COMPARATIVE ANALYSIS OF STANDARD PAVEMENT LAYERS AND GEOCELL-REINFORCED PAVEMENT LAYERS

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ABSTRACT:

The pavement layer has been considered as an inferior type of support over the other types of paving systems. The analysis compares numeric findings between standard pavements and geocell-reinforced pavement layers through simulations in PLAXIS. Some of the assessments taken into consideration are the structural behaviour of geocell reinforcement, comparison of stress distribution, deformation characteristics, settlement rate, and overall stability improvement. Standard pavement layers are effective in load distribution but suffer from normal degradation under heavy traffic loading and environmental conditions. They constitute a three-dimensional confining system wherein performance is rated to be higher in distributing loads, controlling settlement, and resisting shear. The current research gives a prospective insight into the trade-Offs involved in the cost-benefit profile of geocell application, which is potentially helpful in enhancing pavement life and minimizing maintenance costs. The challenges of installation expenses, material selection, and standardization have been accommodated in the study. Therefore, study results recommend encouraging geocell technology acceptance in areas with very weak subgrade conditions, high traffic volumes, and potential economic constraints. Further study on the long-term performance, optimization of geocell parameters, and incorporation with sustainable pavement materials should be considered.

KEYWORDS:

Geocell reinforcement, pavement engineering, reinforced soil structures, numerical modelling, PLAXIS software, stress–strain analysis, deformation behaviour.

1 INTRODUCTION

Pavement design has thus its importance in the life span and efficiency of transport infrastructures. Traditional pavements are designed for their subgrade, subbase, base course, and finally surface layers. These structures withstand traffic load, environment conditions, and the weather effects over time. However, these have been known to fail in providing adequate support to paved areas for either weak subgrade soils or heavy traffic on them, for example in an extreme ambience, around the areas above-mentioned. This can lead to cracking, rutting, and increased expenditures on maintenance [1].

Geocells are cellular confinement systems that were created as an easy and durable material that are used for stabilizing and protection. Cellular confinement systems effectively maintain the soil's compaction, and, by doing so, create a stronger structure for both the infill and pavement. The cells' three-dimensional, honeycomb design ensures that the Geocell is strong and durable. This format creates a structure that improves load distribution. The cell is made from a high density polyethylene (HDPE), which is used to stabilize weak or unsteady soil. That ability is a result of their ability to reduce lateral movement of soil particles while vertically loading on the contained infill. In addition to the stability, Geocells also provide a mattress effect and improve the elasticity of the materials. The cells have a high elastic stiffness and high tensile strength, and because of this, they improve the load distribution of the product. Because of the weight distribution that the cells create, less rutting occurs in the surface materials above. This also reduces the required granular infill. The cells' design allows for the infills to be imported locally, which also enables the use of marginal soil for infill. Lastly, Geocells improve the asphalt layers of the product, which leads to many benefits. The first is the ability to use less asphalt, due to the fact that the cells have a longer lifespan than regular asphalt. Secondly, with the transfer of vertical forces to the geocell grid by passive resistance, Geocells improve the modules of adjacent layers. The ability to use Geocells greatly helps save in the base and subbase layers, directly affecting the upkeep and cost for users [2].

This paper presents a comparative numerical analysis of standard pavement layers and geocell-reinforced pavement layers, along with laboratory testing for each model. The numerical analysis will be conducted using PLAXIS software to simulate the behaviour of both pavement types under varying traffic loads and environmental conditions. In addition, there will be an economic analysis of both systems of pavement. The study will investigate the performance and cost-effectiveness of a geocell-reinforced pavement and the different types of conventional pavements.

The major concern of this article is the gap in the application of geocell-reinforced pavements in Bosnia and Herzegovina. The adoption of this technology faces several challenges, including:

1. Lack of knowledge and awareness,
2. High initial investment costs,
3. Limited availability of materials,
4. Complexity in installation,
5. Regulatory and Standardization Challenges,

6. Limited Research and Case Studies,
7. Resistance to Change.

2 BACKGROUND AND METHODS

2.1 BACKGROUND

Pavement structures play a central role in ensuring long-term functionality, safety, and economic efficiency of transportation networks. Standard pavement systems are composed of multiple layers, each designed to provide structural strength and effective load distribution. These layers typically include the subgrade, subbase, base course, and surface course. Their performance depends on material quality, compaction, drainage, and environmental exposure. However, conventional pavements often degrade prematurely when constructed over weak subgrade soils or exposed to heavy traffic loads and harsh climatic conditions. Issues such as cracking, rutting, deformation, and moisture-related damage frequently contribute to reduced service life and increased maintenance interventions [3] [4] [5] [1] [6] [7] [8] [9].

To address these limitations, the application of geosynthetic reinforcement has expanded in the past several decades. Among these materials, geocells represent one of the most effective technologies for enhancing pavement stability, particularly in problematic soil environments. Geocells are three-dimensional honeycomb-like structures composed of polymeric materials such as high-density polyethylene (HDPE) or polypropylene (PP). When filled with granular material, they form a semi-rigid mattress that confines the infill, restricts lateral spreading, and improves the mechanical response under loading [10].

2.1.1 Standard Pavement Layers

A conventional pavement system relies on a layered design, where each layer contributes differently to structural performance:

- **Subgrade:** natural soil foundation whose stiffness strongly affects pavement durability [4].
- **Subbase:** distributes loads and acts as a buffer between subgrade and upper layers, typically composed of crushed stone or stabilized soil [5].
- **Base course:** provides the main structural support, commonly constructed using granular aggregates or treated materials [1].
- **Surface course:** asphalt or concrete layer that resists traffic-induced wear, provides skid resistance, and protects lower layers from moisture [6].

Failures in conventional pavements often arise from traffic loads exceeding design capacity, environmental effects such as freeze-thaw cycles, poor drainage, and insufficient subgrade stability. Research has shown that weak subgrades are particularly vulnerable to rutting and fatigue cracking, leading to rapid structural deterioration and high rehabilitation costs [7] [8] [9].

2.1.2 Geocell-Reinforced Pavements

Geocell reinforcement has gained recognition for its capability to enhance soil and pavement performance through confinement. The mechanism focuses on restricting lateral displacement of particles, resulting in greater vertical load distribution and reduced deformation. Key mechanical improvements include increased shear strength, higher bearing capacity, reduced settlement, enhanced stiffness, and improved drainage characteristics [10] [11] [12] [13].

Experimental studies demonstrate:

- significant increases in the resilient modulus of geocell-reinforced base layers [14],
- improved horizontal stiffness and stress distribution efficiency [15],
- reduced permanent deformation under cyclic loading [16],
- decreased thickness requirements for granular layers [17].

Geocells allow the use of local or marginal materials as infill, reduce carbon footprint due to minimized aggregate transport, and result in lower long-term maintenance expenditures [18].

2.1.3 Performance Comparison

Previous studies consistently show that geocell-reinforced pavements outperform standard pavements across several categories:

- better stress distribution and confinement of granular layers [11] [19],
- reduced vertical deflection and settlement, particularly under heavy loads [16],
- increased pavement life and structural stability [20] [21],
- cost savings through material reduction and extended lifespan [18].

While geocell technology has proven effective internationally, its use in Bosnia and Herzegovina remains limited, largely due to lack of awareness, higher initial costs, limited availability, installation requirements, and lack of national standards.

2.2 METHODS

The methodological framework of this study was developed to compare the performance of standard pavement layers with geocell-reinforced pavement systems under identical loading and environmental conditions. The approach combines a literature review, numerical simulations conducted in PLAXIS 2D, and an economic evaluation that considers both construction and long-term maintenance costs. Through these components, the study aims to evaluate differences in structural behaviour, deformation response, stress distribution, and overall durability of the two pavement types.

As a foundation for the research, an extensive literature review was carried out to examine current knowledge regarding conventional pavement behaviour and the mechanical principles of geocell reinforcement. Studies addressing load distribution, stress–strain behaviour, geocell confinement mechanisms, and field performance provided the basis for defining the parameters used in the numerical modelling phase [3] [10]. The literature also informed the choice of material properties and the selection of geocell configurations included in the analysis.

Numerical modelling was performed using PLAXIS 2D, a finite element software widely used in geotechnical engineering [22]. In the simulations, standard pavement structures were modelled with four layers: subgrade, subbase, base course, and asphalt surface. Geocell-reinforced pavements included the same structural composition with an added geocell layer positioned within the base or subbase. Both pavement types were modelled using identical geometric dimensions to ensure comparability.

Material properties assigned to each pavement layer were taken from previous studies and laboratory data. These properties included density, elastic modulus, Poisson's ratio, and other relevant mechanical characteristics [4] [14].

Figure 1 Sand properties used in PLAXIS 2D

Material set		
Identification		Well graded gravel
Soil model		Mohr-Coulomb
Drainage type		Drained
Colour		RGB 134, 234, 162
Comments		
Unit weights		
γ_{unsat}	kN/m³	21.00
γ_{sat}	kN/m³	21.00
Stiffness		
E'_{ref}	kN/m²	320.0E3
ν (nu)		0.2000
Alternatives		
G_{ref}	kN/m²	133.3E3
E_{oed}	kN/m²	355.6E3
Depth-dependency		
E'_{inc}	kN/m²/m	0.000
y_{ref}	m	0.000
Wave velocities		
V_s	m/s	249.6
V_p	m/s	407.5
Strength		
Shear		
c'_{ref}	kN/m²	0.000
φ' (phi)	°	38.50
ψ (psi)	°	0.000

Figure 2 Well graded gravel properties used in PLAXIS 2D

Material set		
Identification		ENS-340 100
Material type		Elastic
Colour		RGB 0, 0, 255
Comments		
Unit weights		
w	kN/m/m	9.000
Stiffness		
EA_1	kN/m	39.00
EA_2	kN/m	39.00
E_1	kN/m²	30.01E3
E_2	kN/m²	30.01E3
EI	kN m²/m	5.490E-6
ν (nu)		0.4500
d	m	1.300E-3

Figure 3 Geocell ENS-340 100 properties used in PLAXIS 2D

Boundary conditions were selected to closely replicate field conditions. The bottom boundary of each model was fixed to prevent vertical displacement, while the lateral boundaries were restrained horizontally to represent natural confinement. Loading was introduced using a two-axle truck configuration commonly adopted in pavement design [1]. The front axle carried a total load of 60 kN, equally divided between two tyres (30 kN each), while the rear axle carried 100 kN (50 kN per tyre). A 2.5 m wheel spacing was used, representing a typical distance between tyres on the same axle. These loads enabled simulation of realistic stress transmission and deformation behaviour under traffic.

The geocell-reinforced models included five different geocell configurations: BNS-340 100, ENS-340 75, ENS-340 100, ENS-340 200, and ENS-440 100. Each configuration was analysed separately to evaluate differences in stiffness, confinement efficiency, deformation resistance, and overall pavement response. Previous research shows that geocell performance strongly depends on geometry, wall stiffness, and confinement behaviour [11] [18].

Throughout the simulation process, PLAXIS generated several outputs that served as the primary performance indicators. These outputs included stress fields (vertical, horizontal, and shear stresses), principal strain distributions, total displacement measurements, mobilized shear strength, and calculated safety factors.

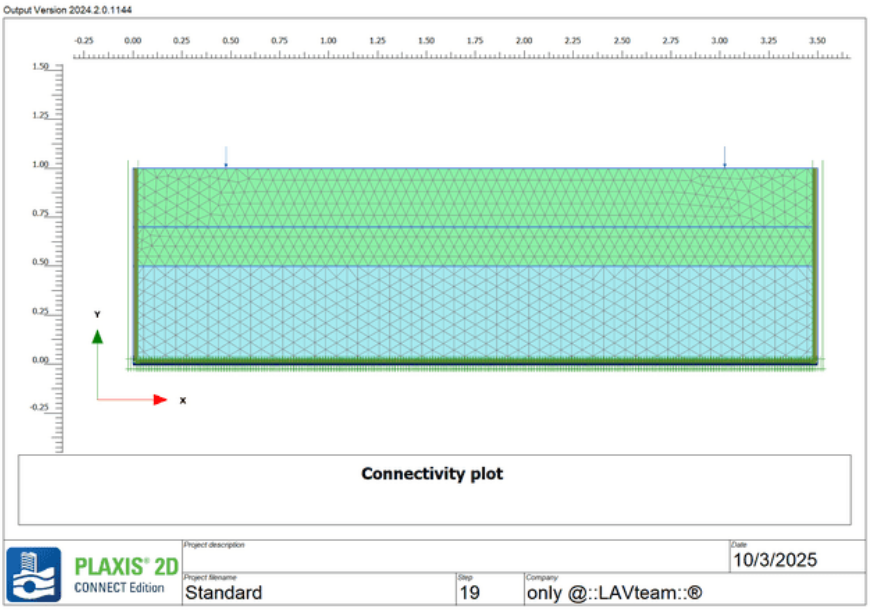

Figure 4 Connectivity plot of Standard pavement layers

These results were captured for each pavement configuration and used to assess differences in load distribution, settlement, stress reduction, and shear performance between standard and geocell-reinforced structures.

In addition to structural behaviour, an economic evaluation was conducted to compare construction and maintenance costs of both pavement types. The analysis accounted for material quantities, installation requirements, expected maintenance frequency, and the projected service life of each pavement system. Environmental aspects, such as reduced material usage and the potential use of local infill materials in geocell layers, were also considered [18]. A sensitivity analysis was performed to examine how variations in soil conditions, traffic intensity, and material costs influence the overall cost-effectiveness of geocell reinforcement.

Through this integrated methodological approach, the study provides a comprehensive basis for comparing conventional and geocell-reinforced pavements, enabling evaluation of their structural and economic performance.

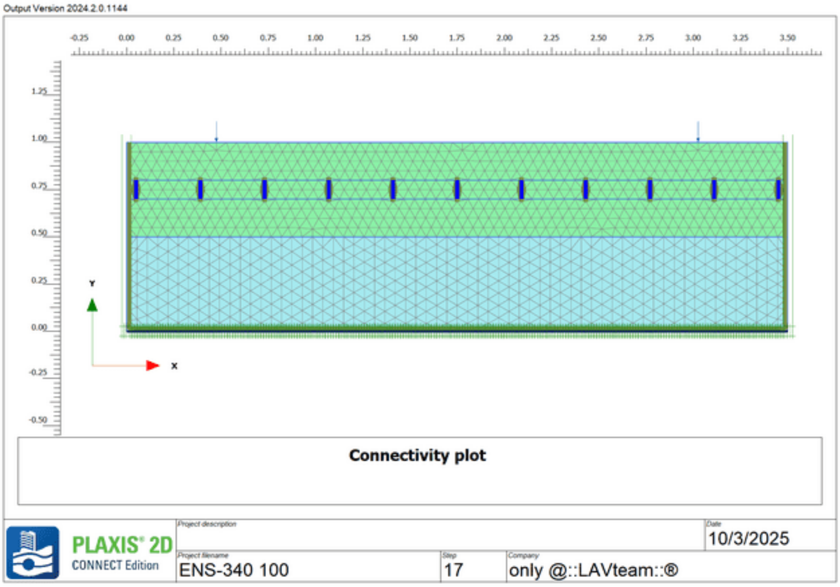

Figure 5 Connectivity plot of Reinforced pavement with geocell ENS-340 100

3 RESULTS AND DISCUSSION

The results generated through PLAXIS 2D simulations provide a comparative assessment of the mechanical behaviour of conventional and geocell-reinforced pavement systems. The analysis focuses on stress distribution, deformation response, strain behaviour, and shear strength performance under identical loading conditions. The findings consistently demonstrate notable differences between the two pavement types, especially in the ability of geocell-reinforced systems to reduce deformation and improve load distribution.

3.1 STRESS DISTRIBUTION ANALYSIS

The stress contour plots for the standard pavement model indicate a concentrated stress zone directly below the loaded area, extending vertically into the subgrade. Both the shear and total stress plots show high-intensity stress bulbs forming beneath the wheel loads, with limited lateral dispersion.

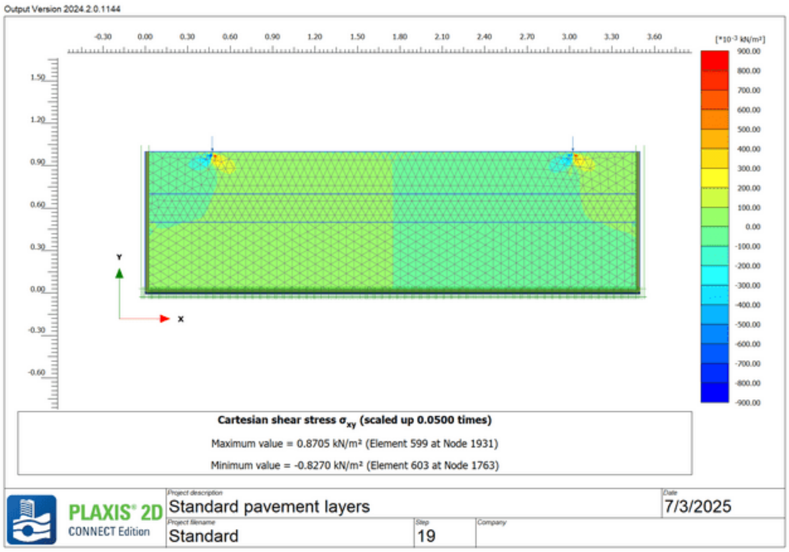

Figure 6 Cartesian shear stress of Standard pavement layers

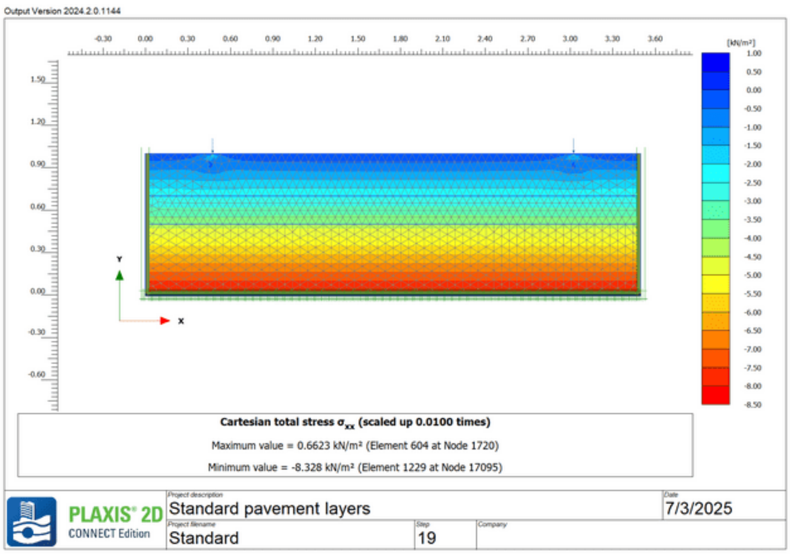

Figure 7 Cartesian total stress of Standard pavement layers

The geocell-reinforced pavement models show a significantly altered stress distribution pattern. For the best-performing configuration, ENS-340 100, the presence of a geocell layer improves the confinement of the base material, causing the applied stress to spread over a wider area. As a result, peak stresses within the subgrade are noticeably reduced.

The stress bulbs become shallower and more laterally distributed, indicating more efficient load spreading and reduced penetration into the lower pavement layers.

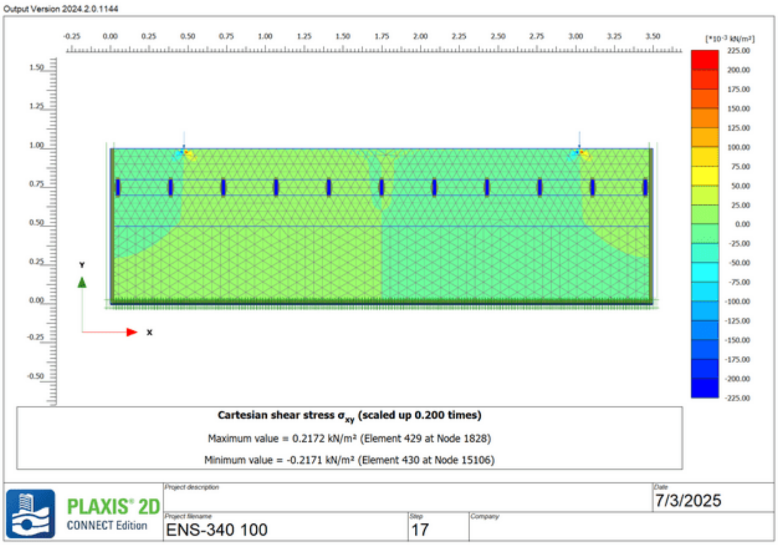

Figure 8 Cartesian shear stress of Reinforced pavement layer with geocell ENS-340 100

When compared to weaker geocell models, such as ENS-340 200, the stress distribution appears less favourable, with deeper stress penetration and reduced lateral spread. Although some improvement is still observed compared to the standard pavement, the performance is inferior to the ENS-340 100 model.

Overall, the stress results confirm that geocell confinement enhances structural stiffness and reduces excessive stress concentrations within the subgrade, which directly contributes to improved long-term pavement performance.

3.2 DEFORMATION AND STRAIN ANALYSIS

The deformation behaviour of the pavement models offers additional insight into the structural benefits of geocell reinforcement. In the standard pavement system, the principal strain plots reveal pronounced vertical deformation beneath the wheel loads. The strain zones extend deeply into the subgrade, indicating weak confinement and a higher susceptibility to rutting and long-term settlement.

Similarly, the total displacement results show significant downward movement in the base and subgrade layers. The deformation contours clearly reflect the concentrated vertical stresses and limited lateral resistance in the standard pavement.

In contrast, the geocell-reinforced pavement (ENS-340 100) demonstrates reduced deformation and improved strain distribution. The principal strain plots show a more confined deformation zone within the geocell layer, with the strain gradient dispersed horizontally rather than vertically. This indicates that the geocell is effectively mobilizing its lateral confinement mechanism.

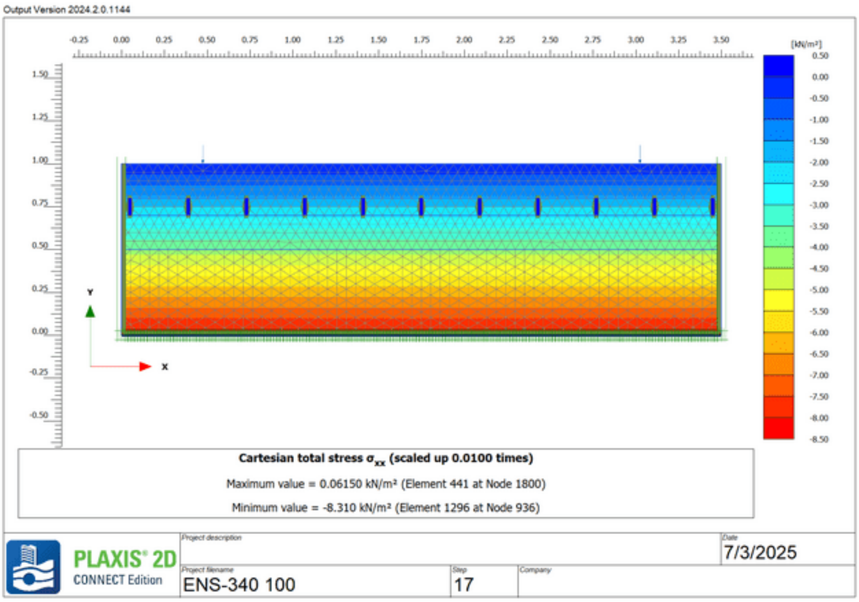

Figure 9 Cartesian total stress of Reinforced pavement layer with geocell ENS-340 100

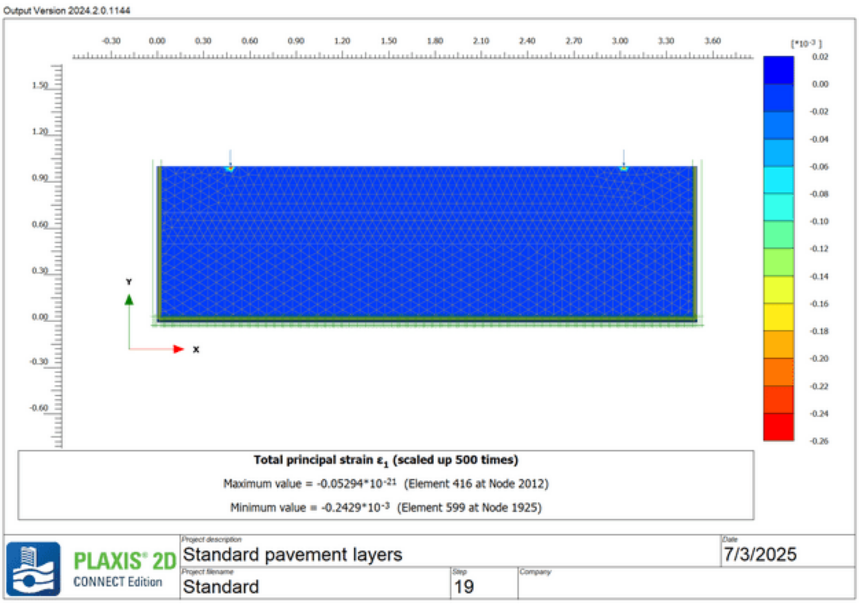

Figure 10 Total principal strain of Standard pavement layers

Total displacement results further support this observation. The geocell layer acts as a semi-rigid mattress that distributes the load, resulting in a noticeably shallower displacement basin. The reduction in downward displacement indicates increased stiffness of the reinforced structure and decreased settlement potential.

Overall, the deformation analysis shows that geocell reinforcement substantially enhances pavement stability by limiting vertical deformation and improving the load-bearing behaviour of the granular layers.

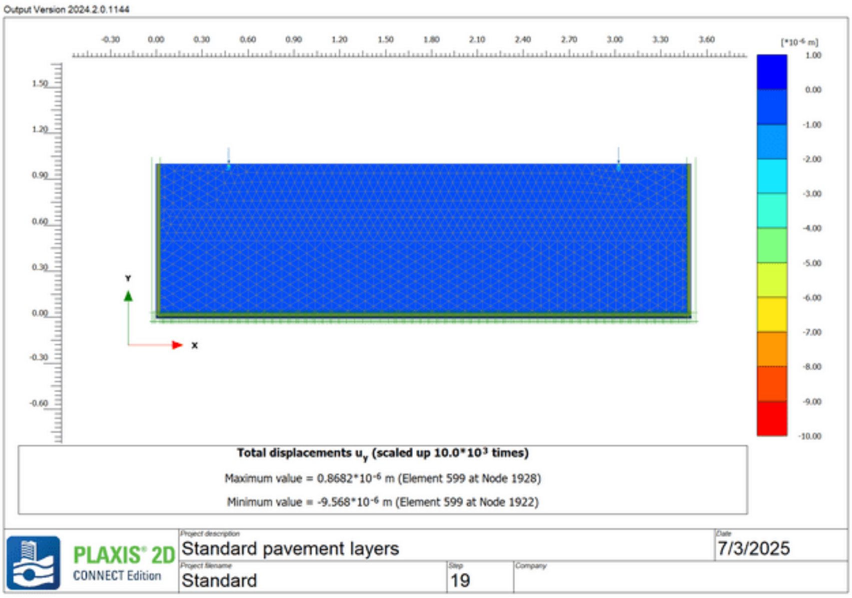

Figure 11 Total displacement of Standard pavement layers

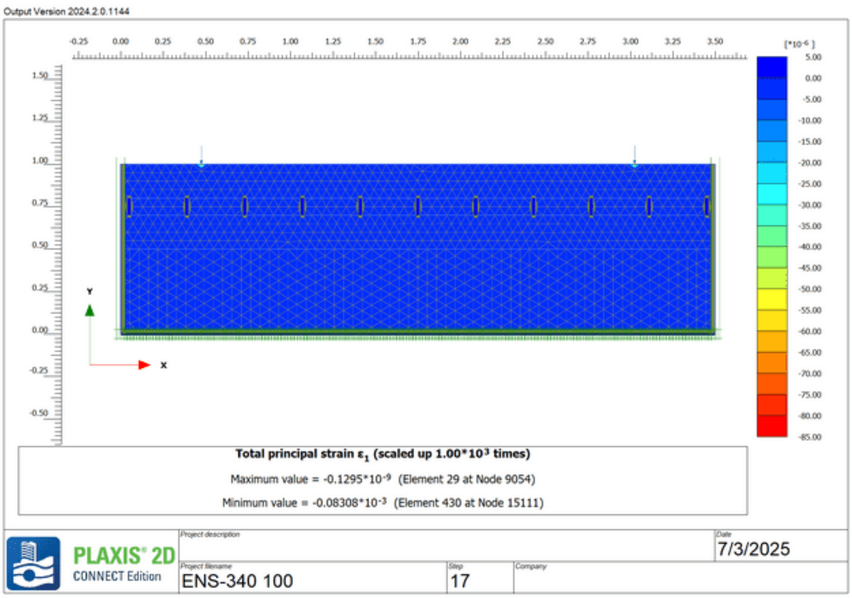

Figure 12 Total principal strain of Reinforced pavement layer with geocell ENS-340 100

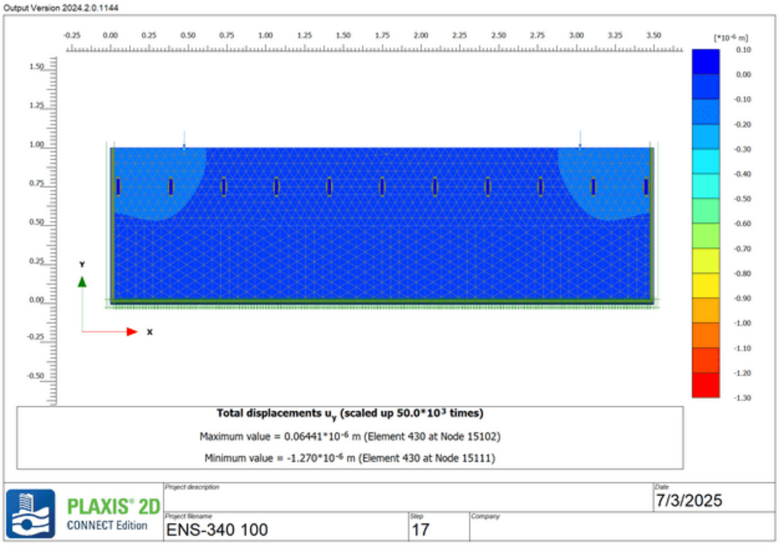

Figure 13 Total displacements of Reinforced pavement layer with geocell ENS-340 100

3.3 SHEAR STRENGTH AND STABILITY ANALYSIS

Shear stress patterns offer critical insight into the failure potential of pavement systems. In the standard pavement model, high shear stresses accumulate along the interface between the base course and the subgrade. These elevated stress concentrations are indicators of potential shear failure, particularly under repeated traffic loads.

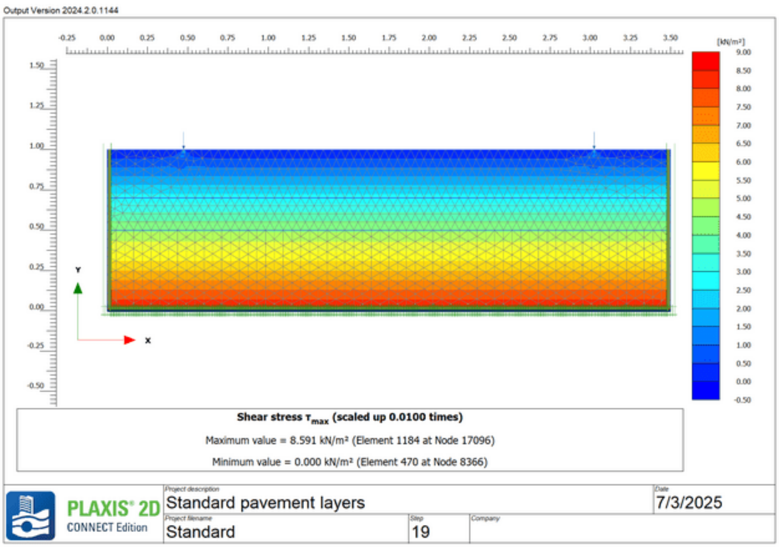

Figure 14 Shear stress of Standard pavement layers

The geocell-reinforced model displays a different distribution. Shear stresses are more evenly spread across the reinforced layer, reducing peak values and lowering the likelihood of shear-induced distress. The geocell structure creates a stabilizing effect by restraining lateral movements, resulting in reduced shear mobilization in the underlying layers.

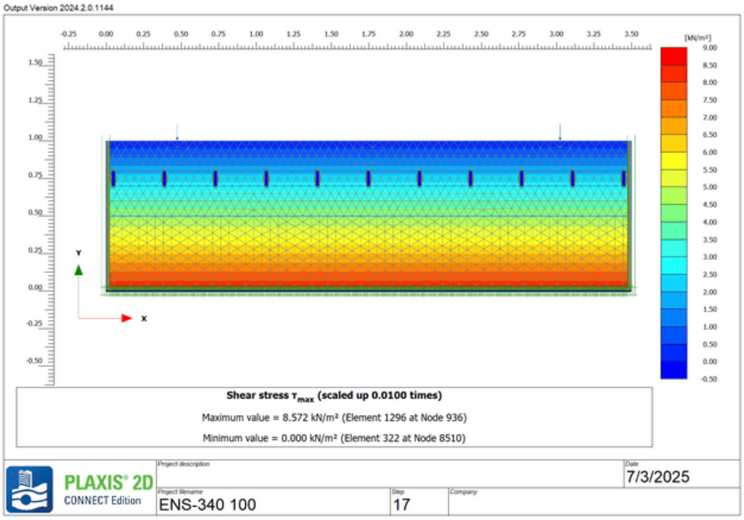

Figure 15 Shear stress of Reinforced pavement layer with geocell ENS-340 100

The mobilized shear strength plots further illustrate this improvement. In the geocell-reinforced system, mobilized shear strength is lower and more uniformly distributed, indicating enhanced stability and resistance to shear deformation.

These results confirm that geocell reinforcement improves pavement resistance to shear failure mechanisms, contributing to longer service life and better structural reliability.

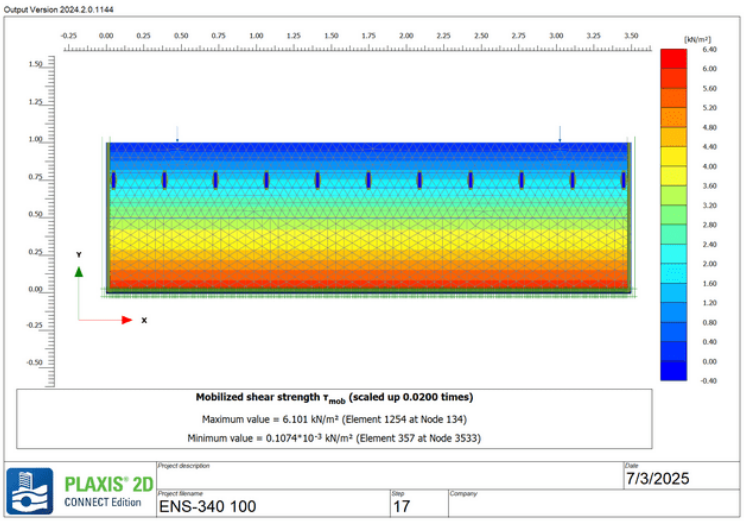

Figure 16 Mobilized shear strength of Reinforced pavement layer with geocell ENS-340 100

Table 1 Summary of results in PLAXIS 2D

	Standard		BNS-340 100		ENS-340 75	
	max	min	max	min	max	min
σ_{xy} [kN/m^2]	0,8705	-0,8270	0,2172	-0,2171	0,2771	-0,2769
σ_{xx} [kN/m^2]	0,6623	-8,328	0,06150	-8,310	0,06957	-8,311
σ_{yy} [kN/m^2]	0,4385	-20,56	0,06476	-20,51	0,06816	-20,51
σ_{zz} [kN/m^2]	0,2281	-8,329	0,03122	-8,31	0,03428	-8,311
ε_1 [-]	-0,05294x10^{-21}	-0,2429x10^{-3}	-0,1297x10^{-9}	-0,08308x10^{-3}	0,02467x10^{-6}	-0,9009x10^{-3}
ε_2 [-]	0,09283x10^{-6}	-0,5670x10^{-6}	8,608x10^{-9}	-0,2246x10^{-6}	0,2112x10^{-6}	-0,5756x10^{-6}
ε_3 [-]	0,2446x10^{-3}	-0,01171x10^{-6}	0,07851x10^{-3}	-1,855x10^{-9}	0,8950x10^{-3}	-3,067x10^{-9}
u_y [m]	0,8682x10^{-6}	-9,568x10^{-6}	0,06441x10^{-6}	-1,270x10^{-6}	2,105x10^{-6}	-0,01276x10^{-3}
τ_{rel} [kN/m^2]	1,0	0,5541	1,0	0,6585	1,0	0,5643
τ_{mob} [kN/m^2]	6,117	0,3377x10^{-3}	6,101	0,1074x10^{-3}	6,102	0,2593x10^{-3}
τ_{max} [kN/m^2]	8,591	0	8,572	0	8,573	0
Fs [-]	1,0	1,0	1,0	1,0	1,0	1,0
	ENS-340 100		ENS-340 200		ENS-440 100	
	max	min	max	min	max	min
σ_{xy} [kN/m^2]	0,2172	-0,2171	1,219	-1,250	0,8069	-0,8067
σ_{xx} [kN/m^2]	0,06150	-8,310	0,8966	-8,342	0,7210	-8,333
σ_{yy} [kN/m^2]	0,06476	-20,51	0,6910	-20,60	0,4917	-20,57
σ_{zz} [kN/m^2]	0,03122	-8,310	0,3265	-8,343	0,2483	-8,334
ε_1 [-]	-0,1298x10^{-9}	-0,08308x10^{-3}	0,1588x10^{-21}	-0,5413x10^{-3}	-6,167x10^{-9}	-0,4333x10^{-3}
ε_2 [-]	8,608x10^{-9}	-0,2246x10^{-6}	0,5118x10^{-6}	-2,138x10^{-6}	0,09196x10^{-6}	-1,911x10^{-6}
ε_3 [-]	0,07851x10^{-3}	-1,855x10^{-9}	0,5476x10^{-3}	-0,02720x10^{-6}	0,4181x10^{-3}	-0,01673x10^{-6}
u_y [m]	0,06441x10^{-6}	-1,27x10^{-6}	3,034x10^{-6}	-0,02386x10^{-3}	2,152x10^{-6}	-1,246x10^{-6}
τ_{rel} [kN/m^2]	1,0	0,6585	1,0	0,5397	1,0	0,5563
τ_{mob} [kN/m^2]	6,101	0,1074x10^{-3}	6,130	1,630x10^{-3}	6,122	2,395x10^{-3}
τ_{max} [kN/m^2]	8,572	0	8,606	0	8,597	0
Fs [-]	1,0	1,0	1,0	1,0	1,0	1,0

3.4 COMPARATIVE INTERPRETATION AND SUMMARY OF RESULTS

Across all evaluated parameters — stress distribution, deformation, strain behaviour, and shear performance — the geocell-reinforced pavement significantly outperforms the standard pavement system. The improvements observed in the ENS-340 100 model demonstrate the effectiveness of geocell confinement in enhancing load distribution, reducing stresses on the subgrade, increasing stiffness, and minimizing deformation. All key comparative values for standard and geocell-reinforced models are summarized in Table 1, providing a consolidated overview of the performance differences.

The weaker geocell models show performance levels that fall between the standard pavement and the best-performing reinforced model, indicating that geocell geometry, height, and material properties play an important role in achieving optimal results. However, even the least effective geocell configuration still provides measurable benefits compared to the conventional structure.

The combined numerical results suggest that geocell reinforcement is a viable and efficient solution for pavements constructed over weak subgrades or subjected to heavy traffic loads. The reduced stress penetration and minimized settlement contribute not only to improved structural reliability but also to extended pavement service life and reduced maintenance requirements.

3.5 GEOCELLS IN BOSNIA AND HERZEGOVINA

The use of geocell reinforcement in Bosnia and Herzegovina remains limited despite its proven benefits in international practice. The main obstacles include insufficient professional awareness, higher initial investment costs, limited market availability, lack of domestic standards, and a general reluctance to adopt new construction technologies. These barriers have prevented wider implementation, especially in public infrastructure projects.

However, the geotechnical conditions commonly encountered in Bosnia and Herzegovina — such as weak subgrade soils, moisture-sensitive terrains, landslide-prone areas, and large seasonal variations in groundwater levels — indicate that geocell systems could provide significant advantages. Their ability to improve load distribution, reduce settlement, increase structural stability, and allow the use of locally available infill materials makes them particularly suitable for the region's diverse soil conditions.

Although current applications are scarce, existing international research and pilot projects suggest that geocell-reinforced pavements could contribute to lower maintenance costs and longer service life, especially on roads exposed to heavy traffic or constructed over problematic soils. Wider adoption would likely depend on improved professional education, clearer design guidelines, and long-term demonstration projects that prove the economic and functional benefits in local conditions.

3.6 DISCUSSION

The comparative analysis of standard and geocell-reinforced pavement layers highlights the clear structural and mechanical advantages provided by geocell confinement. Across all simulations, geocell-reinforced models demonstrated improved stress distribution, reduced deformation, and higher resistance to shear and settlement. These performance improvements are most evident in the ENS-340 100 configuration, which consistently achieved the best results among all evaluated geocell types.

The stress distribution results show that standard pavements experience concentrated vertical stresses beneath the wheel loads, with deep stress bulbs penetrating the subgrade. This behaviour suggests limited ability of the granular layers to redistribute loading, thereby increasing the risk of rutting and fatigue cracking. In contrast, the geocell-reinforced structures exhibited a noticeably wider lateral distribution of stresses. The confinement created by the geocell cells reduces vertical stress intensity and diminishes the depth at which stresses propagate into the subgrade. This finding aligns with existing literature, which emphasizes the role of geocells in improving load-spreading efficiency through increased lateral stiffness of the reinforced layer.

Deformation and strain results further support these observations. The standard pavement model displayed significant vertical movement and widespread strain zones, reflecting insufficient structural support under applied loads. Meanwhile, the geocell-reinforced model presented a shallower displacement basin, with strain concentrated within the reinforced zone. This behaviour confirms that geocell confinement effectively limits particle movement and increases the overall stiffness of the base layer. Reduced deformation directly correlates with lower rutting potential, a key performance indicator in long-term pavement sustainability.

Shear stress and mobilized shear strength plots also highlight the stabilizing effect of geocell confinement. Standard pavements showed high shear concentrations at the interfaces between layers, particularly in transitions from base to subgrade, where differential movement is most likely. Geocell-reinforced pavements, however, displayed more uniform shear distribution and considerably lower peak values. The reduction of shear mobilization indicates improved interlayer stability and enhanced resistance to shear-related failures. These results demonstrate the ability of geocells to function as a semi-rigid mattress, restraining lateral deformation and increasing the composite action of pavement layers.

The comparison among different geocell configurations shows that not all models perform equally. While all geocell-reinforced pavements outperform the standard pavement, the degree of improvement varies based on geocell height, wall thickness, stiffness, and geometry. The ENS-340 100 model consistently delivered the most favourable results, suggesting an optimal balance between cell height and stiffness for the given loading and soil conditions. Conversely, the ENS-340 200 model performed less efficiently despite its larger cell height, indicating that increased depth does not automatically translate to better structural performance. These differences highlight the importance of proper geocell selection based on project-specific demands.

Overall, the numerical results demonstrate that geocell reinforcement can significantly enhance pavement performance by reducing stress concentrations, minimizing deformation, and improving shear resistance. These improvements contribute directly to extended pavement lifespan, reduced maintenance requirements, and increased cost-effectiveness over time. While initial installation costs may be higher compared to traditional pavement construction, the long-term benefits — particularly in regions with weak or moisture-sensitive subgrades — reinforce the suitability of geocell systems as an effective pavement reinforcement solution.

4 CONCLUSIONS

This research presented a comprehensive comparative analysis of standard pavement layers and geocell-reinforced pavement systems through numerical simulations conducted in PLAXIS 2D. By evaluating stress distribution, strain behaviour, deformation patterns, and shear performance under identical loading conditions, the study established clear evidence of the structural advantages provided by geocell confinement technology. The overall findings demonstrate that geocell reinforcement enhances pavement behaviour in multiple critical aspects and can serve as a highly effective alternative to conventional pavement design, particularly in regions with weak or moisture-sensitive subgrades.

The results from the stress distribution analysis showed that standard pavements are characterized by concentrated vertical stresses beneath the applied loads, with deep stress bulbs penetrating into the subgrade. This stress concentration is indicative of limited load distribution capacity and increased vulnerability to long-term deterioration mechanisms, such as rutting and fatigue cracking. In comparison, geocell-reinforced pavements displayed a substantially more favourable stress response. The presence of the geocell layer allowed the stresses to be distributed over a wider area, resulting in reduced stress intensity and decreasing the depth of stress propagation. Among all examined configurations, the ENS-340 100 model exhibited the most efficient stress redistribution, confirming its suitability for systems exposed to moderate and heavy traffic loads.

Deformation and strain analyses further reinforced the advantages of geocell reinforcement. The standard pavement model experienced significant vertical deformation, with strain zones extending into the subgrade. These patterns correspond to reduced structural stiffness and increased potential for permanent deformation over the pavement’s service life. In contrast, the geocell-reinforced pavement—particularly the ENS-340 100 configuration—showed a shallower displacement basin and more confined strain zones, demonstrating the ability of the geocell layer to limit particle movement through lateral confinement. Reduced deformation contributes directly to enhanced structural integrity and extends the lifespan of the upper pavement layers by mitigating rutting and reducing the accumulation of plastic deformations.

The shear stress and mobilized shear strength results provided additional insights into the stability improvements achieved through geocell reinforcement. Standard pavements exhibited elevated shear stresses at the interfaces between layers, where differential movement is most likely to occur. These high-stress regions represent potential failure zones under repeated loading. The geocell-reinforced structures, on the other hand, showed a more uniform shear distribution with lower peak values, indicating improved interlayer stability. The reduction in mobilized shear strength suggests that the reinforcement minimizes the likelihood of shear-related failure mechanisms, which is particularly relevant for pavements subjected to heavy or repetitive traffic loads.

An additional contribution of this study lies in the comparison of different geocell configurations. Although all geocell-reinforced models performed better than the standard pavement, the magnitude of improvement varied. The ENS-340 100 system consistently delivered the strongest performance, balancing cell height and material stiffness in a way that optimized load distribution and deformation control. Other configurations, such as ENS-340 200, demonstrated improvements but showed that greater cell height does not necessarily guarantee superior performance. These differences underscore the importance of careful geocell selection based on project-specific factors, including subgrade properties, anticipated traffic loads, and design lifespan requirements.

From an economic perspective, the improved performance of geocell-reinforced pavements suggests potential long-term cost savings, even if initial installation expenses may be higher than those of traditional pavement systems. Reduced deformation, minimized stress accumulation, and improved structural stability collectively translate into lower maintenance frequency and extended pavement life. In regions with challenging soil conditions—such as those commonly found in Bosnia and Herzegovina—these advantages may be particularly significant, as they directly address common causes of premature pavement deterioration.

Overall, the findings of this study strongly support the adoption of geocell reinforcement as a viable and effective design strategy for modern pavement structures. The improved mechanical behaviour, enhanced stability, and potential economic benefits position geocells as a promising solution for both new road construction and rehabilitation projects. While further field validation and long-term monitoring would strengthen the conclusions drawn from numerical modelling, the results presented here provide a solid foundation for considering geocell technology as an integral component of sustainable and resilient pavement engineering.

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