Finite Element Modelling of Asphalt Concrete Pavement Reinforced with Geogrid by Using 3-D Plaxis Software

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Abstract
This paper studied the application of 3-D Plaxis software on reinforced asphalt concrete pavement with geogrid layer at two positions within the pavement structure to investigate effect of geogrid on the critical pavement responses such as total stress and vertical surface displacement. An axisymmetric finite element model was loaded with an incremental cycling contact pressure from 50 to 600 kPa and the geogrid layer was placed either at the bottom of surface asphalt concrete or at top of subbase course to study influence of geogrid position on pavement performance. The analysis results indicated that under various tire pressure values, a significant effect on the pavement behaviour was observed when the geogrid layer was located at bottom of asphalt concrete surface layer. The Plaxis output results also showed a moderate improvement in pavement system response was obtained when geogrid reinforcement layer was placed at top of subbase layer.

Keywords
Asphalt Concrete, Geogrid, 3-D Plaxis and Vertical Displacement

1. Introduction

The high modulus polymer geogrid has been utilized within the asphalt concrete courses during the past few decades to enhance flexible pavement behaviour and its performance. The geogrid will resist the fatigue stress and strain at bottom of asphalt concrete course due to it has the tensioned membrane effect. The Geogrid-reinforcement layer can be placed at the sub base - sub grade interface or between the base course and sub-base to to reduce total rutting failure at pavement surface [1]. The use of geogrid reinforcement in construction of highway pavement started in the 1970s. Then, the technique of geogrid reinforcement has been increasingly used and many experimental and analytical studies have been performed to assess geogrid behaviour in the flexible pavement [2, 3, 4, and 5].

Pandey et al. [6] studied a two dimensional axisymmetric FE model was used to analyse the response of geogrid reinforced bituminous pavement subjected to static and dynamic loading. They found that the fatigue (horizontal) stain reduced when geogrid was placed at base-bituminous concrete interface. The results showed that placing geogrid layer at the interface of base and subgrade layers caused the highest reduction in vertical strain. Barksdale et. al. [7] investigated the structural performance of unreinforced and geogrid reinforced pavement subjected to laboratory cycling loading testing. The vertical permanent deformation was measured of both unreinforced and geogrid reinforced pavement. The results indicated the stiff geogrid placed at the bottom of granular base did not give any significant improvement for a strong pavement whereas the placing the geogrid at bottom of the base layers resulted in better performance (low permanent deformation) than the use of a geotextile. They carried out FE simulation analysis techniques and showed that the benefits of geosynthetic reinforcements are more pronounced for weaker subgrades. Moayedi et. al. [8] used the FE PLAXIS program to study the effect of geogrid reinforcement in flexible pavement by developed the axisymmetric pavement response model under...
static loading condition. Bituminous concrete layer and geogrid were modeled as a linear elastic isotropic material while the Moho-Coulomb material model was adapted to represented granular base materials. They obtained that the geogrid reinforcement placed at the bottom of bituminous concrete layer reduced vertical pavement deflection.

Hamdy and Ahmed [9] studied a series of FE simulations by Plaxis software on suggested pavement structures consisted of asphalt concrete layer, base layer, subbase layer on subgrade layer. They concluded a significant improvement in pavement behavior by placing one–layer of geogrid reinforcement where the vertical displacement and effective stresses are lower in case of one geogrid layer or two geogrid layers.

In the present study, an attempt has been made to investigate the influence of geogrid reinforcement at two positions within the asphalt concrete system through the application of 3-D Plaxis software program. The geogrid reinforcement layer was firstly placed at bottom of surface asphalt concrete layer and secondly the geogrid was placed at top of granular subbase layer to investigate.

2. Finite Element Model

The flexible pavement system used in 3-D PLAXIS software version 2013 consisted of asphalt concrete (AC) surface layer, asphalt concrete (AC) base layer, granular subbase layer and sandy subgrade layer subjected to repeated cycling loading with 0.10 second loading period. The unreinforced and geogrid reinforced pavement response was evaluated under a repeated cycling loading (50, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550 and 600 kPa) acting on a circular area of 0.15 m radius with frequency of 10 HZ which is corresponding to 0.1 seconds duration. A triangular wave with duration of 0.1 second corresponding to an average speed of around 70 km/h was adopted in this study [10]. The duration time between two subsequent axles is assumed to be 0.2 second.

The two asphalt concrete layers and geogrid were modeled as a linear elastic isotropic material while the Mohr-Coulomb model was used to model granular subbase and subgrade materials.

An axisymmetric model was utilized in the analysis using 45900-noded structural solid elements with medium refinement. Axisymmetric modeling was chosen in this study because it could simulate circular loading and did not require excessive computational time [2, 11].

Alex [12] indicted that the nodal radial strains were assumed to be negligible at approximately 10 times R (radius of loaded area) from the area applied wheel load. Also, the nodal stresses and displacements were assumed to be negligible at 20 times R below the pavement surface. Therefore, the width and the length of the model were set at 5m, and the total thickness of model is 4m. Total pavement structure thickness is 0.45 m above sandy subgrade depth of 3.55 m. The thickness of AC surface course is 0.05 m, the thickness of AC base course is 0.10 m while the thickness of granular subbase course is 0.30 m as shown in Figure 1.

Figures 2 through 3 show the model considered in this study and it was input borehole in 3-D Plaxis software with the cycling repeated wheel load and these figures indicate the placement of geogrid at bottom of asphalt concrete surface course and at top of subbase course reactively.

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**Fig. 1. Cross section of the selected pavement structure**
Since the resilient modulus test equipment is not currently available in many laboratories, researchers have developed correlations to converting CBR values to approximate $M_R$ values. The correlation considered reasonable for fine grained soils with a soaked CBR of 10 or less is [13]:

$$M_R (\text{MPa}) = 10.3 \times (\text{CBR})$$  \hspace{1cm} (1)

The minimum limit of CBR value of subgrade will be taken as 4% in accordance with Iraq specifications requirements (SCRB /R5) [14]. Therefore, resilient modulus of subgrade can be calculated from eq.(1) and it is founded as 40 MPa.

Claessen et al. [15] established the relation between subbase resilient modulus and subgrade resilient modulus according to the following relationship:

$$M_R = 0.2 \times h^{0.45} \times M_R \text{ (subgrade)}$$  \hspace{1cm} (2)

Where

$h$ = the thickness of subbase layer in mm.

In this study, the thickness of subbase layer is 300 mm and $M_R$ for the subgrade was 40 MPa and as a result the $M_R$ value of subbase course is 100 MPa. Material parameters and constitutive models used are shown in Table (1) whereas Table (2) shows mechanical properties of geogrid reinforcement.

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (m)</th>
<th>Young's Modulus (MPa)</th>
<th>Poisson's Ratio</th>
<th>Dry Density (kN/m$^3$)</th>
<th>Saturated Density (kN/m$^3$)</th>
<th>Cohesion (kN/m$^2$)</th>
<th>Friction Angle (degree)</th>
<th>Dilatation Angle (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Surface</td>
<td>0.05</td>
<td>4000</td>
<td>0.35</td>
<td>23</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>AC Base</td>
<td>0.1</td>
<td>3000</td>
<td>0.35</td>
<td>23</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Grave and sand Subbase</td>
<td>0.3</td>
<td>1000</td>
<td>0.45</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Sand Subgrade</td>
<td>2.55</td>
<td>40</td>
<td>0.45</td>
<td>17</td>
<td>17</td>
<td>8</td>
<td>35</td>
<td>5</td>
</tr>
</tbody>
</table>

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Where

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In this study, the thickness of subbase layer is 300 mm and $M_R$ for the subgrade was 40 MPa and as a result the $M_R$ value of subbase course is 100 MPa. Material parameters and constitutive models used are shown in Table (1) whereas Table (2) shows mechanical properties of geogrid reinforcement.
Table 2. Physical and mechanical properties of Netlon CE121 product.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Property</th>
<th>Unit</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh type</td>
<td>Diamond</td>
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<td></td>
</tr>
<tr>
<td>Standard color</td>
<td>Black</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polymer type</td>
<td>HDPE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>Rolls</td>
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<tr>
<td>Dimensional properties</td>
<td></td>
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</tr>
<tr>
<td>Aperture size</td>
<td>mm</td>
<td>6*8</td>
<td></td>
</tr>
<tr>
<td>Mass per unit area</td>
<td>g/m²</td>
<td>740</td>
<td></td>
</tr>
<tr>
<td>Rib thickness</td>
<td>mm</td>
<td>1.6/1.45</td>
<td></td>
</tr>
<tr>
<td>Junction thickness</td>
<td>mm</td>
<td>2.75</td>
<td></td>
</tr>
<tr>
<td>Rib width</td>
<td>mm</td>
<td>2/2.75</td>
<td></td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak tensile resistance</td>
<td>kN/m</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Elastic modules</td>
<td>GPa</td>
<td>0.39</td>
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<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Percentage elongation at maximum load</td>
<td>%</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

3. Results and Analysis

In this section repeated cycling loading condition is presented for both unreinforced and geogrid-reinforced base. Applied contact pressure ranged from 50 kPa to 600 kPa and geogrid was placed at two positions either at bottom of asphalt concrete surface layer or at the interface of asphalt concrete base layer and subbase course. Critical pavement responses i.e. total stress and total vertical displacement of unreinforced and geogrid reinforced pavements are determined under for each contact pressure value.

Figures 4 through 6 illustrate the vertical displacement profile for applied contact load of 600 kPa for case of unreinforced pavement and reinforced pavement with one layer of geogrid placed either under AC layer or above subbase layer.
It may be observed from above figures that a significant decrease in vertical settlement obtained for reinforced pavement at both of bottom of AC surface layer or top of subbase layer. Maximum vertical displacement is $4.213 \times 10^{-3}$ m for case of unreinforced pavement, while it is $-3.518 \times 10^{-3}$ m and $-3.675 \times 10^{-3}$ m for reinforced AC surface and at top of subbase pavement courses respectively. It can be concluded that the reduction in vertical displacement (rutting) at pavement surface by 16.5% when geogrid was placed at bottom of AC surface course.

Figures 7 to 9 illustrate the total stresses profiles for applied tire pressure of 600 kPa for case of unreinforced pavement and reinforced pavement with geogrid placed under AC surface layer and at top of subbase layer respectively.
Fig. 7. Total stresses contour for unreinforced pavement (applied tire pressure = 600 kPa).

Fig. 8. Total stresses contour for reinforced pavement with geogrid at bottom of AC surface layer (applied tire pressure = 600 kPa).
Figures 6 through 8 indicated that for unreinforced pavement, maximum total stress (335.9 kPa) is significantly higher compared with that for case of reinforced pavement with geogrid at bottom of surface layer (118.8 kPa) and reinforced pavement with geogrid at top of subbase layer (224.5 kPa).

Figures 10 and 11 show comparison between pavement system behaviour for three cases: unreinforced pavement, geogrid reinforced pavement at bottom surface layer, and geogrid reinforced pavement at top of subbase layer. The three cases are compared in regards of total stress and vertical settlement responses.
Regardless of applied pressure values, the pavement with geogrid reinforcement at bottom of AC surface layer has a slightly lower maximum vertical displacement and total stress than that of other cases as shown in Figures 10 and 11.

4. Conclusions

Based on 3-D Plaxis software outputs applied on pavement structure to evaluate the benefits of reinforcing pavement with geogrid at two positions, the following conclusions can be drawn:

1. A significant improvement in pavement behavior is obtained by placing geogrid layer at bottom of asphalt concrete surface layer. Vertical displacement and effective stress responses are significantly lower for reinforced pavement system in comparison with unreinforced pavement.

2. Moderate improvement in pavement system behavior was gained by adding geogrid at top of subbase layer.

3. The best location of adding geogrid within the pavement structure is near to applied tire pressure within the asphalt concrete layers.

4. The use of geogrid significantly enhances the resistance of asphalt concrete to the deformation and development of cracking failure.

References


