

Reinforced low-volume flexible pavement response to accelerated loading

Al-Qadi, I., Dessouky, S. & Tutumluer, E.

Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, IL, USA

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ABSTRACT: Geogrids have been used to reinforce paved and unpaved roads constructed on soft subgrade for three decades. To evaluate the effectiveness of geogrids in pavement performance, nine low-volume flexible pavement sections were recently constructed to measure their response to accelerated loading. The pavement sections were divided into three cells; each cell had three pavement sections. The pavement sections comprised of a hot-mix asphalt (HMA) layer (3-5in.) on top of a granular base layer (8-18in.). Geogrid reinforcement was placed at the base-subgrade interface; as well as in the upper half of the base layer in two sections. All pavement sections were instrumented for measuring pavement response to axle wheel loading and environmental effects. The loading-response instruments were placed in the center of the lane, where the wheel loading was expected; while environmental response instruments were installed at 3-ft from the centerline. The first pavement cell, which consisted of 3in. HMA and 8in. base on a subgrade having a California Bearing Ratio (CBR) of 4, was loaded using the Accelerated Testing Loading ASsembly (ATLAS). One section was the control (unreinforced), while the other two were reinforced with geogrids having different grip strengths at the base-subgrade interface. A 10-kip load was at 5 mph. Preliminary responses of the instrumented test sections are presented for reinforced and control sections. Preliminary results suggested that use of geogrids reduced the permanent deformations in low-volume flexible pavements.

1 INTRODUCTION

Geogrid reinforcement has been used in the construction of low-volume flexible pavements for over three decades. Several studies have suggested that geogrid was a promising pavement reinforcement material (Al-Qadi et al. 1994; Saathoff and Horstmann 1999; Cancelli and Montanelli 1999); however, limited information on the quantification of the performance of geogrid-reinforced pavement systems exists (Al-Qadi et al. 1998). Because of the complexity of layered pavement systems and applied loading conditions, it was difficult to reliably identify the effectiveness of geogrid as a reinforcing system in flexible pavements. Hence, mainly performance-based tests were conducted to evaluate the structural contribution of geogrid.

Pavement responses to loading, which are defined as the critical stresses and strains in each pavement layer, could be predicted from theoretical analysis. However all theoretical methods suffer from major drawbacks including the availability of information on in-situ material properties and actual tire pressure distribution. In most cases, elastic layer properties

are assumed and a uniform circular contact pressure equal to the tire inflation pressure is used. To overcome these drawbacks, pavement instrumentation is a valid approach to directly measure stress and strain distributions in pavement structures.

To quantify the effectiveness of geogrid-reinforced flexible pavements, a full-scale accelerated pavement testing research has been initiated. This will also allow the validation and calibration of mechanistic response models, such as the one recently developed by Kwon et al. (2005), as well as develop transfer functions (or distress models) for predicting rutting and fatigue performances of geogrid-reinforced pavements.

Nine low-volume flexible pavement sections were constructed on a low California Bearing Ratio (CBR) of 4 (see Figure 1). The instruments used include pressure cells, strain gages, time domain reflectometry (TDR) probes, linear variable displacement transducers (LVDTs), piezometers and thermocouples. The sensors were placed at different depths in the pavement layers. The sections were loaded using a moving tire controlled by an in-house accelerated loading facility. This paper presents a description of the tested sections, the instrumentation process, data collection

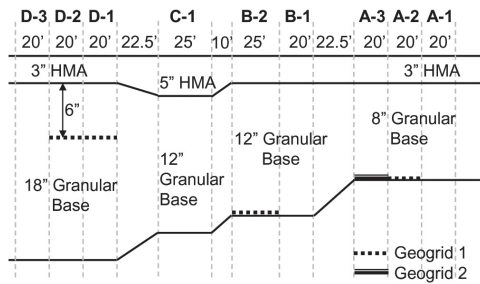


Figure 1. Cross-sections of the nine full-scale pavements.

management, and preliminary pavement response to moving load. In addition, to evaluate the effectiveness of geogrid on the performances of low-volume flexible pavements, when constructed on weak subgrade, the pavement system responses of the structurally weakest three sections are presented.

2 LAYOUT OF TESTED SECTIONS

Three instrumented flexible pavement cells were constructed low-volume pavements over weak subgrade. Each cell, which comprises of three sections, includes three granular base layer thicknesses (8, 12, and 18 in.) and one hot mix asphalt (HMA) layer thickness (3in.); except for one section, which has 5-in.-thick HMA layer. Figure 1 provides a schematic of the cross-sections of the nine pavement sections. The experimental pavement design allows the evaluation of the geogrid reinforcement effectiveness. The effectiveness of geogrid as well as its strength can be evaluated in the first cell (A-1 to A-3), which has a control section and two geogrid-reinforced sections each having a different strength geogrid. The three sections were loaded by the Accelerated Testing Loading ASsembly (ATLAS) at the same time. The effectiveness of geogrid at different HMA thicknesses is investigated in the second cell (B-1, B-2, C-1). To optimize the location of the geogrid in the granular base layer, cell three (D-1 to D-3) was also built. Results from the three cells collectively will serve to evaluate the effect of base layer thickness on the geogrid effectiveness.

The HMA consisted of a 3-in. SM-9.5 surface mix. An additional 2-in. BM-25.0 base mix was placed for the 5-in. thick HMA. PG 64-22 binder was used in all mixes. Base layer was constructed using a typical dense-graded unbound granular material (CA-6) in accordance with Illinois DOT specifications. Prior to the granular material placement, transverse and longitudinal drainage pipes were installed along the section edges. Attempt was made to maintain a uniform subgrade CBR of 4 during construction by controlling the moisture content and the compaction effort. Subgrade density and Dynamic Cone Penetrometer

(DCP) tests were conducted regularly prior to construction.

3 PAVEMENT INSTRUMENTATION

Instruments used in the pavement sections are divided into two categories: those used to measure environmental effects such as temperature, moisture and pore water pressure, and the ones used to measure responses due to loading effects such as stress, strain, and deflection. Environmental instruments consisted of thermocouples for temperature measurements, piezometers for measuring pore water pressure and time domain reflectometry (TDR) probes for moisture measurements. Load-associated instruments include pressure cells for measuring vertical pressure, LVDTs for measuring vertical and horizontal movements, and strain gauges for measuring transverse and longitudinal strains (see Figure 2). Environmental instruments were installed at a 3-ft offset from the centerline of the 12-ft lane section, while load-associated instruments were installed at the centerline where the wheel loading was expected. Instruments were staggered vertically to reduce rigid body effect on measurements.



Figure 2. Load-associated instruments include (a) Pressure cells and (b) LVDTs.

4 DATA COLLECTION AND MANAGEMENT

The pavement test sections were loaded using a 10-kip load at 5mph utilizing ATLAS. The loading was conducted uni-directionally to simulate vehicular field loading conditions. In addition to loading the instrumented centerline, the pavement was loaded at additional three offsets, 6, 12, and 18in, to consider wander effects.

In-house developed software was used with International Instrument data acquisition (DAQ) system. The DAQ system consists of five modules, in which each module is capable of transmitting the voltage signals produced by the instruments to the software. The transmitted volts were converted to engineering responses by utilizing calibration relationship provided by the manufactures and verified in this research or developed in this study. The system is cable of monitoring and recording pavement responses to different loading and environmental conditions in real time. Each cell was monitored by a single DAQ system.

Two categories of data were collected: Environmental data, which were recorded at specific time intervals varying from 15 minutes for temperature to 30 minutes for moisture and pore water pressure; and the load-associated data, collected at 100-200 Hz, as the tire traveled over the sensor.

5 ANALYSIS AND RESULTS

Figure 3 presents strain gauge, pressure cell, and LVDT responses due to 10-kip wheel load at 5 mph applied to cell A. The first peak on the left represents the response from the control section, while the other two peaks represent the responses from the two geogrid-reinforced sections. The geogrid-reinforced

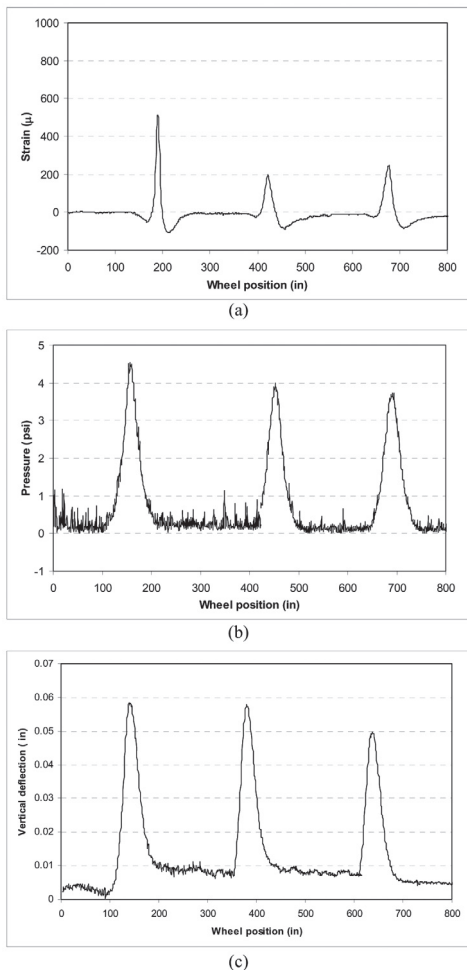


Figure 3. Cell A pavement response to 10-kip wheel loading at 5mph: (a) Strain gauges, (b) Pressure cells, and (c) LVDTs.

sections appear to exhibit less tensile strains at the bottom of HMA, less vertical pressures at the base-subgrade interface, and less vertical deformations at the subgrade. Further detailed analyses are underway to better quantify these preliminary results.

Results of wheel trafficking on cell A suggested that the reinforced section exhibited less permanent deformation than the control section as shown in Figure 4. Because the tests were conducted on the three sections of cell A at the same time and the pavement has excellent drainage, the effect of environment is considered negligible. However, as would be expected, the effect of temperature variation decreases with increasing layer depth.

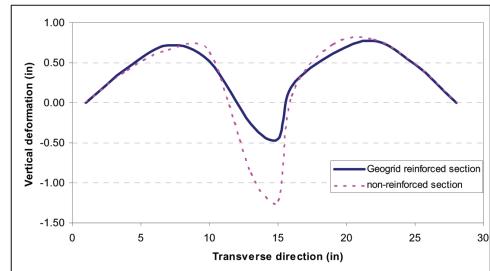


Figure 4. Rutting profiles of geogrid reinforced and unreinforced pavement sections.

Typical temperature variations in cell A pavement system are shown in Figure 5. The HMA layer is more sensitive to temperature changes because of exposure to sun and air. At this point, effect of temperature on HMA was not considered as only qualitative comparisons were made between the tested sections. Detailed analyses including nonlinear characterizations of pavement geomaterials and viscoelastic HMA response are currently underway.

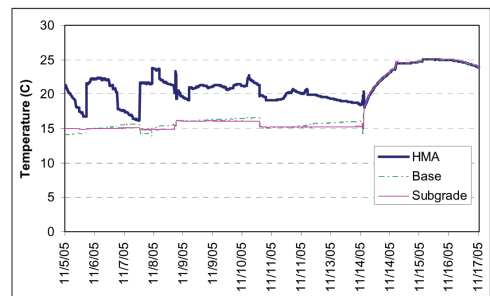


Figure 5. Temperature distribution in the pavement layer system.

6 SUMMARY

Pavement test sections were built to evaluate the effectiveness of geogrid on flexible pavements performance when built on weak subgrade. The

sections were heavily instrumented with pressure cells, LVDTs and strain gauges to measure pavement responses to moving wheel load. In addition, thermocouples, TDRs and piezometers were installed to measure environmental responses at regular intervals. Testing was conducted using the mobile accelerated testing loading assembly ATLAS. A software program was developed to monitor and record the response collected by the data acquisition (DAQ) system.

Preliminary analysis of pavement response to loading suggested that geogrid-reinforced sections experienced less tensile strain at the bottom of HMA, less vertical pressure at the top of base layer, and less vertical deflection in the subgrade. Hence, significant improvement would be expected when geogrid is used in low-volume roads constructed on weak subgrade. Testing of other pavement sections is underway.

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