Effect of Geogrid Reinforcement on Behavior of Unpaved Roads

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Abstract. The aim of this research is to investigate the behavior of unpaved roads using a 3D finite element model using a well-known commercially available finite element package ‘ABAQUS’ version (6.12-1). The reinforcement geogrid spread the traffic loading on a wider area and effectively transmitted the pressure to the underlying foundation subgrade layer. The finding of this research shows a reduction in permanent deformation on the subgrade layer and surface layer by about (44\%) and (35.5\%) respectively. In accordance with results observations, there was a reduction in vertical stresses to about (50\%) at the mid-depth between the surface and subgrade layer for unpaved roads due to the installation of the geogrid layer. The horizontal strains under the centerline of traffic loading were about (1.6\%) and (2\%) for unreinforced and reinforced unpaved road models. There is a noticeable reduction of horizontal strains with horizontal distance till (1 m) from the centerline of loading was obtained. Also, the horizontal strains increased under the loading area as compression then declined with horizontal distance and transformed to tensile strain and reached minimum values at (2.5m) for both models. For vertical strains, a noticeable reduction is obtained. The installation of geogrid on the top of the subgrade layer for unpaved roads reduced the vertical strains by (12\%). A maximum of vertical compressive strain is on the top of the subgrade layer due to the mechanism of geogrid reinforcement that produce friction and restriction between the geogrid reinforcement and the subgrade layer; this restriction occurs due to the grid holes and ribs on the foundation soil and prevents from lateral movement of the particles and granular materials for unpaved roads. The geogrid reinforcement at the top of the subgrade layer was found to cause an increase of (73\%) in the service life of unpaved roads.

Keywords: Unpaved roads; geogrid; Finite element; rutting; subgrade layer; reinforcement.

1. Introduction

Unpaved roads are used primarily under low traffic volume, and many agencies upgrade their performance to sustain heavy traffic volume. The geosynthetic materials play an important function that are specifically fabricated to be used in road construction engineering. The geosynthetic reinforcements reduced the deterioration of unpaved roads and increased their service life in terms of reducing plastic (permanent) deformation. Li [1] studied the cost-effectiveness of improving the unpaved roadway systems using several technologies were considered. A total of 17 test sections over 3.22 km of unpaved road in Hamilton, Iowa. Field tests based on mechanistic approaches and visual inspection were conducted to investigate the relative performance and durability of selected test sections [1].

Geosynthetic is considered one type of synthetic material that is applied for increasing the rutting resistance through transmitting and distributing the traffic loads to the subgrade. Different researches have been carried out on using geosynthetic reinforcement in pavements [2]. Calvarano et al. [3] explored the effect of geosynthetic reinforcement on pavement performance using the finite element
method (ABAQUS) software. The results indicated a saving in the thickness of the base layer, which led to savings of granular aggregate materials used: less CO₂ emissions and less environmental impact [3]. There are two main reinforcement mechanisms; tension membrane and lateral confinement effect that require rutting depth with different values in order to mobilize. With the small value of rut depth, the lateral restraint mechanisms are generated due to the interlocking of aggregate with a geogrid layer [4]. Mamatha and Dinesh [5] investigated the effectiveness of geogrid on the pavement performance by installing at different depths; one-third from the top, middle, two-thirds from top, and interface of subgrade layer with granular base). The settlement results in terms of plastic deformation were recorded. The geogrid reinforcement improved the permanent deformation to about (34%) and (52%) based on geogrid stiffness and thickness of granular base materials [5]. Alkaissi Z.A. (2020) studied the effect of combined thermal loading conditions on pavement performance using the finite element method. It has been concluded that the resistance to permanent deformation of pavement based on high temperature as well as on traffic loading and higher damage is occurred under combined thermal and traffic loading as compared with traffic loading model conditions only [6]. Alkaissi Z.A. (2011) modeled the geotextile reinforcement for road embankments using the finite element program (ANSYS) ver. 5.2. The results obtained indicated a significant reduction in displacement by about (81%) and (32%) for horizontal and vertical displacement respectively [7]. The results obtained for base layer showed reduction in rutting damage by about (58%) while subgrade layer provided damage reduction only (10%). Also the critical value for vertical compressive stresses is (480 kPa) below the wheel loading area which is about (70.9%) of the applied tire pressure and then decreased gradually with depth to about (118 kPa) approximately (17%) of the applied tire pressure within the base layer and remains almost constant with depth through the subgrade layer [8]. Alkaissi Z.A. (2006) developed a finite element program PAVES to model the pavement system, visco-elasto plastic model exhibited more realistic behavior of asphaltic material than elasto- visoplastic model when compared with experimental results [9]. Alkaissi, et.al (2017) studied the effect of adding steel fiber on rutting of flexible pavement using a three-dimensional finite element model was implemented with ABAQUS (6.14-4) to simulate the laboratory tests [10].

2. Simulation Model
A 3D finite element model using a well-known commercially available finite element package ‘ABAQUS’ version (6.12-1) was adopted to analyze non-reinforced and reinforced roads. Therefore, two models were simulated for complete three-dimensional (5000 mm width and 7000 mm length) sections for unpaved roads: one for geogrid reinforcement between the granular base layer and subgrade, and the second was for the typical unpaved road segment, see Figure 1. The C3D8R brick solid element with three degrees of freedom at each node, translations in the nodal x, y, and z directions with reduced integration (1 integration point) located in the middle of the element also not stiff enough in bending was implied in finite element model analysis.

Figure 1. Finite element model with applied pressure and boundary conditions using ABAQUS program.
The simulated model consists of an unpaved surface granular layer of 150 mm and subgrade soil of 300 mm. With respect to the geogrid layer as presented in Figure 2 for the complete unpaved granular system; it’s modeled as membrane element between the surface and subgrade layers as a sheet in space that can carry force but do not have any bending or traverse shear stiffness. That means, the only nonzero stress components in the membrane are those components parallel to the middle surface of the membrane: the membrane is in a state of plane stress [11], see Figure 2. A traffic loading pressure of (600 kPa) [12] is applied to the surface with input parameters for granular layers taken from local properties used for road construction in Baghdad city, see Table 1.

![Figure 2. Geogrid layer model using ABAQUS program.](image)

| Local Layer Properties                  | Elastic Modulus (MPa) | Poisson ratio |
|-----------------------------------------|-----------------------|---------------|
| Unpaved surface layer [13],[14]         | 18.53                 | 0.35          |
| Subgrade soil [15]                      | 40                    | 0.4           |

3. Results and discussion

3.1 Effect of geogrid reinforcement on rutting
In order to investigate the effect of geogrid installation on the rutting of unpaved roads, different runs were carried out using the finite element program ABAQUS ver. 6.12.1 with equivalent traffic loading and boundary conditions. Figures 3 and 4. Show the results of different simulation runs for vertical deformation with unreinforced and reinforced modeled layers. The observed rutting value for the unreinforced model was 6.73 mm under the center of applied pressure and reduced to about 4.34 mm for the reinforced section, which confirmed that geogrid reinforcement reduces rutting deformation to 35.5%. Also, the reinforcement geogrid model spread the traffic loading on a wider area and effectively transmitted the pressure to the underlying foundation subgrade layer. A reduction in permanent deformation on the subgrade layer and surface layer is obtained by about 44% and 35.5%, respectively, and this provides an effective increase in the service life of roads.

3.2 Effect of geogrid reinforcement on vertical stresses
Figures 5 and 6 show the effect of geogrid reinforcement on vertical stress distribution for reinforced and unreinforced sections as a function with depth variation. In accordance with results observations, there was a reduction in vertical stresses to about (50%) at the mid-depth between the surface and subgrade layer for unpaved roads due to the installation of the geogrid layer.
**Figure 3.** Vertical deformation without geogrid reinforcement.

**Figure 4.** Vertical deformation with geogrid reinforcement.

**Figure 5.** Distribution of vertical stresses with depth.
3.3 Effect of geogrid reinforcement on strains

The horizontal strains under the centerline of traffic loading are about 1.6% and 2% for unreinforced and reinforced unpaved road models. There was a noticeable reduction of horizontal strains with horizontal distance till (1m) from the centerline of loading; see Figure 7. Also, Figures 8 and 9 show the image of the horizontal strain distribution. From the graph, it can be seen that the horizontal strains increased under the loading area as compression, then decline with horizontal distance and transform to tensile strain and reached the minimum values at (2.5m) for both models.

For vertical strains, a noticeable reduction was obtained, as shown in Figure 10. The installation of geogrid on the top of the subgrade layer for unpaved roads reduced the vertical strains by 12%. A maximum of vertical compressive strain was on the top of the subgrade layer due to the mechanism of geogrid reinforcement that produced friction and restriction between the geogrid reinforcement and the subgrade layer; this restriction occurs due to the grid holes and ribs on the foundation soil and prevents from lateral movement of the particles and granular materials for unpaved roads.

![Figure 6. Effect of geogrid reinforcement on vertical stress reduction.](image_url)

![Figure 7. Variation of horizontal strain with distance from the center of loading.](image_url)
Figure 8. Distribution of horizontal strains for geogrid reinforcement.

Figure 9. Distribution of horizontal Strains for unreinforcement.

Figure 10. Effect of geogrid reinforcement on vertical strains for subgrade layer.
3.4 Effect of geogrid reinforcement on service life of unpaved road

Permanent deformation (rutting) is considered as one of the major distresses in road pavement; therefore, geogrid reinforcement is one of the prevention methods to reduce rutting and increased the service life of pavements. Figure 11 shows the effect of geogrid reinforcement on the number of load repetitions to cause rutting damage failure. The number of load repetitions to limit rutting are estimated according to Asphalt Institute (MS-1, 1982) [11], see Eq. 1:

\[ N_r = 1.365 \times 10^{-9} \left[ \frac{1}{\varepsilon_c} \right]^{4.477} \]  

where

- \( N_r \): No. of load repetitions to limit rutting.
- \( \varepsilon_c \): Vertical compressive strains at the top of the subgrade layer.

The geogrid reinforcement at the top of the subgrade layer was found to cause an increase of (73%) in the service life of unpaved roads. Which provide a substantial improvement in their functional performance against rutting distresses.

![Figure 11. Effect of geogrid reinforcement on service life of unpaved road to limit rutting.](image)

4. Conclusions

The main conclusions can be illustrated as follows:

- The observed rutting value for the unreinforced model was 6.73 mm under the center of applied pressure and reduced to 4.34 mm for the reinforced section, which confirmed that geogrid reinforcement reduces rutting by about 35.5%.
- The reinforcement geogrid model spread the traffic loading on a wider area and effectively transmitted the pressure to the underlying foundation subgrade layer. A reduction in permanent deformation on the subgrade layer and surface layer is obtained by about 44% and 35.5%, respectively, and this provides an effective increase in the service life of roads.
- In accordance with results observations, there was a reduction in vertical stresses to about 50% at the mid-depth between surface and subgrade layer for unpaved roads due to the installation of the geogrid layer.
- The horizontal strains under the centerline of traffic loading were about 1.6% and 2% for unreinforced and reinforced unpaved road models. There is a noticeable reduction of horizontal strains with horizontal distance till 1 m from the centerline of loading was obtained. Also, the horizontal strains increased under the loading area as compression then declined with horizontal distance and transformed to tensile strain and reached minimum values at 2.5 m for both models.
For vertical strains, a noticeable reduction is obtained. The installation of geogrid on the top of the subgrade layer for unpaved roads reduced the vertical strains by 12%. A maximum of vertical compressive strain is on the top of the subgrade layer due to the mechanism of geogrid reinforcement that produces friction and restriction between the geogrid reinforcement and the subgrade layer; this restriction occurs due to the grid holes and ribs on the foundation soil and prevents from lateral movement of the particles and granular materials for unpaved roads.

The geogrid reinforcement at the top of the subgrade layer was found to cause an increase of 73% in the service life of unpaved roads.

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