Transmission of Stresses in Pavement Layers Subjected to Earthquake Excitation

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Abstract. A reinforcement interlayer retards the development of cracks in the asphalt overlay by absorbing the stresses induced by both heavy traffic and underlying cracking in the old pavement. The experimental work in this study used laboratory model tests to developed an understanding of the behaviours of sand used as a subgrade under earthquake condition and the its effects of this on flexible pavement and base course layer. The sand subgrade layer has a thickness of 600 mm and the base course was set to 200 mm; the asphalt layer was prepared as a panel with dimensions of 300 × 300 × 50 mm, representing the surface layer. These layers were then tested under the influence of earthquake loading with different frequencies 0.5, 1 and 1.5 Hz. The tests were performed in two parts without adding a geogrid, and with geogrids in the centre of the base layer and between the base and sand layer. Stresses in all three layers are measured using stress sensors, and the displacements of the asphalt layer were measured using two laser displacement sensors. The results for the tests on pavement layers showed that, the stress recorded in models reinforced with geogrids was higher than that seen in unreinforced models, while the displacement was decreased by adding the geogrid in the layers at all three frequencies. When the geogrid is laid between the base and sand layer, the stress in the subgrade layer also lower than that in the base and asphalt layers.

Keywords: pavement layers, geogrid reinforcement, dynamic, stresses, displacements.

1. Introduction

Pavement damage, such as fatigue or permanent deformation, is contingent on pavement responses in the form of horizontal and vertical strains due to dynamic loads or repetitive traffic loads. Such stresses depend on the stiffness of pavement layers which are generally considered uniform in all directions. Pavement is constructed by compacting pavement layers in vertical direction, which can lead to unequal material stiffness, however, as described by the elasticity modulus E in the horizontal and vertical directions.

Moayedi et al. [1] examined the addition of geo-grid reinforcement of paved roads to improve the performance of transportation. Geo-grid reinforcement was provided at three different positions at distances of 0.5 m, 0.25 m and at 0.05 from the bottom of the model and the findings showed that maximum shear stress and normal stress increased when the geo-grid was placed at a distance of 0.5 m from the bottom. It was also observed that the vertical deflection under the centre of the load was reduced with the use of geo-grid just under the asphalt layer: hence, it was concluded that the effectiveness of a
geo-grid is more pronounced when it is placed at the bottom of an asphalt concrete section and improved if effective bending is maintained between the asphalt concrete and geo-grid. Kumar and Rajkumar [2] studied the influence of adding a geotextile layer between subgrade soil and a base course layer and found that the resistance to penetration increases with the addition of a geotextile layer. A mean of calculating the reinforcement ratio, that involved comparing loads with geo-textiles to loads without geo-textiles, was used, and the reinforcement ratio in the sample was found to be greater than 1. It was also concluded that the use of geo-textiles with a soft subgrade at higher penetration was more effective under road conditions.

Jasim et al. [3] focused on two primary objectives. The first was the impact of geogrid (Tensar SS) on reinforcing conventional flexible pavements constructed on subgrade. While the second was to confirms the optimal location for integrating a pavement system with geogrid. To quantify the effectiveness of a geogrid in a flexible pavements structure, a 3D finite element simulation was conducted using a thick base pavement structure. In order to identify the best location for the installation of geogrid in such pavements, two different geogrid locations were implemented. A constant loading condition was then applied while the geogrid locations were moved within in the proposed pavement structures. This process highlighted several effects of geogrids on pavement performance such as the reduction of longitudinal and transverse shear deformation in unbound layers. The study thus offered two different conclusions. Pavement performance can be improved by implementing a single geogrid layer within the upper third of the flexible layer and, in order to achieve structural stability, the subgrade-base layer interface may also require a geosynthetic stabilization layer.

The experimental work of this study consisted of laboratory model tests to develop an understanding of the behaviour of pavement layers on a sand subgrade under the effect of earthquake condition. Geogrid reinforcement was then placed at different locations; between the base course and sand, and at the centre of the base course layer, and the resulting stresses and displacement measured using stress and displacement gauge sensors.

2. Experimental Work

2.1 Materials

The soil utilised as a subgrade layer in this research was a natural cohesionless soil (sand) from Iraq's Karbala region. A variety of physical tests were conducted on it, and allowing it to be classified as SP-SM soil according to the USCS (ASTM D2487-11) [4]. The base course was selected from the Al-Nibae quarry, north of Baghdad. In flexible paving construction, this type of material is generally utilised as a base layer. Crushed aggregates from Al-Nibaay were also used. With their physical and chemical properties determined utilising tests (of angularity, sieve analysis, flatness and elongation, toughness (Los Angeles abrasion), specific gravity, and soundness, in addition to the equivalent sand (clay content), as shown in Table 1. Table 2 shows the results of the sieve analysis specifically. In this work, the grade of asphalt utilised was 40 to 50, according to the classification obtained from Al-Daurah Refinery. The physical properties of the asphalt are presented in Table 3.
### Table 1. Physical properties of selected aggregate.

| Laboratory Test          | ASTM Designation and Specification | Sieve size (mm) | Result                  |
|--------------------------|------------------------------------|-----------------|-------------------------|
| Specific gravity         | Coarse aggregate, ASTM C 127       |                 |                         |
|                          |                                    | 12.5            | 2.674                   |
|                          |                                    | 9.5             | 2.591                   |
|                          |                                    | 4.75            | 2.582                   |
| Fine aggregate, ASTM C 128|                                    | 4.74-0.075      |                         |
| Angularity for Coarse aggregate | ASTM D 5821, Min 95%       |                 |                         |
| Soundness for coarse aggregate | ASTM C 88 10-20% Max         |                 |                         |
| Equivalent sand (clay content) | Natural (< # 4), ASTM D2419, Min 45% |                 |                         |
|                          | Crushed (< # 4), ASTM C 128         |                 |                         |
| Flat & Elongation aggregate | Flat, ASTM D 4791, Max 10% |                 |                         |
|                          | Elongation, ASTM C 128               |                 |                         |
| Toughness by (Los Angeles abrasion) | Aggregate size < 25 mm, ASTM C131, 30% Max |                 |                         |

### Table 2. Sieve analysis of base course.

| Sieve size (mm) | Passing % | Specification limits |
|-----------------|-----------|----------------------|
| 37.5            | 100.0     | 100.0                |
| 25.0            | 98.3      | 80 – 100             |
| 19.0            | 87.5      |                      |
| 12.5            | 67.9      | 50 – 80              |
| 4.75            | 47.2      | 30 – 60              |
| 0.425           | 19.9      | 10 – 30              |
| 0.075           | 9.3       | 5 – 12               |
| Pan             |           |                      |

### Table 3. Physical properties of asphalt cement.

| Test                                      | Result        | SCRIB Specifications |
|-------------------------------------------|---------------|----------------------|
| Penetration (25°C, 100 g, 5 sec)          | 47            | 40-50                |
| Ductility (25°C, 5 cm/min)                | 110           | ≥ 100                |
| Softening point (ring & ball).            | 53            |                      |
| Flash and fire point                     | 261, 264      | ≥ 232                |
| Loss on heating (163°C, 50 gm, 5h)%      | 0.07          | < 0.75               |
| Specific gravity asphalt                 | 1.049         |                      |
| Rotational Viscosity (pa. sec)            | 0.6425@135 °C |                    |
|                                           | 0.164@165°C   |                      |
2.2 Pavement layer preparation
To simulate a pavement layer, compacted asphalt mixture slabs were prepared. The slab dimensions were 300 mm, x 300 mm, x 50 mm. A steel mould was used to compress the asphalt slab, and approximately 10522.4 gm of the asphalt mix was prepared at optimum asphalt content (5.25%) based on the formula developed in a previous study to obtain an asphalt slab with the desired dimensions. The asphalt mixture was laid uniformly in the oiled steel mould by with a hot spatula, and the surfaces was then levelled.
A compression static load of 100 kN was applied for 6 minutes at 154°C to attain the Marshall specimen bulk density equal to 2.32 gm/cm³ at the desired thickness of 50 mm. The slab was left overnight then removed from the mould and covered with polyethylene to prevent the influence of environmental conditions on its properties as shown in Figure 1.

![Figure 1. Asphalt slab models.](image)

2.3 Thickness of the model layers
The thickness of the selected layers was based on several previous studies; the thickness of subgrade was chosen based on the work of Al-Utabi [5], Reddy [6], and Teama [7] to be 600 mm while the thickness of the base layer was 200 mm and that of the asphalt layer was 50 mm, dimensions close to those adopted by Teama [7] and Reddy [6]. Figure 2 shows the profile of the pavement layers.

![Figure 2. Profile of model layers.](image)
2.4 Geogrid reinforcement
The geogrid utilised in this work in all tests was type SS2 produced by QMOF Co. The same sheet of geogrid was utilised in several tests and replaced whenever it became visibly overstressed or damaged.

2.5 Shaking machine
To simulate earthquake excitation in the laboratory, a shaking table, which simulates the loading that happens during dynamic excitation such as during an earthquake, was used. The loading types for this device can be harmonic, random or modelled on real earthquake movement. The shaking table device consists of four main parts, the shaking table base, electrical motor and AC-drive, A steel box and the damping system.

The shaking table used, as shown in Figure 3, was designed and manufactured by AL-Recaby [8]. The steel box was placed on L-shaped plate and linked with a by screw bolt (15 mm in diameter). The steel box has internal dimensions of 800 × 800 × 1,000 mm.

![Figure 3. The shaking box.](image)

Tactile pressure sensors with 10 kPa capacity were utilised to record the pressures, and a laser displacement sensor was utilised to determine the distance between the sensor and an object by measuring the volume of displacement across a number of elements and converting this into a distance. To record the horizontal displacement, two sensors were fastened on opposite sides of the sample panel.

2.6 Unreinforced models
Before earthquake forces were applied, a bed of sand was placed in the steel container, with the first sensor placed at a depth of 50 mm under the surface of the sand. Then the base layer was placed above the subgrade and compacted manually using a steel hammer until levelled. The second sensor was positioned at a depth 50 mm below the middle of the base course layer. The slab specimen of the asphalt layer was then placed on the base course while the third sensor was positioned directly under the asphalt layer. A steel plate with dimensions 900* x 900 mm was placed on the asphalt layer, as shown in Figure 4.
2.7 Reinforced models

After the preparation of the bed of sand soil, the SS2 geogrid layer was positioned on the surface of the sand layer. The base course layer was then laid, with compaction, as mentioned previously, with the asphalt slab positioned on the base layer. After that, the steps were repeated with any necessary amendments to the geogrid position, whether in the centre of the base layer over the base layer. The first sensor was positioned at a depth of 50 mm below the surface of the sand, the second sensor was placed at depth of 50 mm under the middle of the base course layer and the third sensor was placed directly under the asphalt layer.

A prime coat was poured between pavement layer and base granular course, as the focus of study was to determine the effect of earthquakes on the layers of pavement and the potential benefits of the presence of the geogrid in various pavement layers in the event of earthquake.

3. Results and Discussion

3.1 Stress and displacement results for the unreinforced models

Figures 5 to 7 illustrate the vertical stresses transferred to the sand base, base course and asphalt layer under dynamic loads of 0.5, 1 and 1.5 Hz frequencies respectively. As shown in these figures, the stress changed the frequency increased, with rapid changes observed for stress at 1 and 1.5 Hz as compared to 0.5 Hz, where there was little change. The maximum stress recorded at 1 Hz was higher than that recorded at 0.5 and 1.5 Hz.

Figures 8 to 10 show the horizontal displacement measured under the same loading conditions. From the figures, the maximum horizontal displacement is recorded at 1 Hz, while the horizontal displacement at 0.5 and 1.5 Hz is low. Oscillation of horizontal displacement due to rapid movement can also be observed.

The duration for each test was constant 140 seconds. Generally, the lower the frequency value, the less vibration, and the higher the frequency, the stronger the vibration.
Figure 6. Variation of vertical stress in road layers at 1 Hz.

Figure 7. Variation of vertical stress in road layer at 1.5 Hz.

Figure 8. Variation of displacement in road layers at 0.5 Hz.

Figure 9. Variation of displacement in road layers at 1 Hz.

Figure 10. Variation of displacement in road layers at 1.5 Hz.
3.2 Stress and displacement results in the reinforced models

Figures 11 to 16 illustrate the vertical stresses transferred to the sand base, base course and asphalt layer under dynamic loads of different frequencies. From the figures, where geogrid is used in the middle of the base layer, the stress reduced in the base course layer at all frequencies.

Based on the results obtained, when the geogrid is laid between the base course and sand layer, the stress in the sand subgrade layer is less than that in the base and asphalt layers. When the geogrid is between the base and sand in the base layer, the maximum stress occurs at 0.5 Hz; however.

When geogrid is positioned at the centre of the base, the maximum stress occurs at 1 Hz at the asphalt layer and the maximum stress at 1.5 Hz occurs when the geogrid is between the base and the sand, in the asphalt layer.

The distorted geogrid supplies vertical upholding to the overlying soil mass subject to loading; the deformed geogrid, thus sustains normal and shear stresses with membrane force with a vertical component that withstands applied loads. This aspect of geogrid is known as its "membrane influence". The interlocking effect observed by Fattah et al. [9] in geogrids has other benefit based on the overlapping of soil through the apertures (openings) between the longitudinal and transverse ribs.

From the figures, the stress at 0.5 Hz while the geogrid is positioned at the centre of base layer is greater than that in the unreinforced model under the same frequency by 92%, and the stresses at 1 Hz with the geogrid at the centre of the base are greater than those in the unreinforced model under the same frequency by about 86.9%. At 1.5 Hz, for the model with geogrid at the centre of the base course, the stress is 75% greater than that in unreinforced model.

Fattah et al. [10] concluded that the effect of load frequency on the settlement ratio is almost constant after 500 cycles. In general, for reinforced cases, the effect of load frequency on the settlement ratio was certainly very small, ranging between 0.5 and 2% variation as with the unreinforced case.

The maximum stress measured at 0.5 Hz in the model with geogrid between the base and sand was greater than that in the unreinforced model under the same frequency by 86.4%, while at 1 Hz, for model with geogrid between the base and sand, the maximum stress was greater than that in the unreinforced model by 65.9%. Finally, 1.5 Hz for models with geogrid between the base and sand, the maximum stress was greater than that measured in the unreinforced model by about 81%.

Figures 17 to 22 show the horizontal displacement measured in the asphalt layer under the same loading conditions. The horizontal displacement at 1 Hz changes more than at 0.5 Hz, and while at 1.5 Hz, the horizontal displacement becomes even more variable and significant. The highest horizontal displacement for reinforced models was obtained at 1.5 Hz when the geogrid was installed at the centre of the base course layer.

When geogrid was at the centre of the base course, at 0.5 Hz, the horizontal displacements were smaller than those measured in unreinforced models by 70.2%. The horizontal displacement when the geogrid is at the middle of the base course layer at 1 Hz was also smaller than that in unreinforced model by 54.5%. However, at 1.5 Hz, the model with geogrid at the centre of the base course layer showed horizontal displacement greater than that measured in the equivalent unreinforced model by 55.1%.

When geogrid is positioned between the base course and sand, the horizontal displacement recorded at 0.5 Hz is smaller than that seen in the unreinforced model by about 76.5%, while the horizontal displacement at 1 Hz in the model with geogrid between the base course and subgrade is smaller than that in the equivalent unreinforced model by 61.3%. The horizontal displacement recorded at 1.5 Hz in the model with geogrid between the base course and subgrade is decreased as compared to that seen in the unreinforced model by about 7.6%.

In general, the soil without geogrid is granular and behaves as a flexible layer. When geogrid is added, an overlap occurs between the soil and geogrid, forcing the soil mass to work as one unit which increases the inertia force, thus increasing stress in the layer. In addition, the geogrid stiffness is high, so the stresses become higher; thus, the stresses are particularly increased on increased loading frequency in the layers.
The granular layers reinforced with geosynthetics reveal minimal elastic deflections and maximal elastic moduli. These results are consistent with those of Edil et al. [11].

Tables 4 and 5 shown that the maximum horizontal and vertical displacement of the asphalt pavement layer decreases with the inclusion of reinforcement in the layers as the geogrid reduces the motion of the asphalt layer.

![Figure 11. Variation of vertical stress in road layers under frequency 0.5 Hz, SS2 geogrid at the center of base course layer.](image1)

![Figure 12. Variation of vertical stress in road layers at 1 Hz, SS2 geogrid at the centre of the base course layer.](image2)

![Figure 13. Variation of vertical stress in road layers at 1.5 Hz, SS2 geogrid at the centre of the base course layer.](image3)
Figure 14. Variation of vertical stress in road layers at 0.5 Hz, SS2 geogrid between the base course and subgrade.

Figure 15. Variation of vertical stress in road layers at Hz, SS2 geogrid between the base course and subgrade.

Figure 16. Variation of vertical stress in road layers at 1.5 Hz, SS2 geogrid between the base course and subgrade.
Figure 17. Variation of displacement in road layers at 0.5 Hz, SS2 geogrid at the centre of base layer.

Figure 18. Variation of displacement in road layers at 1 Hz, SS2 geogrid at the Centre of base layer.

Figure 19. Variation of displacement in road at 1.5 Hz, SS2 geogrid at the centre of base layer.

Figure 20. Variation of displacement in road layers at 0.5 Hz, SS2 geogrid between base course and sand.

Figure 21. Variation of displacement in road layers at 1 Hz, SS2 geogrid between Base course and sand.
Figure 22. Variation of horizontal displacement in road at 1.5 Hz, SS2 geogrid between base course and sand.

**Table 4.** Summary of maximum stress and maximum displacement in each case.

| Case study                        | Frequency (Hz) | Layer   | Max. stress | Max. displacement |
|-----------------------------------|----------------|---------|-------------|------------------|
|                                   |                |         | Value (kPa) | Time of occurrence (sec) | Value (mm) | Time of occurrence (sec) |
| **Without geogrid**               |                |         |             |                  |            |                         |
| 0.5                               | Sand           | 111.8026| 84          | 47               | 100        |
| 1                                 | Sand           | 235.5443| 63          | 132              | 94         |
| 1.5                               | Sand           | 231.6086| 27          | 39               | 68         |
| **With geogrid at the middle of the base** |                |         |             |                  |            |                         |
| 0.5                               | Asphalt        | 1401.563| 52          | 14               | 68         |
| 1                                 | Asphalt        | 1799.541| 84          | 60               | 127        |
| 1.5                               | Asphalt        | 928.7818| 153         | 87               | 137        |
| **With geogrid between the base and the subgrade** |                |         |             |                  |            |                         |
| 0.5                               | Asphalt        | 354.1631| 22          | 11               | 31         |
| 1                                 | Asphalt        | 692.082 | 73          | 51               | 128        |
| 1.5                               | Asphalt        | 1230.189| 88          | 36               | 129        |

**Table 5.** Summary of maximum vertical displacement at thickness of base course layer 200mm.

| Case study                        | Frequency (Hz) | Max. vertical displacement | Time of occurrence (sec) |
|-----------------------------------|----------------|----------------------------|----------------------------|
|                                   |                | Max. displacement | Value (mm) | Time of occurrence |
| **Without geogrid**               |                |                     |             |                  |
| 0.5                               | 16             | 34                  | 71          |
| 1                                 | 11             | 126                 | 126         |
| 1.5                               | 70             | 126                 | 126         |
| **With geogrid at the centre of the base** |                |                     |             |                  |
| 0.5                               | 9              | 38                  |             |
| 1                                 | 10             | 34                  |             |
| 1.5                               | 35             | 138                 |             |
| **With geogrid between the base and the subgrade** |                |                     |             |                  |
| 0.5                               | 10             | 81                  |             |
| 1                                 | 19             | 70                  |             |
| 1.5                               | 29             | 99                  |             |
4. Conclusions
In view of the outcomes acquired from the model tests of different variables with regard to the impact of earthquakes on road layers, the following conclusions may be obtained:
1- The results for tests on pavement layers showed that in models reinforced with geogrid, the vertical stresses recorded are higher than in the equivalent unreinforced models.
2- Adding geogrid reinforcement in the centre of the base layer and between the base course and sand layer increased the transmitted stress by 22 to 48 % and decreased in displacement by 76 to 78 % under an increase in frequency from 0.5 to 1 Hz. At 1.5 Hz, the maximum stress decreases; however, the displacement increases when the geogrid is positioned at the base and decreases when the geogrid is between base course and sand.
3- When the geogrid is laid between the base course and sand layer, the stress in the sand subgrade layer is less than that in the base and asphalt layers by 48 to 71%.

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