeled using a geogrid element initially installed in the Plaxis 2D program. Details of the pavement layers' parameters for calculations are presented in Table 1. The pavement model in this study is presented in Fig. 2.

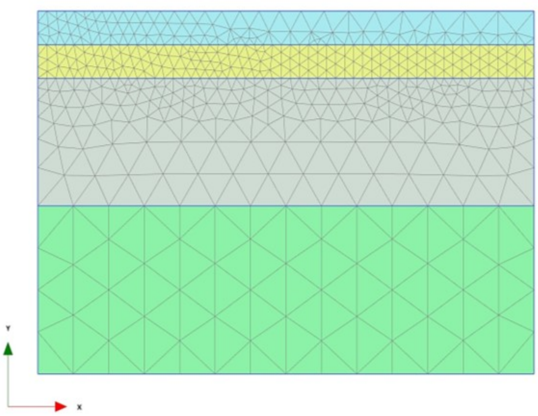


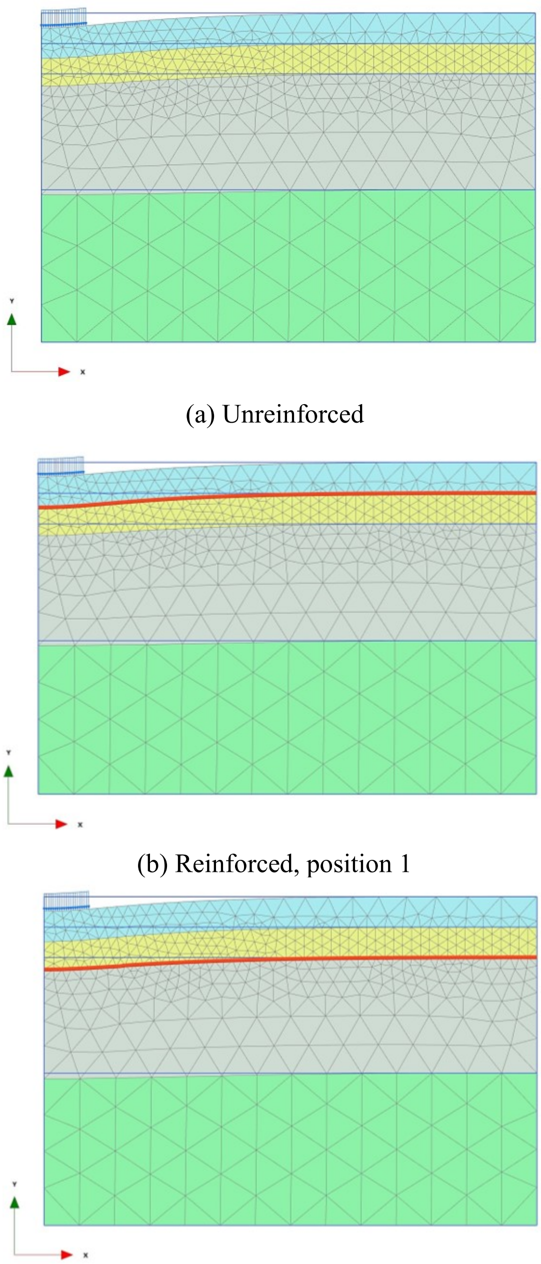
Figure 2. Pavement model in Plaxis 2D program

3. RESULTS AND DISCUSSION

3.1. Effect of position of the geogrid

To observe the effect of geogrid position on the performance of reinforced pavement, two different positions for the geogrid were examined. The pavement with deformation results of the unreinforced and the reinforced pavements with different geogrid positions are presented in Fig. 3. In this study, to examine the benefit of the geogrid's position on the deformation of the pavement, the pavements without geogrid (unreinforced) and with geogrid (reinforced) were analyzed. In this analysis, the axial stiffness of the geogrid is consistently used as 1000 kN/m. The reinforced pavement was calculated by taking into consideration different positions of geogrid. The geogrid was laid on the top of each pavement layer, one by one, to determine the position that creates the highest resistance to the deformation. Vertical surface deformation on the top surface of the pavement is used to evaluate the pavement deformation. Fig. 4 shows the surface deformations of the unreinforced and reinforced pavement with different geogrid positions.

It can be seen from Fig. 4 that the unreinforced pavement provided the highest deformation among the pavements. The results are consistent with those in the study of Al-Jumaili (2017) and Faheem and Hassan (2014). The conclusion was made that the use of geogrid remarkably improved the performance of the pavement. The explanation was that when geogrid is used in the pavement body; it helps accumulate the stress above it. As a result, it transfers lesser stress intensity to the layer below (Vibhoosha et al., 2021).



(a) Unreinforced

(b) Reinforced, position 1

(c) Reinforced, position 2

Figure 3. Unreinforced and reinforced pavements in the Plaxis 2D program

Furthermore, the pavement deformation result indicated that the position of geogrid has a significant effect on the pavement performance. While the geogrid at the top of the base layer (position 1) produced a deformation of 2.357 mm, one at the top of the subgrade (position 2) had a deformation of 2.433 mm. Hence, the use of geogrid on the top of the base layer showed the highest positive effect on the pavement performance.

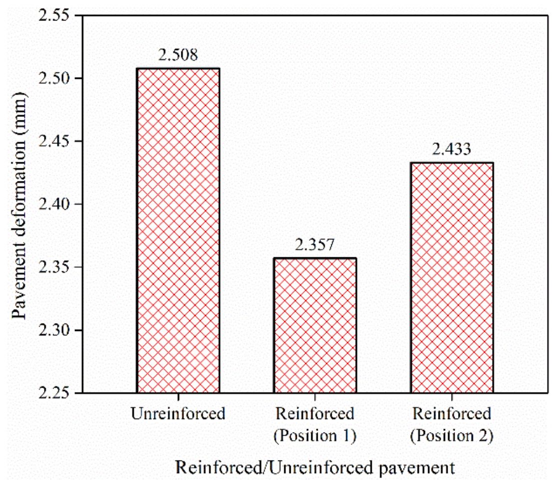


Figure 4. Deformation of the unreinforced and reinforced pavements

3.2. Effect of axial stiffness of geogrid on the deformation of reinforced pavement

Based on the results and discussions above, in the case of position 1, the reinforced pavement had the lowest deformation. To observe the effect of the axial stiffness of geogrid on the deformation of pavement, the reinforced pavement with geogrid laid position 1 was analyzed. The values of axial stiffness of geogrid were shown in Table 2 for the analysis.

Table 2. Geogrid's parameters for the finite element analysis

Model		Linear elastic
Axial stiffness, (kN/m)	Case 1	400
	Case 2	600
	Case 3	800
	Case 4	1000

Fig. 5 shows the relationship between the axial stiffness of geogrid and the deformation of pavement. The results showed a slight reduction in the deformation of pavement according to the increase in axial stiffness of geogrid. This reduction could be caused by the confinement effect of the geogrid (Ahirwar & Mandal, 2017). When the axial stiffness of the geogrid rose from 400 kN/m to 1000 kN/m, the reduction in deformation dropped only from 2.494 mm to 2.433 mm. In other words, when the axial stiffness increased 2.5 times, the deformation of the pavement decreased only about 0.061 mm. This behavior in the current study highlighted that the axial stiffness of the geogrid has a less significant effect on the pavement deformation.

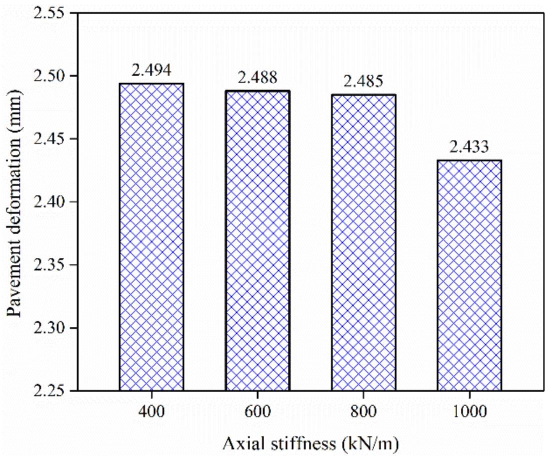


Figure 5. Effect of axial stiffness of geogrid on the pavement performance

3.3. Effect of applied stress on the deformation of reinforced pavement

In this study, the effect of applied stress on the deformation behavior of the reinforced pavement was observed. A series of the applied stress values as 575, 1150, 1725, and 2500 kN/m^2 were applied on the reinforced pavement with the geogrid position 1 and axial stiffness of 1000 kN/m, respectively. The two applied stress types in this study were static and dynamic. The dynamic stress was considered to be in the form of a harmonic sinusoidal function with a frequency of 100 Hz (Nazari & Dabiri, 2016).

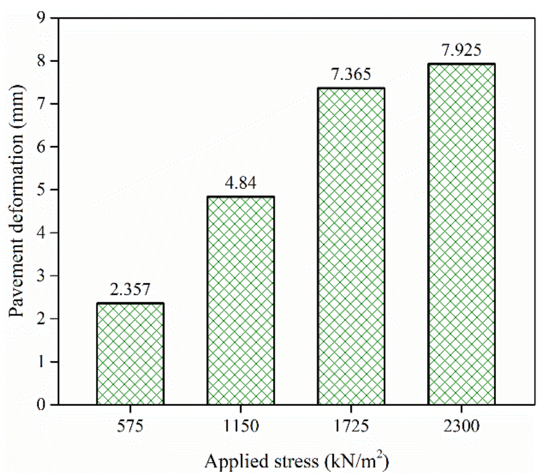


Figure 6. Effect of applied stress on reinforced pavement performance

The relationship between the applied stress in the static case and the pavement deformation results is illustrated in Fig. 6. The results showed that when the applied stress increased, the pavement deformation increased. It is noted that even though the applied stress increased linearly, the increase in pavement deformation was not linear. For example, when the applied stress doubled, from 575 to 1150 kN/m^2, the deformation increased about two times, from 2.357 to 4.840 mm. However, at the high applied stress as 1725 and 2500 kN/m^2, the results for pavement deformation were only 7.365 and 7.925 mm. The increment is only 1.08 times. Previous studies have reported a nonlinear relationship between stress-strain of the pavement (Kuo & Huang, 2006; Rahman et al., 2011).

The deformation response of the reinforced pavement in the dynamic case is displayed in Fig. 7. It can be seen that when the dynamic applied stress increased, the pavement deformation increased. It is noted that in terms of dynamic stress, the relationship between stress-strain of the reinforced pavement seems to be linear. This behavior is consistent with that in the study of Lu et al. (2014). In the comparison, the results show that the deformation of the reinforced pavement in the dynamic stress was higher than those in the static stress. A similar conclusion could be found in the study of Zheng et al. (2012).

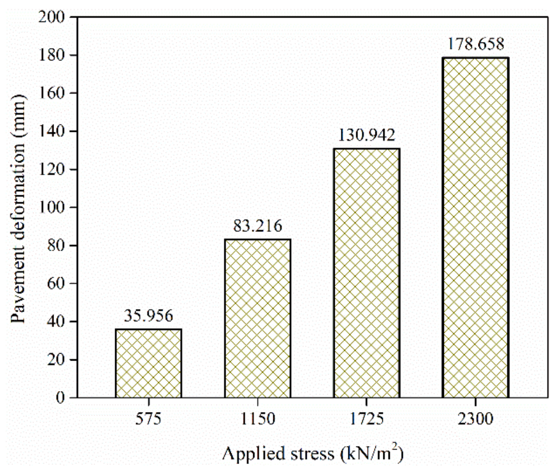


Figure 7. Effect of dynamic applied stress on reinforced pavement performance

4. CONCLUSION

The use of geogrid in the pavement body can help prevent distress, contamination, erosion, and root barriers. The deformation of the unreinforced and reinforced pavement with geogrid has been analyzed in this study. From the results, the effect of geogrid position and axial stiffness values on pavement deformation has been evaluated. The conclusions were drawn as follows:

(i) The use of geogrid remarkably improved the performance of the pavement. The position of the geogrid has a significant effect on the pavement performance. As shown, the geogrid at the top of the base layer (position 1) is the optimum position since it resulted in the lowest deformation. In other words, the use of geogrid at the top of the base layer showed the highest positive effect on the pavement performance.

(ii) There was a slight reduction in the deformation of pavement according to the increase in axial stiffness of geogrid. When the axial stiffness increased 2.5 times, the deformation of the pavement decreased only about 0.061 mm. Thus, the axial stiffness of the geogrid has a less significant effect on the pavement deformation.

(iii) The investigation of the response of pavement under different applied stress types showed a nonlinear relationship between stress and strain for the static stress. However, there was a linear relationship between stress and strain for the dynamic stress. It is noted that the results in this study were theoretically extracted using finite element analysis. Hence, further studies for pavements reinforced with geogrid by experiments in the laboratory and on-site should be carried out to understand the impact of geogrid on pavement performance.

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