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Effects of Geosynthetic Reinforcement on the Propagation of Reflection Cracking and Accumulation of Permanent Deformation in Asphalt Overlays

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Abstract

An experimental program was conducted to determine the effects of geosynthetic reinforcement on mitigating reflection cracking in asphalt overlays. The first part of this study revealed that geosynthetic reinforced specimens exhibited superior resistance to reflection cracking. In the current investigation, an attempt is made to characterize the accumulation of permanent deformation and better understand the physical mechanisms associated with geosynthetic reinforced AC overlays. The objectives of this study were to: (a) assess the effects of geosynthetics inclusion and its placement location on the accumulation of permanent deformation; and (b) identify the mechanisms involved in geosynthetic reinforcement and its interaction with the AC layers in which it is placed. Results indicate a significant reduction in the rate of crack propagation and rutting in reinforced samples with embedded geosynthetics compared to un-reinforced samples. Samples with a tacked reinforcement layer performed the same or worse than the control samples. Based on this study, it is concluded that the reinforcement must be well embedded in the asphalt to ensure a good physical connection between the geogrid and AC layer if consistent improvements in performance are to be achieved.

Keywords

cracking, asphalt, overlays, deformation, geosynthetics

1. Introduction

1.1 Overview

Placement of asphalt concrete (AC) overlays or resurfacing is one of the common ways of rehabilitating deteriorated and fractured Portland cement concrete (PCC) pavements to improve ride quality. One of the most common problems associated with AC overlays on PCC pavements has been the propagation of cracks to the surface of overlays from overlain PCC joints commonly known as "Reflection Cracking." Various researchers have identified that the main reasons for the origin and propagation of reflection cracks are: (1) load-induced differential movements of the cracks or joints of the underlying layer, (2) horizontal movements caused by length changes due to variations in temperature, and (3) curling and warping of PCC slabs caused by the presence of temperature and moisture gradients in the slab. The simultaneous movement of an overlay caused by wheel loadings, temperature changes, and temperature gradients induces a complex state of cyclic bending, tension and shear within the overlay (Barksdale, 1991). Inclusion of a geosynthetic interlayer may enhance the resistance to reflection cracking either by a stress-relief or a reinforcement mechanism, or by a combination of both. If the interlayer is flexible, it is capable of undergoing large deformation and absorbing some of the energy that would otherwise be available for crack propagation. The current study investigates the rate of crack propagation and the rate and amount of accumulation of permanent deformation as the reflection crack advances through the geogrid reinforced asphalt sample.

1.2 Relevant Studies

During the past decade or so, various researchers and highway engineers have proposed solutions to mitigate reflection cracking based on field, laboratory and/or analytical investigations (Jayawickrama and Lytton, 1987; Owusu-Antwi et al., 1998). A number of studies were identified in the literature dealing with the experimental simulation of reflection cracking through geosynthetic reinforced AC overlays placed over PCC joints. Some of these include: (1) Brown et al. (1989) and Chang et al. (1998), who placed asphalt beam specimens on two pieces of plywood having a 1 cm gap at the center to simulate an existing joint or crack underneath the overlay, with the whole system resting on a resilient rubber base representing the soil foundation; (2) Reddy et al. (1999), who studied the propagation of reflection cracks by placing asphalt beam specimens on small concrete blocks (at different gap intervals) simulating the broken PCC resting on an elastic foundation prepared with compression springs; and (3) Goulias and Ishai (1999), who used a wheel-tracking device to simulate moving traffic loads on geogrid reinforced AC overlay with a pre-sawn crack or notch underneath the specimens. These previous studies serve as a guide for the tests performed by Sobhan and Tandon (2003).

1.3 Objectives and Research Approach

A coordinated laboratory experimental program and detailed analysis were employed in this investigation. Initially, the primary objectives of the experimental phase were as follows: (1) to design an appropriate laboratory setup for simulating the reflection cracking mechanisms in AC overlays placed on PCC joints; (2) to study the effects of placement conditions and physical locations of geosynthetics on the growth and propagation of reflection cracks; and (3) to quantify the effectiveness of geosynthetics in mitigating reflection cracking. The results of the first part of this study can be seen in more detail in Sobhan and Tandon (2003). Further investigation of the data was now conducted to: (1) analyse the effects of various methods of geosynthetic inclusion on the accumulation of permanent deformation; and (2) to identify the physical mechanisms involved in the behavior of geogrid reinforced AC layers.

2. Experimental Program

2.1 Test Set-up

The current study evaluated the test configurations available in the literature, and developed a setup shown schematically in Figure 1. It consists of the following major components representing a layered pavement structure: (a) a prismatic asphalt overlay measuring 152.4 mm x 76.2 mm x 457.2 mm, either unreinforced or containing geosynthetic reinforcement tacked to the bottom, embedded at the bottom or embedded in the middle of the overlay, (b) simulated concrete pavement joints modeled with two plywood planks centered underneath the overlay, and (c) a resilient subgrade modeled with neoprene sponge rubber. Additionally, a fabricated steel loading head was used whose radius of curvature represented a tire imprint on top of the overlay. An MTS servo-hydraulic machine with computerized test control and data acquisition system was used for conducting the experimental program.

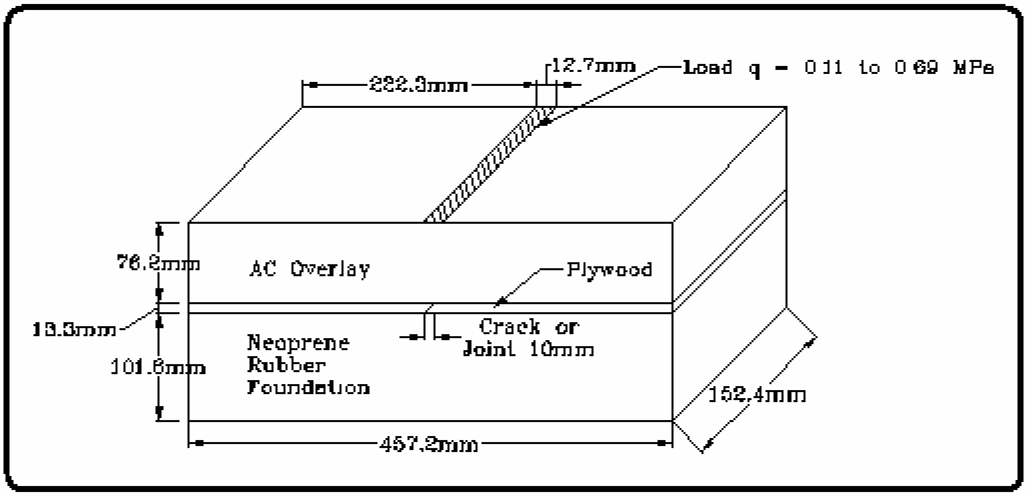


Figure 1 - Schematic of Test Setup

2.2 Materials Used

The AC used in this study to represent the overlay layer is made of coarse aggregate, fine aggregate, and asphalt binder. The course aggregate is mostly rhyolite with a lesser amount of chert and limestone, and having a maximum size of 19 mm. The fine aggregate is an arroyo sand composed of rounded quartz, sub-angular feldspar, and trace amounts of fine-textured soils. A Superpave asphalt binder obtained from Chevron Oil Company (located in El Paso, TX) and meeting a PG-64-22 specification was used. The hot mixed asphalt (HMA) contained 4.5% asphalt binder by weight. Tensar Biaxial Geogrid (BX 1500), manufactured by Tensar Corporation, located in Atlanta, Georgia, having tensile strengths of 1786 kg/m (machine direction) and 2038 kg/m (cross machine direction) at 5% strain was used in this investigation.

2.3 Specimen Preparation and Placement Configuration

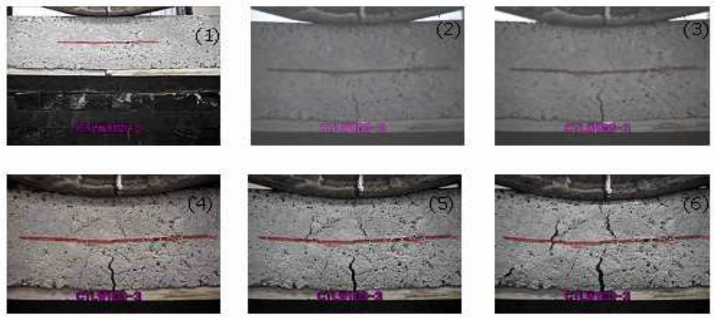
Slab specimens of asphalt concrete representing the overlay were prepared in a detachable steel meld using roller compaction techniques developed empirically in the laboratory. Specimens were prepared in two lifts at a target unit weight of 20.4 kN/m^3, corresponding to a bulk specific gravity of 2.08. Although the density of the compacted HMA specimen is slightly lower than the typical density used in the field, this density level was selected because it could be consistently achieved with the available roller compaction device in the laboratory. The following four types of specimens were prepared: (i) Unreinforced slabs, which served as control specimens (a total of 18 samples); (ii) Slabs with geogrid attached at the bottom by means of a tack coat achieved by evenly spreading 50 grams of liquid asphalt binder on the bottom of the specimen (a total of 6 samples); (iii) Slabs with geogrid embedded at the bottom by placing the geogrid at the bottom of the mold prior to pouring and compacting the first lift of loose mix (total of 11 samples); and (iv) Slabs with geogrid placed in the middle of the asphalt beam achieved by placing the geogrid on top of the compacted first lift prior to pouring and compacting the loose mix of the second lift, thus sandwiching the reinforcement within the overlay (a total of 8 samples). After demolding, and 24 hours before testing, two plywood pieces were attached at the bottom of the specimen (with a 1 cm gap in between) by means of a tack coat to represent the joints of the underlying concrete pavement. The overlay system (specimen plus plywood) was then placed on the rubber foundation for testing. Each experiment was recorded in its entirety by a digital video camera to allow the physical observation of reflection crack formation and propagation. More details can be found in Sobhan and Tandon (2003).

2.4 Test Procedures and Data Acquisition

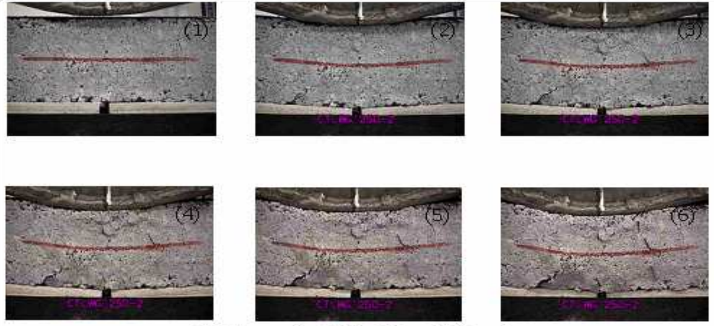
The following types of tests were conducted in this study: (i) Static tests: These included series of tests on unreinforced specimens with monotonically increasing loads in order to evaluate the ability of the test setup to successfully simulate the initiation and propagation of reflection cracking, to determine the static load bearing capacity, and to develop various failure criteria (discussed later); and (ii) Cyclic tests: These included series of cyclic/fatigue tests on both unreinforced and various geogrid reinforced specimens, conducted using a sinusoidal loading waveform at peak amplitudes of 222, 444, 888, 1110, and 1332 N (based on static test results discussed later), and at a constant frequency of 2 hz. The data acquisition included the time, load, and deformation, in addition to continuously recorded digital video for all loading cycles to failure. The continuous digital video was focused on the zone of the simulated concrete joint during the progress of the test and was recorded for visual analysis of crack propagation. Exact specifications of the test methods used are available in Sobhan and Tandon (2003).

2.5 Failure Criteria

Based on observed length of crack propagation, three failure criteria were established: (i) the load or number of cycles at which a reflective crack is first visible is called initial crack or C_{if}; (ii) the load or number of cycles it takes for the reflection crack to propagate half the overlay depth is designated as a matured crack or C_{mf}, and (iii) the load or number of cycles it takes for the crack to advance to the top of



(a) Unreinforced Overlay



(b) Geosynthetic Reinforced Overlay

Figure 2 – Progression of Reflection Cracks for (a) Unreinforced Overlay and (b) Geogrid Reinforced (Embedded at Bottom) Overlay. Note : The Numbers (1), (2), (3), (4), (5) and (6) Correspond to 0%, 20%, 40%, 60%, 80% and 100% of Fatigue Life, Respectively.

the overlay is called terminal crack or C_{tf}. These observed criteria for seven static tests conducted on the AC overlay system revealed that the average load value of C_{if} was about 1110 N. Later on, this average failure value was used as a basis for designing the load amplitudes for the cyclic test program and defining a Load Ratio (applied cyclic load divided by 1110 N) to analyze the test results. All cyclic tests were terminated upon reaching C_{tf}, cycles to terminal cracking. For this reason, certain tests ran several orders of magnitude longer depending on load ratio as well as varying rates of crack propagation. Figure 2 shows typical failed, unreinforced and bottom-embedded geosynthetic reinforced AC overlays at different stages of failure. The three failure criteria described above were defined by visual observation of the recorded experiments. Details are discussed elsewhere (Sobhan and Tandon, 2003).

3. Results and Analysis

3.1 Fatigue Behavior

Figure 3 shows the fatigue performance of various specimens with respect to the number of cycles to terminal cracking. It is observed that all specimens with embedded geogrids outperformed both the unreinforced and tacked specimens; details were discussed by Sobhan and Tandon (2003).

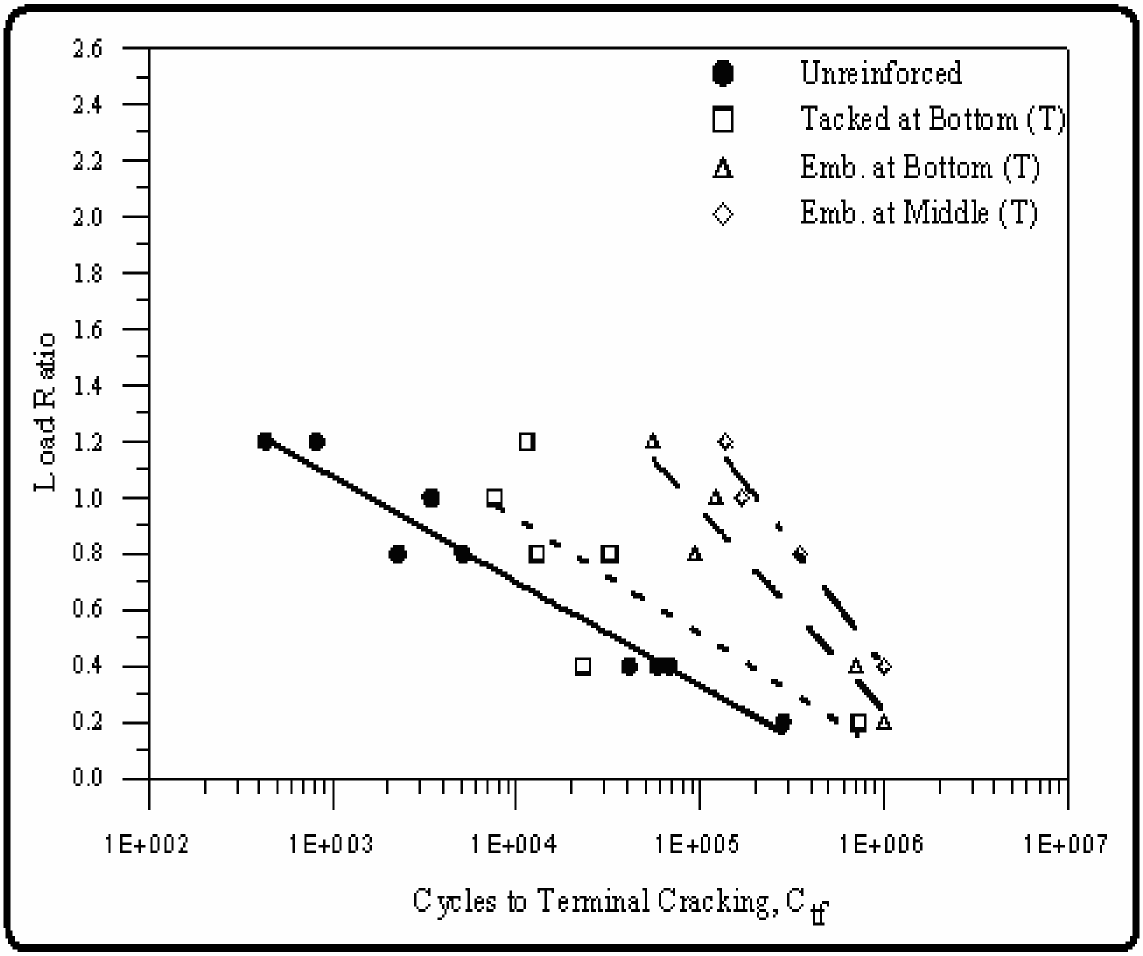


Figure 3 – Number of Cycles Sustained for Various Reinforcement Conditions and Load Ratios

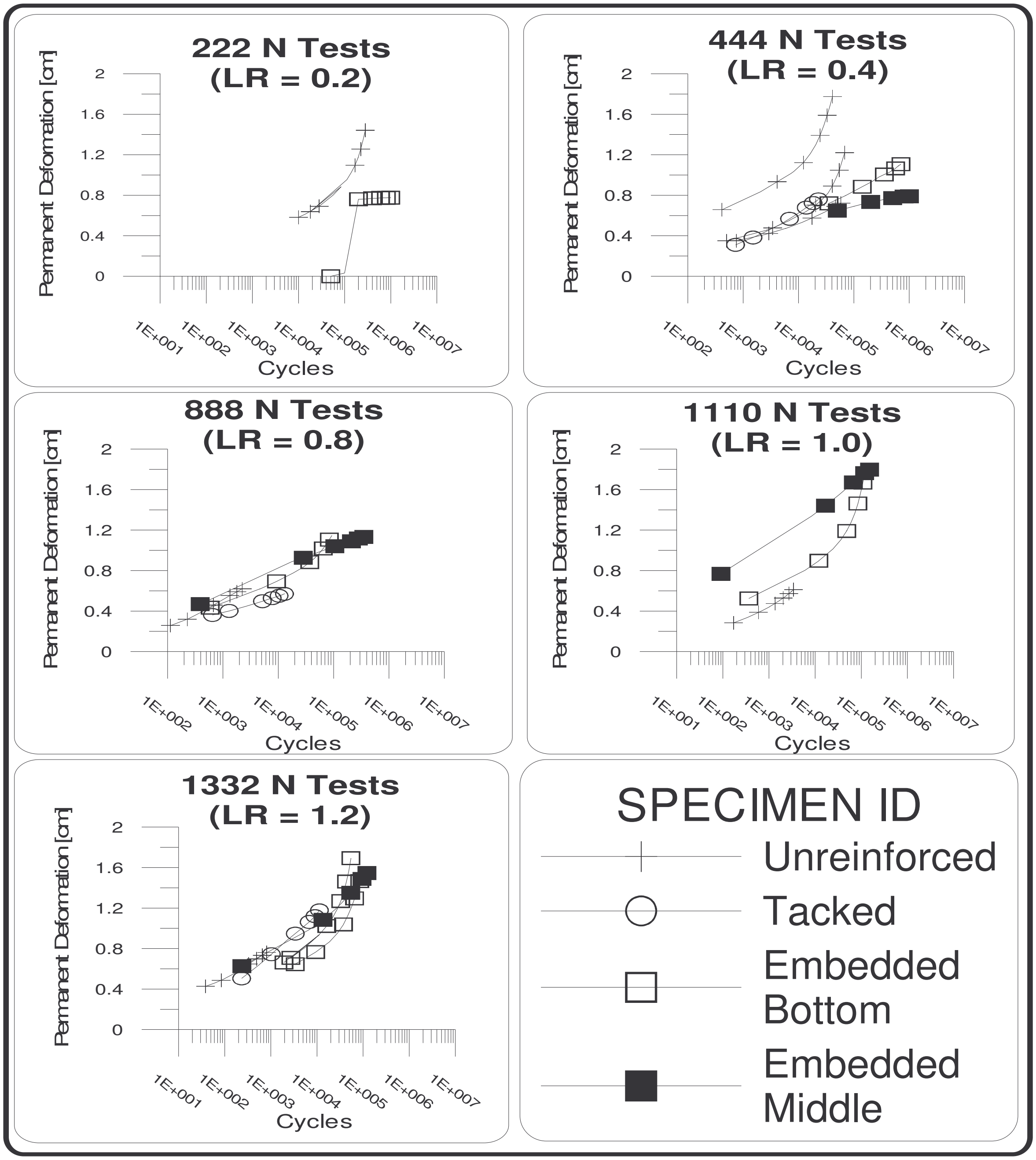


Figure 4 - Permanent Deformation Over Fatigue Life for Different Load Ratios

3.2 Analysis of Permanent Deformation

It is observed that samples with reinforcement embedded in the middle lasted longer than those embedded at the bottom while accumulating the same or less permanent deformation. Figure 4 show the variation of Permanent Deformation (PD) with loading cycles for specimens subjected to Load Ratios (LR) of 0.2, 0.4, 0.8, 1.0, and 1.2. For load ratios of 0.2 and 0.4, specimens with embedded geogrid sustained about ten times the number of cycles while accumulating as much as 40% less deformation than unreinforced samples before terminal cracking. At load ratios above 0.4, some embedded samples sustained more than twice the deformation of unreinforced specimens, however they withstood over 100 times the number of cycles before terminal cracking. The results in general indicate significant improvements for geogrid embedded samples in terms of resistance to permanent deformation.

3.3 Effects of Placement Location

Despite inherent limitations of the data collected, it can certainly be said that AC overlays with properly embedded geosynthetic reinforcement sustain significantly more cycles before terminal cracking than unreinforced samples at all load ratios. It can also be said that at load ratios of 0.4 and below, samples with embedded reinforcement not only show superior resistance to reflection cracking, but also accumulate much less permanent deformation despite the increased number of loading cycles they sustain. Specimens with reinforcement tacked at the bottom performed poorly due to the physical separation of the dislike materials, also known as debonding. We can also hypothesize that deeper embedment provides a better physical connection between the asphalt and geogrid, resulting in a superior performing composite material.

With respect to permanent deformation, it was observed that the properly embedded geosynthetic material retards the rate of PD accumulation under normal loading conditions ($LR \leq 0.4$). Samples with geogrid tacked to the bottom showed no significant increase in their resistance to rutting and only slight improvements in retarding crack propagation. All tests indicate that the geogrid must be properly embedded inside the AC layer for optimum performance.

3.4 Physical Mechanisms of Geosynthetic Interaction with AC Layers

Barksdale (1991) observed that if the reinforcement mechanism is effective, the crack first propagates upward to the reinforcing interlayer. It then moves laterally until there is no longer sufficient energy available to advance. This may indicate that cracks can only propagate past the reinforcement if the reinforcement layer fails or if it separates from the asphalt layer. Because of the elastic properties of this material and the plastic behavior of AC, embedded geogrid seems to separate from the AC layer gradually. We can see that specimens with embedded geogrid experience much slower crack propagation and last many more cycles, however there is no evidence of sudden failure or a sudden increase in the rate of crack advancement. Numerical data suggests that the geogrid gradually becomes less effective as the sample experiences advanced deterioration (Sobhan and Tandon, 2003).

A solid physical connection is needed to enable the AC layer and geogrid to behave as a composite material. It is believed that the AC layer with geogrid tacked to the bottom develops a slip plane at the layer's interface. This slip plane causes the tacked specimens to perform the same or worse than unreinforced samples. Proper embedment is required to achieve the energy absorption, elasticity, and increased life attainable with geosynthetic reinforcement.

3.5 Effectiveness of Geosynthetics

In order to quantify the beneficial effects of geogrid inclusions, a Fabric Effectiveness Factor (FEF) defined as follows:

$$FEF = \frac{c_{tf}\,(\text{reinforced})}{c_{tf}\,(\text{unreinforced})}$$

where c_{tf} is the number of cycles to terminal crack corresponding to any particular load ratio. The performance of reinforced samples compared to unreinforced overlays at various load ratios in terms of FEF is illustrated in Figure 5 on the next page.

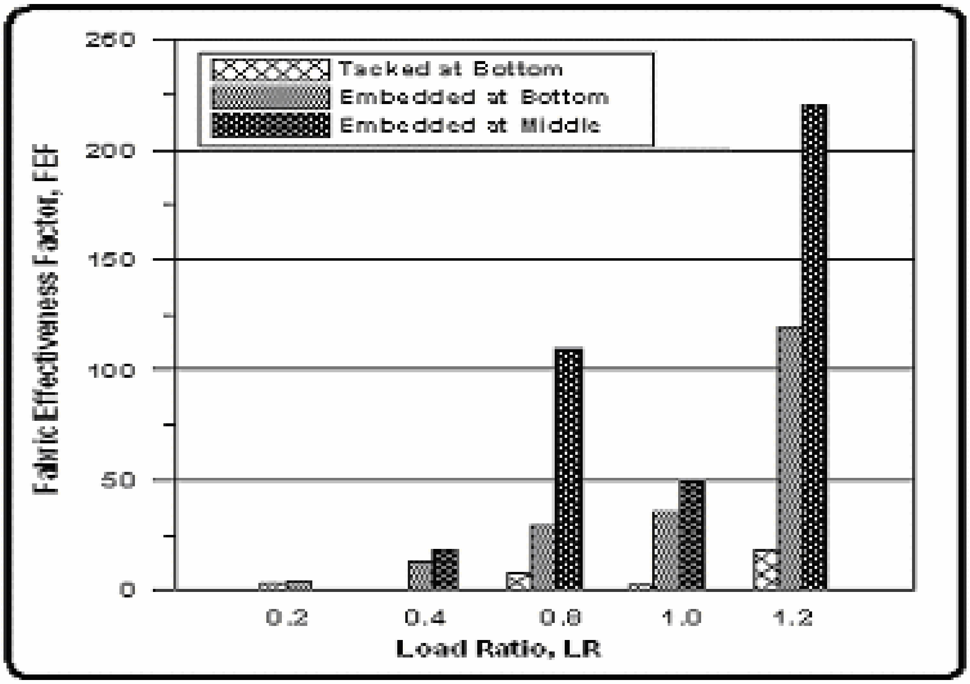


Figure 5 – Illustration of Fabric Effectiveness Factor, FEF in Terms of Fatigue Life for Different LR's and Reinforcement Conditions

With enough reliable data, a similar quantification could be made with reference to the number of cycles required to cause a specific amount of permanent deformation.

4. Conclusion

Numerical data collected from this experiment verifies that geogrid inclusion in asphalt samples leads to a significant increase in performance. Specimens with embedded geogrid outperformed non-reinforced samples both in terms of resistance to cracking as well as rutting. Although additional research is needed to fully quantify the effects of geogrid inclusions in AC overlays, evidence strongly suggests the importance of a good physical connection between the geogrid and AC layers for achieving improved performance characteristics. The poor performance of tacked samples indicates debonding of the geogrid from the AC layer as the primary failure mechanism. Based on this study, it is hypothesized that deeper embedment of geogrid within the AC layer leads to increased fatigue life in terms of crack propagation and resistance to permanent deformation. More comprehensive testing and analytical/numerical modeling is needed to better predict the field performance of geogrid reinforced AC overlays. Future tests should focus on geogrid placement methods applicable to field use.

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