Distribution of Stresses in Reinforced and Unreinforced Flexible Pavement Layers under Dynamic Load

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Abstract. Nowadays, the increasing demand for road transport makes maintenance and repair of road infrastructures key tasks for road engineering. The current experimental work consists of laboratory model experiments to understand the conduct of sand as a subgrade under dynamic load and its effect on the flexible pavement and base layer. Geogrid reinforcement was applied at the interface between the base and subgrade using SS2 type of geogrid. The road layers were exposed to harmonic dynamic load with two load amplitudes 10 and 15 kN and two frequencies 0.5 and 1 Hz. The vertical stresses in the road layers are measured using stress gauge sensor. It revealed that when laying the geogrid between the base course and subgrade and when base course thickness is 150 mm, the stress and displacement decreased with increase in the frequency and load amplitudes. But in the case of reinforcing layer at the center of the base course layer, the displacement decreased with increase in the frequency and loads except for one case when the load was 15 kN and frequency 0.5 Hz. It can be suggested that the maximum vertical displacement increased with the increase of base course thickness for both reinforced and unreinforced base layers. Also, it can be observed that the vertical stress increased by increasing the base course layer-thickness for unreinforced models.

Keywords: Dynamic load; geogrid; pavement layers; stress.

1. Introduction
Dynamic axle loads have different effects other than their static values, i.e., those obtained with the vehicle stopped at a truck inspection station. This is due to the dynamic interaction between vehicles and pavement, which induces the activity of vehicle frame and axles. Carroll et al. [1] studied the resulting dynamic axle loads are affected by a number of factors such as pavement roughness, vehicle operating speed and axle suspension type. It was found that reinforcement with geogrid reduces the deformation occurring in the road and reduces 50% of the thickness of the base. Hass et al. [2] suggested that the best position to place geogrid was under the base when its layer thickness was 250 mm, while for high loads and bases whose thickness is more than 250 mm, the best location for placing the reinforcement layer was in the middle of base. Kinney and Fu [3] described a large-scale test research was carried out at the University of Alaska, where a wheel weighing 20 kN was used to find out the benefit of having a biaxial geogrid layer on the subgrade of the flexible paving system. It was found that placing the geogrid layer between the bottom layer of poor clay and the base aggregate greatly increased the road performance. Fanning and Sigurdsson [4] performed laboratory experimentation on a geosynthetic-reinforced unpaved roadway constructed over a weak clayey organic silty subgrade. The road, which consisted of an aggregate layer that varied from 250 mm to 500 mm in thickness, was sub-divided into multiple test sections, and these were reinforced with different types of geotextiles and one type geogrid. The rut development rate and its observed profile on the geogrid reinforced road surface were monitored as the number of loading cycles increased.
study found that the place of a reinforcement layer decreases the average rut depth, and significantly reduced the rut development and its depth. Moayedi, et al. [5] provided three layers of geogrid placed in paved roads to improve the performance of the pavement. They were placed in three different locations at a distance of 0.5 m and 0.25 m and at 0.05 m from the undermost of the sample. The normal stress and shear stress of the model increased when the reinforcing layer was placed on 0.5 m from the undermost. The vertical deflection was reduced by applying geogrid directly below the asphaltic layer. The main objective of this work is to quantify the performance benefits from using geosynthetic reinforcements in flexible pavements using modified laboratory machine and measuring and observing the different stresses and deflections in the flexible pavement structure at various locations and load values. In addition, comparison is made between the performance of an unreinforced overlay section with that of a geogrid-reinforced asphalt overlay section with reduced base course thickness to determine the best location of geogrid reinforcement.

2. Experimental Work

2.1 Materials

The soil utilized in this research as a subgrade layer was sand which brought from Karbala city that located in Iraq. Several physical tests were conducted. The soil was classified as SP-SM soil according to the Unified Soil Classification System USCS and AASHTO. The base was selected from Al-Nibaie quarry that located to the north of Baghdad city. This type of base was usually applied as a layer in flexible pavement construction. Base course was brought as well from al-Nibaei quarry. One type of asphalt was used which was AC (40 -50) from Daurah refinery located in Baghdad city. Several physical properties tests were conducted as illustrated in Table 1.

| Test                                      | Result       |
|-------------------------------------------|--------------|
| Penetration (25°C, 100 g, 5 sec)           | 47           |
| Ductility (25°C, 5 cm/min)                | 110          |
| Softening point (ring & ball)             | 53           |
| Flash and fire point                      | 261, 264     |
| Loss on heating (163°C, 50 gm, 5h) %      | 0.07         |
| Rotational Viscosity                      | 0.6425@135°  |
|                                           | 0.164@165°C  |
| Specific gravity asphalt                  | 1.049        |

2.2 Pavement layer preparation

The dimensions of asphalt slab are 30 cm width, 30 cm length, and 5 cm thickness as shown in Figure 1. The weight of asphalt mixture was calculated as 10522.4 gm at optimum asphalt content of 5.25%. The asphalt mixture was put uniformly in the steel mold by using heated spatula then it was put in the slightly oiled surface of the mold. After that, the surfaces were leveled. The utilized compression static load of 10 ton was maintained for 6 minutes to achieve the same value of Marshall Specimen's bulk density which is equal to 2.32 kg/m³.
2.3 Preparation of asphalt concrete mixture
Marshal method was utilized to prepare the asphalt mixture slabs. Asphalt mixture slabs were mixed and compacted at asphalt temperatures which were identical to viscosity of 0.17± 0.02 and 0.28 ± 0.03 Pascal-seconds (Asphalt Institute, 2003) [6].

2.4 Thickness of the model layers
The thickness of subgrade was selected based on the previous works of Al-Utbi [7] and Teama [8] which was suggested as 600 mm. The thickness of base layer was 150 mm while the asphalt layer was 50 mm following the works of Reddy [9] and Teama [8].

2.5 Geogrid reinforcement
The geogrid reinforcement selected in the present work is SS2 geogrid, it is produced by QMOF CO (Quality Material of Oil Field) company as shown in Figures 1 and 2. Table 2 shows the physical and mechanical properties of SS2 geogrid.

![SS2 geogrid used in tests.](image)

Table 2. Physical and mechanical properties of the SS2 geogrid.

| The physical properties | Data |
|-------------------------|------|
| Polymer                 | PP   |
| Color                   | Black|
| Polymer type            | SS2  |
| Rib shape               | Rectangular |

| Dimensional Properties  | Unit | Data   |
|-------------------------|------|--------|
| Roll width              | M    | 4      |
| Roll length             | M    | 50     |
| Unit weight             | kg/m²| 0.29   |
| Aperture size           | Mm   | 28*40  |
| WLR                     | Mm   | 3      |
| WTR                     | Mm   | 3      |

2.6 Unreinforced models
At the beginning, the sand was poured in the steel container, then sensor was placed at depth of 5 cm from the surface of the sand and compacted by a steel hammer and leveled. Next, the base layer was placed above the subgrade. The second sensor was placed at a depth of 5 cm from the middle of the base course layer thickness. The third asphalt layer was placed above the base. The third sensor was placed on a thin plate which was placed directly under the asphalt layer as shown in Figure 3.

2.7 Reinforced models
After the elaboration of sand soil, the SS2 geogrid layer was laid over the subgrade layer. Next, the base course layer was placed on the geogrid layer. Then the pavement slab was put on the box center. This was considered as a test, then the procedure was repeated with changing the geogrid location to the middle of the base layer as shown in Figure 4.
2.8 Load application apparatus
To simulate the dynamic load in the laboratory applied on pavement layers, a vibration loading device was utilized. The device was developed by Aswad [10]. An electric air compressor with a maximum load amplitude of (12 kN) was used. The loading amplitude was increased to (60 kN) throughout device modification developed by Aswad [10]. The device consists of the following parts: Steel loading frame, Hydraulic loading system, Load spreader beam, Data acquisition, Shaft encoder and Steel container. The device adopts a dynamic load of half sine wave shape (only positive). Pressure sensors that are capable of measuring the stresses while the vertical surface displacements of the pavement system are monitored by the device.

3. Results and Discussion
3.1 Stress results for unreinforced models
Figures 5 and 6 present the stresses transmitted to the asphalt layer and, underlying base and subgrade layers for some models using 150 mm base course thickness with two load amplitudes; 10 and 15 kN and two frequencies 0.5 and 1 Hz. It can be observed that there was a decrease in the vertical stress when increasing frequency from 0.5 to 1 Hz and the load amplitude was 10 kN, However, when increasing the load amplitude to 15 the vertical stress decreased as well.
3.2 Stress results for reinforced models – 150 mm base course layer
In this section, the results of a reinforcing layer at the mid of the base course and over sand were discussed in details.

3.2.1 Stress results for reinforced models, SS2 type of geogrid is used at the middle of base layer. The relationship between vertical stress and time, when the frequency was 0.5 Hz and load amplitude 10 kN illustrated that the maximum stress reduced by 40.2%. When increasing the frequency to 1 Hz and load amplitude was 10 kN, it was noticed that the presence of reinforcement reduced the maximum stress by 23.5% as illustrated in Figure 7. When increasing the load amplitude to 15 kN and the frequency is 0.5 Hz, the maximum stress reduced by 42.8%. But when increasing the frequency to 1 Hz and the load was 15 kN, the maximum stress reduced by 35.4% as illustrated in Figure 8.
It can be concluded that the presence of geogrid reinforcement in the middle of base course layer reduces the transmitted stresses by 23.5-42.8% depending on the load amplitude and frequency. Fattah et al. [11] found that placement of the geogrid layer or layers in or at the bottom of the base course allowed shear interaction to develop between the aggregate and the geogrid, as the base...
attempted to spread laterally. Shear load was transmitted from the base aggregate to the geogrid and placed the geogrid in tension. The relatively high stiffness of the geogrid acted to retard the development of lateral tensile strain in the base adjacent to the geogrid. Lower lateral strain in the base resulted in less vertical deformation of the railway surface. Hence, the first mechanism of reinforcement corresponds to direct prevention of lateral spreading of the base aggregate. Geogrid mesh provides best interlocking with the soil particles. The improvement in the load carrying capacity could refer to improved load dispersion through reinforced base on to the subgrade. This in turn, results in lower stresses from transfer to subgrade, thus leading to less subgrade distress. The geogrid reinforcement limits the lateral displacement in the reinforced zone, which is approximately 50 mm above and below the geogrid as concluded by Leshchinsky and Ling [12]. The geogrid also improves aggregate confinement and interaction, leading to enhanced structural performance of the unpaved aggregate base.

3.2.2 Stress results for reinforced models, SS2 type of geogrid is used between base layer and subgrade. When the geogrid was placed over the sand subgrade and the load amplitude was 10 kN and the frequency was 1 Hz the maximum stress reduced by 20.4%. The maximum stress reduced by 31.5%, when increasing load amplitude to 15 kN and the frequency was 1 Hz. as illustrated in Figures 9 and 10.

On the other hand, inserting geogrid mesh in the interface between subgrade and base layers reduces the stress transmitted by 20.4-39.4%. There is a difference in the frictional forces generated between the geogrid and the soil surrounding it. When it was placed in the middle of the subgrade layer, friction occurs with coarse materials. However, friction with coarse and fine materials occurs when placing the geogrid at the interface between the subgrade and base layers.

![Graphs showing vertical stress variation](image)

**Figure 9.** Variation of vertical stress in road layers under a frequency 1 Hz and load amplitude 10 kN, geogrid between base course and subgrade.
3.3 Displacement results for unreinforced models- 15 cm thickness of base course

In this study, the vertical displacement of the pavement layers was measured at the surface of asphalt layer. In Figure 11, it was noticed that there was an increase in the displacement as the increase of frequency from 0.5 to 1 Hz.

The results agree with the findings of Fattah et al. [13] who found that the factors that helped increase the load under the base are the increase in dynamic force, operating frequency and degree of saturation. Meanwhile, it was decreased with rising the relative density of sand, modulus of elasticity and embedding inside soils.

3.4 Displacement results for reinforced models

Figures 12 and 13 represents the case of locating geogrid layer at the mid of base course layer when the load was 10 kN and frequency was 1 Hz, the maximum displacement decreased by 57.9%. However, when the frequency was 0.5 Hz, the displacement decreased by 84.5%. When considering different load amplitude of 15 kN and frequency was 1 Hz, the displacement decreased by 32.4%. When the frequency was 0.5 Hz, the maximum displacement increased by 37.41%.
When laying the geogrid between the base course and subgrade, the maximum displacement decreased by 46.7% under a load amplitude 10 kN and 1 Hz frequency. Otherwise when the frequency was 0.5 Hz displacement decreased by 62.7%. When increasing load amplitude to 15 kN and frequency was 1Hz, the maximum displacement decreased by 3.2%, but when the frequency was 0.5 Hz, the displacement increased by 12.79%. Table 3 summarizes the test results.

![Figure 12. Variation of displacement in road layers with geogrid in the middle.](image)

![Figure 13. Variation of displacement in road layers with geogrid on sand.](image)

**Table 3. Summary of test results for models with SS2 type of geogrid.**

| Case                                | Frequency (Hz) | Load (kN) | Layer   | Max. stress (kPa) | Time of occurrence (sec.) | Max. displacement (mm) | Time of occurrence (sec.) |
|-------------------------------------|----------------|-----------|---------|------------------|---------------------------|------------------------|---------------------------|
| Without geogrid                     | 0.5            | 10        | Asphalt | 332.6            | 678                       | 3.61                   | 800                       |
| Without geogrid                     | 1              | 10        | Asphalt | 283.2            | 470                       | 5.54                   | 800                       |
| Without geogrid                     | 0.5            | 15        | Asphalt | 386.0            | 645                       | 1.87                   | 800                       |
| Without geogrid                     | 1              | 15        | Asphalt | 435.7            | 555                       | 5.15                   | 800                       |
| with geogrid in the midst of base   | 0.5            | 10        | Asphalt | 198.6            | 740                       | 0.56                   | 800                       |
| with geogrid in the midst of base   | 1              | 10        | Asphalt | 216.6            | 705                       | 2.34                   | 800                       |
| with geogrid in the midst of base   | 0.5            | 15        | Asphalt | 220.7            | 690                       | 2.98                   | 800                       |
| with geogrid in the midst of base   | 1              | 15        | Asphalt | 281.3            | 760                       | 3.48                   | 800                       |
| with geogrid on sand                | 0.5            | 10        | Asphalt | 201.3            | 675                       | 1.35                   | 800                       |
| with geogrid on sand                | 1              | 10        | Asphalt | 225.3            | 780                       | 2.96                   | 800                       |
| with geogrid on sand                | 0.5            | 15        | Asphalt | 248.8            | 210                       | 1.64                   | 800                       |
| with geogrid on sand                | 1              | 15        | Asphalt | 298.1            | 615                       | 4.98                   | 800                       |
3.5 Stress results for unreinforced models - 300 mm base course layer

Figures 14 and 15 present the stresses transmitted to the asphalt layer and underlying base and subgrade layers for some models with 300 mm thickness of base course layer under different load amplitudes; 10 and 15 kN and two frequencies 0.5 and 1 Hz. It can be observed that in the absence of a reinforcing layer, there was an increase in the vertical stress with the increase of frequency from 0.5 to 1 Hz and load amplitude from 10 to 15 kN. Geogrid mesh provides best interlocking with the soil particles. The improvement in the load carrying capacity could refer to improved load dispersion through reinforced base on to the subgrade. This in turn, results in lesser strength of stresses getting transfer to subgrade, thus leading to lesser subgrade distress.

**Figure 14.** Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 10 kN.

**Figure 15.** Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 15 kN.
3.6 Stress results for reinforced models - 300 mm base course layer

3.6.1 Stress results for reinforced models, SS2 type of geogrid is used in the middle of base layer. In Figure 16, the maximum stress increased by 54.9% when the frequency was 0.5 Hz, and load amplitude 10 kN. But when increasing the frequency to 1 Hz and the load amplitude is 10 kN, it was noticed that the presence of reinforcement decreased the maximum stress by 18.6%. The maximum stress decreased by 14.0% when increasing the load amplitude to 15 kN and the frequency is 0.5 Hz as shown in ‘Figure 17’. The maximum stress reduced by 10.6% when the load was 15 kN and the frequency was 1 Hz. In general, the soil without adding the geogrid is granular and behaves as a flexible layer. When the geogrid is added, an overlap occurs between the soil and geogrid, so the soil mass is working as a one unit which increases the inertia force, thus making the stress increases in the layer. In addition, the geogrid stiffness is high, so the stresses become higher so that the stresses increased especially when increasing the loading frequency in the layers except when adding the geogrid in the center of the base layer under a frequency 0.5 Hz where the stress became less.

**Figure 16.** Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 10 kN, geogrid at the middle of base layer.

**Figure 17.** Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 15 kN, geogrid at the middle of base layer.
3.6.2 Stress results for reinforced models, SS2 type of geogrid is used over subgrade layer. When the location of geogrid layer was between the base course and subgrade and when the load amplitude was 10 kN and the frequency 0.5 Hz, it was observed that the presence of geogrid increases the maximum vertical stress by 53.6% as shown in Figure 18. While when increasing the frequency to 1 Hz the maximum stress decreased by 28.3%. When increasing load amplitude to 15 kN and the frequency was 0.5 Hz, the maximum stress reduced by 38.3%. A decrease in stress by 26.9% was observed when the frequency was 1 Hz and load amplitude 15 kN.

![Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 10 kN, geogrid between base course and subgrade.](a. Asphalt)

![Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 10 kN, geogrid between base course and subgrade.](b. Base and subgrade courses)

**Figure 18.** Variation of vertical stress in road layers under a frequency 0.5 Hz and load amplitude 10 kN, geogrid between base course and subgrade.

In general, soil without adding the geogrid is granular and behaves as a flexible layer. When the geogrid is added, an overlap occurs between the soil and geogrid, so the soil mass is working as a one unit which increases the inertia force, thus making the stress increases in the layer. In addition, the geogrid stiffness is high, so the stresses become higher so that the stresses increased especially when increasing the loading frequency in the layers except when adding the geogrid in the center of the base layer under a frequency 0.5 Hz where the stress became less.

3.7 Displacement results for unreinforced models – 300 mm base course layer
In Figure 19, it is noticed that there is an increase in the displacement by increasing the frequency from 0.5 to 1 Hz.
Since subgrade erosion is a function of base deflection, the increase in speed (or frequency) may accelerate the erosion of subbase or subgrade materials which may occur at transverse or longitudinal edges of the pavements as argued by Darestani et al. [14].
3.8 Displacement results for reinforced models – 300 mm base course layer

In Figures 20 and 21, when SS2 type of geogrid was used in the middle of the base course layer, when the load was 10 kN and frequency was 1 Hz, the maximum displacement decreased by 59.8%. However, when the frequency was 0.5 Hz, the displacement increased by 9.1%. When increasing the load amplitude to 15 kN and frequency was 0.5 Hz, the displacement increased by 5.2% only.

When laying the geogrid between the base course and subgrade, the maximum displacement increased by 63.9% under a load amplitude 10 kN and 1 Hz frequency. However, when the frequency was 0.5 Hz displacement increased by 61.73%. When increasing load amplitude to 15 kN and frequency is 0.5 Hz, the maximum displacement decreased by 22.7%. Table 4 summarizes the test results for this case.
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4. Conclusions

By performing laboratory tests on models with different variables under the influence of dynamic loads, the following conclusions can be drawn:

1. In the case of a reinforcing layer at the middle of base course layer when the base thickness is 150mm, the stress and vertical displacement decrease with increase in frequency and load amplitude.

2. When laying the geogrid between the base course and subgrade, a lower decrease in the stress and vertical displacement could be obtained with an increase in frequency and loads.

3. The maximum vertical displacement increased with increasing the base course thickness for both reinforced and unreinforced base layer.

4. The vertical stress increased by increasing the base course layer thickness for unreinforced models, while there is increase in the vertical stress in some cases for reinforced models.

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**Table 4. Summary of test results for SS2 type of geogrid for the case of 300 mm thickness of base course.**

| Case | Frequency (Hz) | Load (kN) | Layer | Max. stress (kPa) | Time of occurrence (sec.) | Max. displacement (mm) | Time of occurrence (sec.) |
|------|----------------|-----------|-------|-------------------|----------------------------|------------------------|----------------------------|
| Without geogrid | 0.5 | 10 | Asphalt | 95.2 | 5 | 2.753 | 800 |
| Without geogrid | 1 | 10 | Asphalt | 277.0 | 778 | 5.808 | 800 |
| Without geogrid | 0.5 | 15 | Asphalt | 360.6 | 303 | 6.224 | 800 |
| Without geogrid | 1 | 15 | Asphalt | 308.2 | 785 | 6.577 | 800 |
| With geogrid in the midst of base | 0.5 | 10 | Asphalt | 211.1 | 775 | 3.029 | 800 |
| With geogrid in the midst of base | 1 | 10 | Asphalt | 225.5 | 751 | 2.330 | 800 |
| With geogrid in the midst of base | 0.5 | 15 | Asphalt | 310.0 | 105 | 6.567 | 800 |
| With geogrid in the midst of base | 1 | 15 | Asphalt | 275.3 | 790 | 10.230 | 800 |
| With geogrid on sand | 0.5 | 10 | Asphalt | 205.3 | 782 | 7.194 | 800 |
| With geogrid on sand | 1 | 10 | Asphalt | 198.4 | 800 | 16.130 | 800 |
| With geogrid on sand | 0.5 | 15 | Asphalt | 223.2 | 710 | 4.805 | 799 |
| With geogrid on sand | 1 | 15 | Asphalt | 225.1 | 788 | 10.454 | 800 |
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