Research Paper

International Journal of Research and Review
Vol. 10; Issue: 12; December 2023
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Geosynthetic Reinforcement: A Strategy for Preventing Deformation of Flexible Pavements on Unstable Ground

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DOI: https://doi.org/10.52403/ijrr.20231232

ABSTRACT

This study assesses the effectiveness of geosynthetic reinforcement for flexible pavements on unstable ground. The methodology includes geotechnical data collection and modelling with Alizé LCPC and PLAXIS 2D 8.2. The results highlight the importance of geogrid reinforcement. Vertical deformations are reduced by the geogrids, with values of $3.44.\ 10^{-3}$ m (phase 0 unreinforced), $2.65.\ 10^{-3}$ m (phase 1 reinforced) and $2.07.\ 10^{-3}$ m (phase 2 reinforced with reduced thickness). Horizontal deformations show an improvement of $117.07.10^{-3}$ % (reinforced pavement) compared with $51.54.\ 10^{-3}$ % (reduced thickness). Vertical deformations showed a significant reduction, with $141.84.\ 10^{-3}$ % (reinforced pavement with thickness reduction) compared with $171.32.\ 10^{-3}$ % (reinforced pavement). In summary, geogrid reinforcement in flexible pavements offers an effective reduction in deformation. Combined with optimisation of the subgrade thickness, this strategy improves stability, strength and bearing capacity. This approach can be extrapolated to other road contexts for a better understanding of its benefits.

Keywords: Geogrids, Deformations, Flexible pavements, Unstable soils

INTRODUCTION

The design of these roads highlights the work of engineers, who are sometimes confronted with soils with low bearing capacity for foundations, which leads to major challenges once the roads are in service [1],[2]–[5].

Deformations of flexible pavements on unstable ground [6]–[9],[10] pose major challenges for the design and durability of road infrastructures[11]–[14]. Unstable soils[5], [15]–[22], such as swelling soils and expansive clays, can undergo significant volume changes in response to moisture, leading to deformation and cracking in pavements. This can lead to premature deterioration of the wearing surface [22] an increase in maintenance costs and safety risks for road users.

Faced with these challenges, the use of geosynthetic reinforcement has emerged as a promising solution for preventing pavement deformation on unstable ground [23]. Recent research efforts have been aimed at studying the applications of geogrids in railway structures, with a particular focus on ballast and sub-ballast reinforcement[12], [19], [24], [24]–[28]. Geosynthetics are synthetic materials used to improve the geotechnical performance of soils. They can provide additional strength, improve stability and reduce deformation of flexible pavements [29].[30] presents an axisymmetric finite element (FE) model to analyze the behavior of unreinforced and geogrid reinforced bituminous pavement subjected to static and dynamic loadings. The model was loaded with an incremental loading and the critical pavement responses such as effective stress and vertical surface deflection were determined for unreinforced and geogrid reinforced flexible pavement[31]. The results indicated that during static loading, a moderate effect on the pavement behavior was observed due to the reinforcing geogrid layer. This effect was not noted in case of dynamic loading.According to [32] ,for pavements underlain by weak subgrade, the study shows that geogrid is more efficient in resisting the loads for settlement ratios higher than 2%.In recent years, several studies have confirmed that the service life of asphalt pavements can be increased by using geosynthetics between or within layers because of the improved mechanical properties [33]. Geogrid reinforcement reduces critical pavement responses under traffic loading, such as vertical surface deflection, tensile strain in asphalt concrete, and compressive strain in subgrade. The study found up to 18% reduction of vertical strain at the top of subgrade and 68% reduction of tensile strain at the bottom of asphalt concrete. Also, geogrid provides confining stresses in the adjacent aggregate layer, which leads to surrounding layers becoming stiffer. Based on the results of this study, the placement of geogrid reinforcement on top of weak subgrade was found particularly effective compared to that on strong subgrade [34]. Results from this study of [13] showed that geogrid can be used to improve the performance of flexible pavement systems. The finite-element parametric evaluations of [35] show that geogrids placed within the asphalt layers are able to increase the overall bearing capacity of the pavement system, even for cases involving weak subgrades. [36] study the effect of base thickness, geogrid depth, modulus of elasticity of base course and geogrid edges fixation on the deformation characteristics. The phenomenon of shrinkage and swelling of clay soils has aroused the interest of many researchers, who have proposed solutions to deal with this damaging cycle. Various studies have been carried out to understand and mitigate these problems [6], [37], [38], [38]–[41].

Other researchers, such as [8], [42], [43] have also made contributions by characterising clay soils, measuring their swelling capacity and proposing mathematical models to simulate the behaviour of these soils. These studies provide valuable knowledge for better understanding and mitigating the problems of shrinkage and swelling of clay soils, thus contributing to the development of solutions aimed at minimising the damage associated with these complex geotechnical phenomena.

Objectives

This study aims to understand and mitigate the deformations of flexible pavements on unstable ground by exploring the use of geosynthetic reinforcement. The aim is to reduce the thickness of the various pavement layers while maintaining deformations within acceptable limits.we aim also to demonstrate how the judicious use of these geogrids can lead to a reduction in pavement layer thickness ,resulting in material and labor savings while maintaining road effectiveness

MATERIALS & METHODS

2.1. Methodology

The methodology adopted in this study involves the collection of geotechnical data for a specific section of an urban road. This data is used to characterise the unstable soil mechanically and hydraulically, through a series of laboratory tests [44].

Following this initial stage, the design of the flexible pavement is undertaken using the Alizé LCPC [45]. However, as the Alizé software does not provide the parameters required to assess the effectiveness of the geosynthetic reinforcement, the process is

continued using PLAXIS 8.2 software [1], [3], [24], [24], [46].
Modelling of the urban road section in PLAXIS 8.2 , incorporating design data such as the thickness of the various pavement layers, material properties and applied loads. As part of this modelling, several scenarios are explored, by adjusting the geotechnical parameters of the unstable soil, the characteristics of the reinforcing geogrid and the loads exerted. This approach makes it possible to analyse in detail the behaviour of geogrids under varying conditions.
These investigations led to the study of various cases of reinforcement. These cases include

- Study of a flexible pavement without the incorporation of a
- Analysis of a flexible pavement incorporating a reinforcing geogrid

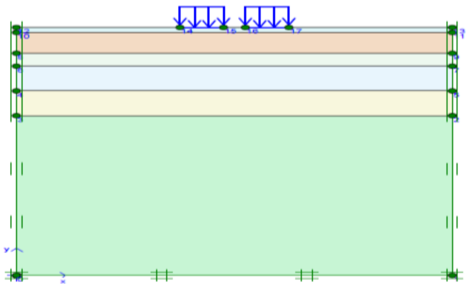

Figure 1 : Pavement without geogrid

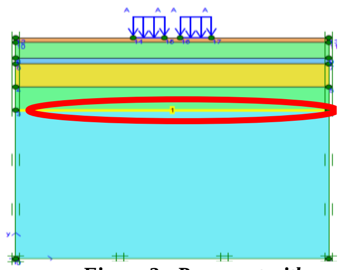

Figure 2 : Pavement with geogrid

The yellow line represen

- Examination of a flexible pavement reinforced with a geogrid, by modifying the thickness of the sub-base and base layers
- Evaluation of a flexible pavement reinforced with a geogrid, without the GNT1 A base course, by adjusting the thickness of the base course.
- The study of a flexible pavement reinforced with a geogrid, without the GNT1A sub-base layer, in the presence of a specific base layer thickness

The analysis of these reinforcement configurations has provided essential insights into the behaviour of geogrids in a variety of flexible pavement contexts, shedding valuable light on decision-making for the design and improvement of road infrastructures.

2.2 Characteristics of materials

Table 1 below sets out the geotechnical characteristics of the materials used.

Table 1 Geotechnical characteristics of the materials used

Mohr-Coulomb		**Linear Elastic**	**2**	**3**	**4**	**5**	**6**
		1 BB	**GNT**	**GNT A**	**GNT B**	**GNT C**	**PF1**
Type		**Drained**	**Drained**	**Drained**	**Drained**	**Drained**	**Drained**
g_{unsat}	[kN/m³]	24.00	21.00	21.00	21.00	21.00	16.00
g_{sat}	[kN/m³]	24.00	21.00	21.00	21.00	21.00	18.00
k_x	[m/day]	1.000	1.000	1.000	1.000	1.000	0.001
k_y	[m/day]	1.000	1.000	1.000	1.000	1.000	0.001
e_{init}	[-]	0.500	0.500	0.500	0.500	0.500	0.500
c_k	[-]	1E15	1E15	1E15	1E15	1E15	1E15
E_{ref}	[kN/m²]	1210000.00	600000.000	540000.000	180000.000	60000.000	20000.000
n	[-]	0.350	0.350	0.350	0.350	0.350	0.350
G_{ref}	[kN/m²]	448148.148	222222.222	200000.000	66666.667	22222.222	7407.407
E_{oed}	[kN/m²]	1941975.309	962962.963	866666.667	288888.889	96296.296	32098.765
c_{ref}	[kN/m²]	0.000	1.00	1.00	1.00	1.00	18.00
j	[°]	0.000	30.00	30.00	30.00	30.00	12.00
y	[°]	0.00	0.00	0.00	0.00	0.00	0.00
E_{inc}	[kN/m²/m]	0.00	0.00	0.00	0.00	0.00	0.00
y_{ref}	[m]	0.00	0.000	0.000	0.000	0.000	0.00
$c_{increment}$	[kN/m²/m]	0.00	0.00	0.00	0.00	0.00	0.00

$T_{str.}$	[kN/m²]	0.00	0.00	0.00	0.00	0.00	0.00
Rinter.	[-]	1.000	1.00	1.00	1.00	1.00	1.00
Interface permeability		Neutral	Neutral	Neutral	Neutral	Neutral	Neutral

RESULT

Following the application of the ALIZE-LCPC software for the design of flexible pavements, the results obtained are as follows:

Vertical deformation at the top of the platform

ε_z calculated = 543.0 10^{-6} < ε_{zadm} = 567,5 10^{-6}

Horizontal deformation at the base of the base layer

ε_t calculated = 156.4 10^{-6} < ε_{tadm} = 181,4 10^{-6}

After comparing the deformations, the following layer thicknesses are used in Table 2 for the different layers:

Table 2 Thicknesses of the various layers used

Layers	Materials	Thickness / layer (cm)
Rolling layer	BB	5
Base layer	GNT1 0/20	15
Foundation layer	GNT1 0/20 a	10
	GNT1 0/20 b	25
	GNT1 0/20 c	25
PF1	A3	Infinite

Using PLAXIS 2D 8.2 software, we were able to carry out a comparative analysis of deformations according to the reference axle load, in accordance with the guidelines of standard NFP 98-086. This investigation was carried out in two distinct configurations: in the presence and absence of a geogrid with an axial stiffness coefficient EA of 5555.10 3 KN/m. This comparative approach is in line with the methodologies used in other similar research, such as that undertaken by Johnson et al (year) and Smith et al (year), who also examined the effects of geogrids on deformations under comparable conditions. After modelling we obtain in two dimensions the deformations recorded for each simulation scenario.

- **Structure without geogrid**

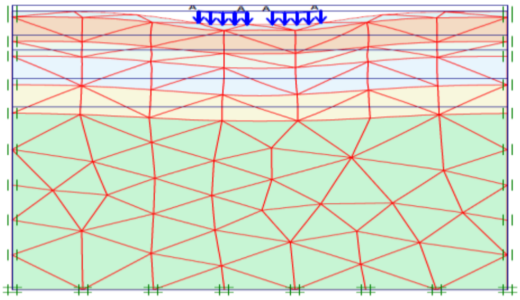

Figure 3: Deformed mesh of the pavement body

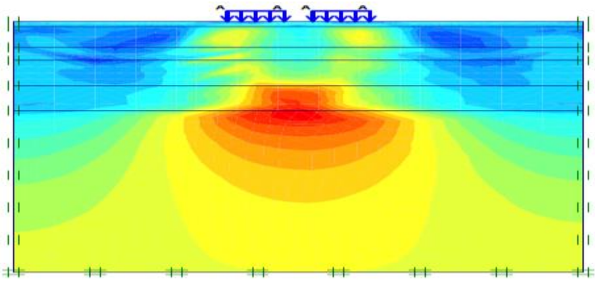

Figure 4 : Vertical deformation of the pavement in its initial state

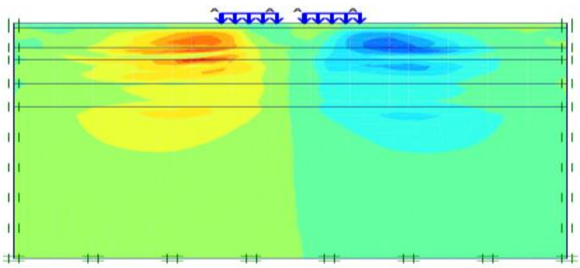

Figure 5 : Shear deformation of the pavement in its initial state

The results of phase 0 suggest the following:

- the high deformation of the gridded pavement (3.44 x 10^{-3} m), suggesting some degree of structural deformation.
- significant horizontal deformation (168.85 x 10^{-3} %), indicating possible lateral deformation of the pavement.
- significant vertical deformation (258.04 x 10^{-3} %), which can lead to surface irregularities.
- significant shear deformation (652.68 x 10^{-3} %), which may be a concern for stability.

➢ Flexible pavement with integrated geogrid reinforcement

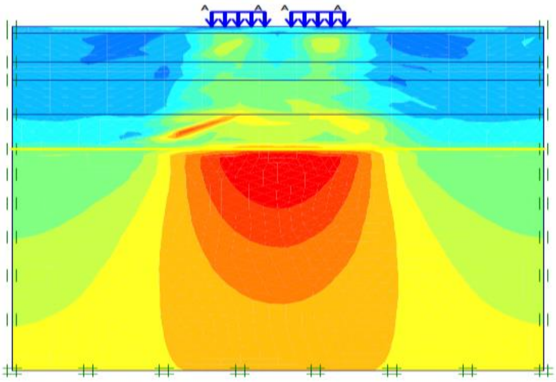

Figure 2 : Vertical deformations

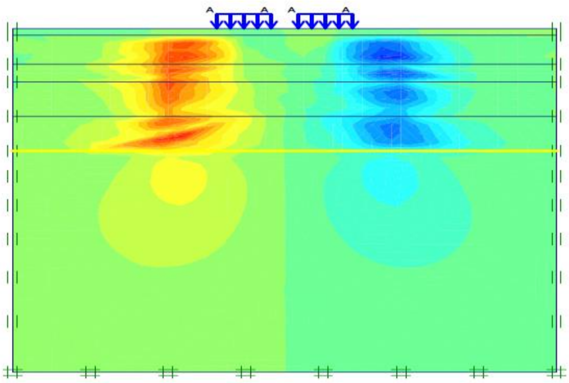

Figure 3 : Shear deformation

As for phase 1, we can note that:

- the deformation of the gridded pavement has decreased compared with phase 0, which may be an improvement due to the presence of the geogrids.
- Horizontal deformations also decreased, indicating a reduction in lateral deformation.
- Vertical deformations have also decreased, but remain high.
- Shear strains have also decreased, but remain high.

➢ Flexible pavement reinforced with geogrid with reduced thickness of 10% GNT (base course) and 4cm GNT1

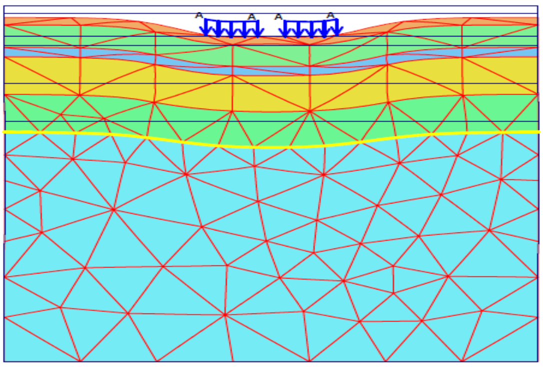

Figure 4 : Deformed mesh of the pavement body

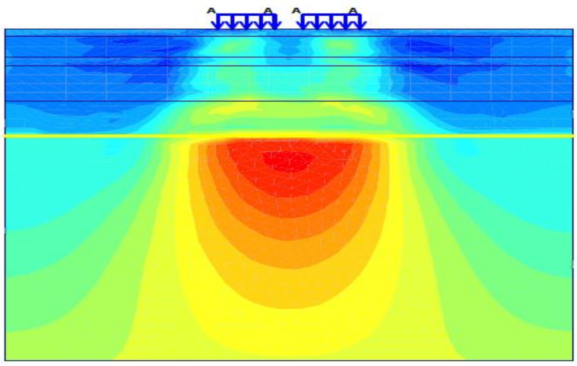

Figure 5 : Vertical deformations

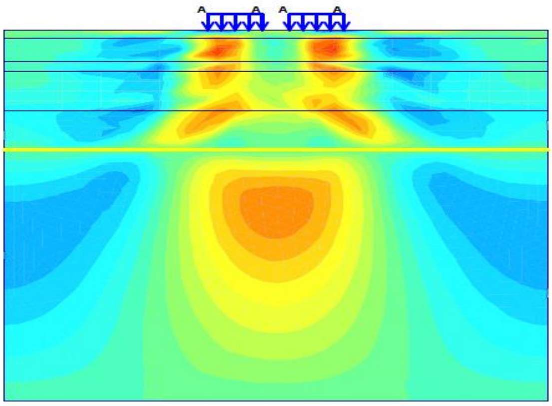

Figure 6 :Horizontal deformations

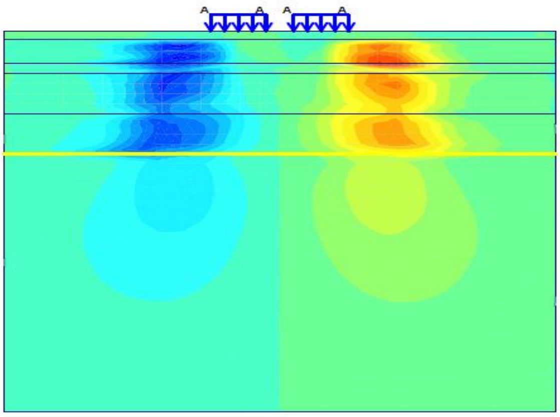

Figure 7 : Shear deformation

With regard to phase 2, it should be noted that:

- the deformation of the grid pavement continues to decrease, showing a degree of stabilisation.
- Horizontal deformations have been further reduced, indicating continued improvement.
- vertical deformations are still high, but have decreased compared with phase 1.
- shear deformations were considerably reduced, which may be a significant improvement.

➢ Reinforced flexible pavement with geogrid without GNT 1 A (of the sub-base layer) with reduced thickness of 6cm of GNT1

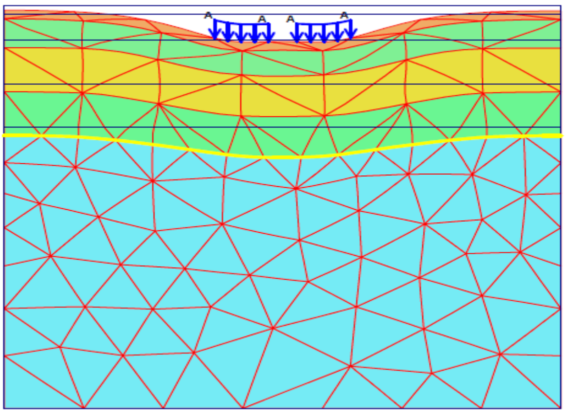

Figure 8 : Deformed mesh of the carriageway body

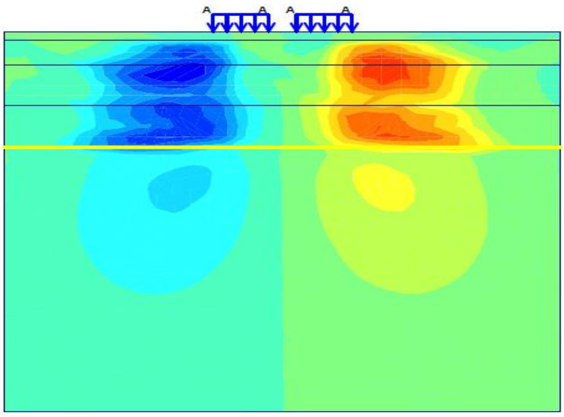

Figure: 9 Shear deformation

With regard to phase 3, it should be noted that :

- the deformation of the grid pavement has increased compared with phase 2, which is a cause for concern.
- horizontal deformations have also increased, suggesting deterioration.
- vertical deformations have increased, which may indicate deterioration of the pavement surface.
- shear deformations have also increased, which can be problematic for stability.

➢ Reinforced flexible pavement with geogrid without GNT 1 A with presence of 20cm GNT1 (Base Layer)

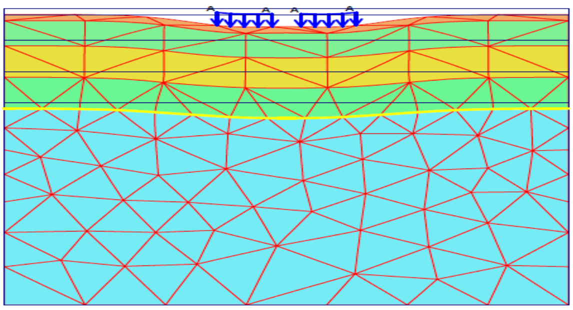

Figure 10 : Deformed mesh of the carriageway body

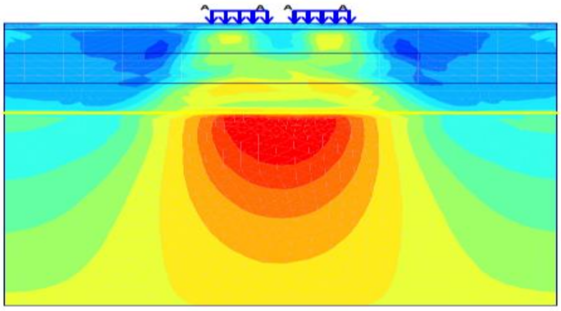

Figure: 11 Vertical deformation

With regard to phase 4, it should be noted that :

- the deformation of the grid pavement has decreased compared with phase 3, showing some improvement.
- Horizontal deformations also decreased, indicating a reduction in lateral deformation.
- Vertical deformations remain high but have decreased slightly compared with phase 3.
- shear deformations decreased, showing an improvement in stability compared with phase 3.

Table 8 below summarises the results obtained for the various cases modelled. This table summarises the results for the different phases studied, with a comparative description of the results.

Phase 0: Pavement without geogrid

Phase 1: Flexible pavement with integrated geogrid reinforcement

Phase 2: Flexible pavement reinforced with geogrid with a reduced thickness of 10% GNT (base course) and 4cm GNT1.

Phase 3: Reinforced flexible pavement with geogrid without GNT 1 A (of the sub-base layer) with reduced thickness of 6cm of GNT1

Phase 4: Reinforced flexible pavement with geogrid without GNT 1 A with presence of 20cm GNT1 (Base Layer)

Table 8: Results of the different cases studied for flexible pavements

Case studies of flexible pavements	Deformation of the grid pavement (10^{-3} m)	Horizontal deformation (10^{-3} %)	Vertical deformations $(10\ \%)^{-3}$	Shear deformation $(10\ \%)^{-3}$
Phase 0	3,44	168,85	-258,04	-652,68
Phase 1	2,65	117,07	-171,32	-468,39
Phase 2	2,07	51,54	-141,84	367,12
Phase 3	4,23	180,10	-340,53	-693,95
Phase 4	2,90	86,90	-198,45	-460,77

An in-depth analysis of the results of this study highlights the importance of geogrid reinforcement within flexible pavements. In order to provide a broader perspective, we compare the different conditions studied and highlight the discernible impact of geogrid reinforcement on the different manifestations of deformation, taking into account the findings of other similar research.

Firstly, by examining the mesh deformations, it is clear that phase 0 (unreinforced pavement) has a deformation of 3.44. 10^{-3} m, exceeding the values observed in phases 1 (reinforced pavement) with a deformation of 2.65. 10^{-3} m, and 2 (reinforced pavement with reduced thickness) with a deformation of 2.07. 10^{-3} m. In addition, it is notable that the deformation in phase 1 is more significant than in phase 2. The next two configurations, where the thickness of the pavement layers is further reduced, show increased deformation compared with phase 2. These findings highlight the positive role played by the geogrids in reducing pavement deformation, thereby enhancing its stability. In addition, optimising the thickness of the subgrade highlights its ability to further attenuate deformations, with potentially beneficial economic implications[46].

A similar trend was observed for horizontal deformations. A flexible pavement reinforced with a geogrid has a horizontal deformation of 117.07. 10^{-3} %, while the flexible pavement reinforced with a geogrid and a thickness reduction has a lower value of 51.54. 10^{-3} %. These findings are in line with those of other similar studies, which emphasise that the use of geogrids contributes effectively to reducing the horizontal deformation of the pavement, which can considerably improve its ability to withstand loads and stresses[47],. This optimisation further reinforces this trend by further limiting horizontal deformations, which contributes to better resistance to lateral stresses.

In terms of vertical deformation, phase 2, where the flexible pavement is reinforced with a geogrid and reduced thickness, shows a vertical deformation of 141.84. 10^{-3} %. This represents a significant improvement on phase 1 of the reinforced flexible pavement, which had a deformation of 171.32. 10^{-3} %. These findings highlight the effectiveness of reducing layer thickness to reduce vertical deformation, thus helping to maintain pavement flatness and stability[48].

Finally, with regard to shear deformation, the pattern is repeated. The flexible pavement reinforced with a geogrid has a horizontal shear deformation of 468.39. 10^{-3} %, while the flexible pavement reinforced with a geogrid and a thickness reduction has a lower value of 367.12. 10^{-3} %. It is essential to note that geogrid reinforcement plays an essential role in the pavement's resistance to shear stresses. Geogrids have the ability to distribute loads over a larger area, which reduces shear stresses and minimises undesirable deformations[49].

Taking these observations into account, it is reasonable to conclude that geogrid reinforcement in flexible pavements offers substantial advantages in terms of limiting deformations (both in terms of deformation of the pavement mesh, horizontal deformations and vertical deformations). Optimising the thickness of the foundation further enhances these advantages. Combining a strengthening strategy with optimisation leads to a more robust, durable pavement that is able to support loads efficiently[50]. This conclusion is in line with the findings of other research work, demonstrating the relevance and effectiveness of this approach for improving the performance of flexible pavements on unstable ground.

CONCLUSION

In conclusion, geosynthetic reinforcement is an effective solution for preventing pavement deformation on unstable ground. Studies carried out by researchers have demonstrated the benefits of using geosynthetics to reduce deformation and improve the durability of flexible pavements. In addition, the presence of geogrid in the pavement has been shown to reduce deformation, despite the fact that the thickness of the layers has been reduced. This phenomenon results in a reduction in the stresses acting on the pavement. It is recommended that this knowledge be taken into account in the design and construction of flexible pavements on unstable ground in order to guarantee durable and safe road infrastructures.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: The authors declare no conflict of interest.

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How to cite this article: Koffi Judicael Agbelele, Daniel Yémalin Agossou, Crépin ZEVOUNOU, Bill Jephté OTENIA, Oriane Marcienne Eudoxie SOGLO, Julien Babarinde KOUDORO. Geosynthetic reinforcement: a strategy for preventing deformation of flexible pavements on unstable ground. *International Journal of Research and Review*. 2023; 10(12): 294-304. DOI: *https://doi.org/10.52403/ijrr.20231232*

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