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Review paper

Geosynthetics reinforced flexible pavement: review of laboratory model studies

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Abstract

Number of laboratory studies; have shown that geosynthetics reinforcement improves the performance of flexible pavement either by extending the service life or by savings in base course thickness. In spite of the good laboratory evidence for the geosynthetics reinforced flexible pavement, the mechanism that enables and governs the reinforcement function is still unclear [1]. Cyclic laboratory test has been one of the ways, used for assessing/evaluating the soil-geosynthetic interaction mechanisms. In such a tests contribution of geosynthetics properties, interface shear provided by geotextiles and interlocking provided by geogrids when used under or within the base course of flexible pavement are mainly concentrated. This paper reviews literature of laboratory model studies carried out by various researchers over the globe. This review indicates that, appreciable improvement due to geosynthetics reinforcement depends upon various factors viz. location of geosynthetics, geogrid aperture size, geosynthetics properties, mainly stiffness, variation of base course thickness and strength of subgrade soil. The findings of these laboratory studies are also correlated with the same nature of field studies finding.

Keywords: *Geosynthetics; Cyclic Loading; Reinforced Pavement; Testing Set Up; Reinforcement Mechanism.*

1. Introduction

The performance of geosynthetics reinforced flexible pavements can be carried out by using field tests, laboratory tests and numerical simulations. These three methods not only differ widely, but have also provided different perspectives on performance data [1]. Full-scale tests include field studies and accelerated pavement tests (APT), where the field test simulates actual pavement behavior, but it takes a long testing period also it could be difficult and unsafe to close lanes on in-service roads for inspection. APT can reduce the testing period but due to its large size and the associated high cost, a limited number of pavement sections can be tested for a year, This situation can very well be changed for laboratory test; because the laboratory test can reduce the testing period as well as it is cheaper than field test, and it can be performed under controlled conditions. However, for small-scale laboratory test, it has been difficult to replicate the actual behavior of the pavement system, but a large-scale laboratory testing facility can be capable of simulating the actual pavement behavior. Finally, numerical studies have been conducted to simulate both field and laboratory tests but numerical simulations are particularly suitable for parametric evaluations. The large-scale cyclic load testing facility can be used for testing pavement sections of different base materials, different subgrade conditions, different cross sections, and different loading conditions, as well as, it can be used for other pavement and geotechnical applications such as testing new materials/products, new stabilizing techniques, and new design methodologies.

2. Confined laboratory tests for geosynthetics reinforced pavement

A number of laboratory tests have been proposed by various researchers for characterizing the behavior of geosynthetics reinforcement in flexible pavements. These tests include the cyclic plate load test, cyclic triaxial test, cyclic pullout test, bending stiffness test, modified pavement analyzer test, and the pullout stiffness test [2] .The main features and relative merits of the various laboratories confined tests are summarized in Table 1. This paper focuses on studies involving laboratory-scale experiments using stationary cyclic plate loads.

2.1. Cyclic plate load test

Cyclic plate loading test has been successfully demonstrated the effect of soil confinement and dynamic loading [8].The test sections have generally consisted of laboratory reinforced, and unreinforced pavement sections constructed in a test box and were cyclically loaded to simulate construction traffic, and the performance response is assessed in terms of the magnitude of rutting with a number of loading cycles [9]. However, the facilities of cyclic plate loading tests are not readily available in public or private agencies, that need to be fabricated hence they are mainly used as a research tool in very limited universities and research institutes thus restricting the application of this test to research studies [7] .
Cyclic plate load testing facility has been developed and used worldwide for observing the performance of geosynthetics reinforced pavement, especially since from 1987 some of the recent cyclic load studies developed by various researchers with their test

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configuration and special features of the model are presented below in Table 2.

Table 1: Features of Confined Laboratory Tests [1]

Test Type	Cyclic plate load test	Cyclic triaxial test	Cyclic pullout test	Bending stiffness test	Modified asphalt pavement analyzer	Pullout Stiffness Test
Loading type	Cyclic	Cyclic	Cyclic	Cyclic	Moving wheel	Monotonic
Ease of running test	Difficult	Difficult	Moderate	Moderate	Easy	Moderate
Control section	Yes	Yes	No	Yes	Yes	No
Repeatability of test results	-	No	No	No	Yes	Yes
Ability to distinguish among various geosynthetics	-	No	No	No	Yes	Yes
Design property	TBR	M_R	G_i	BS	RRR	K_{SGI}
References	Perkins [3]	Perkins et. al [4]	Cuelho & Perkins [5]	Sprague et. al [6]	Hanet.al [7]	Gupta [8]

TBR-Traffic Benefit Ratio, M_R - Resilient modulus, G_i -Interface shear stiffness, BS -Bending stiffness, RRR- Rut reduction ratio, K_{SGI} - Coefficient of soil-geosynthetic interaction

Table 2: Specification and Features of Each Lab Set Up

Researcher (Year)	Test Box size (m)	Test box Configuration	Tire Simulation	Applied Maximum Cyclic Pressure (kPa)	Loading Frequency	Special Feature of the Model
Perkins (1999)	2.0x2.0x1.5	1) Side and back walls of 150 mm thick reinforced concrete 2) Removable front wall of steel channels	Circular plate, 300 mm ϕ	550	0.67 Hz	In order to provide uniform pressure and avoid stress concentrations along the plate's perimeter (i.e., similar to a tire load), a 6 mm thick, waffled butyl-rubber pad is placed beneath the load plate
Leng et.al (2002)	1.5x 1.5 x 1.35	Steel walls for all sides (side, back front and bottom)	Circular plate 305 mm ϕ	550	0.67Hz	The selected box size was verified by Gabr et. al. [16] based on the concept of minimizing interference from the box boundaries on the test results
Tanyu et.al (2003)	3.0 x 3.0 x 3.0	1) Concrete test pit below ground level 2) Side wooden walls above ground level up to 1.0m along the boundaries of the pit	Circular plate, 250 mm ϕ	400	1.0 Hz	Large scale model can replicate the field condition of pavement section as closely as practical by keeping the surface of the subgrade soil is nearly at the top surface of the test pit.
Bhosale S.S. et.al (2008)	0.45x0.20x0.15	Acrylics box of scale factor of 1:7.5	Pair of rectangular shaped MS pads of 55.5mm x 37.5mm	480	-	1) Failure pattern of pavement could be seen during experimentation. 2)Mechanism for simulation of anchorage of the geotextile due to surcharge of sub-base/base aggregate course over subgrade in the field
Abu Farsakh et.al (2012)	1.98x1.98x1.68	1 25.4mm thick steel side and back walls braced with stiffeners	Circular plate, 305 mm ϕ	550	0.77 Hz	The hydraulic actuator with the crosshead (loading beam) can be detached from the box and moved to the field for in-situ testing
Yu Qian et.al (2013)	2.0x2.2x2.0	Steel walls for all sides (side, back front and bottom)	Circular plate, 300 mm ϕ	550	0.77 Hz	The box is consistent with Leng et.al [10]
Sireesh Saride et.al (2015)	1.0x1.0x1.0	Steel walls for all sides (side, back front and bottom)	Circular plate, 150 mm ϕ	440	0.77 Hz	To check the boundary effects on the experimental results strain type earth pressure transducers were placed at the boundaries of the tank

3. Critical appraisal

The studies discussed in the preceding sections have provided insight into the features of cyclic plate load tests and the role of geosynthetics reinforcement mechanisms in flexible pavements. Table 3 summarizes the critical specification and features of each laboratory set up. From the Table 3.0, it is found that the test box size (pavement section) selected by various investigators, varies from 3.0m x 3.0m x 3.0m [11] to 0.45m x 0.25m x 0.15m [12]. Except Leng [10]; no other investigator provided the criteria for selection of box size. The box size may be selected as the basis of minimum interference of box boundaries. It is also noticed that the pavement sections used in most of the studies [3], [13], [14], [15] did not replicate the actual condition of unconfined asphalt layer in the majority of the field situation. Further, Table 3 shows the families of geosynthetics used by various researchers;

Table 3 indicates that, most of the researchers have given stressed only on geogrid of varying stiffness and aperture shape (biaxial or triaxial). However, the confinement effect of geogrid depends on various parameters such as rib shape, apertures size, the stiffness of the ribs, junction strength and the properties of aggregates. Except Bowman [14] no other researcher considers the effect of geogrid rib and junction strength on performance of pavement section. Furthermore, no other researcher considers the effect of base course aggregate properties (Gradation and CBR) on the reinforcement mechanism of geosynthetics.

Critical parameter observed during the test are presented in Table 4, it is found that, the most of the researchers measure the effect of geosynthetics reinforcement in terms of surface deformation and vertical stress distribution at subgrade level.

The summary of major findings from various investigators is tabulated in Table 5, which highlights the comparison between different geosynthetics type with its location effect on pavement performance. From the Table 5, it is found that most of the researchers consider the permanent deformation (Rut depth) of pavement as a performance indicator. For a given rut depth the geogrid reinforced pavement section performed better than unreinforced section, in the form of reduction of base course thickness or reduction of vertical stress distribution at subgrade level.

Table 3: Reinforcement (Geosynthetics) Used in Each Study

Researcher (Year)	Geosynthetics type	Geosynthetics type & Structure	Geosynthetics Location
Perkins (1999)	Geogrid A Geogrid B Geotextile	Punched, drawn, biaxial (Polypropylene) Punched, drawn, woven (Polypropylene)	Base-subgrade interface and 100 mm above base-subgrade interface Base-subgrade interface
Leng et.al (2002)	Geogrid Geonet with geotextile	Biaxial (Polypropylene) Nonwoven	Base-subgrade interface Base-subgrade interface
Tanyu et.al (2003)	Geocell	High-Density Polyethylene (HDPE)	Base-subgrade interface
Bhosale S.S. et.al (2008)	Geotextile	polypropylene multifilament woven	Base-subgrade interface
Abu Farsakh et.al (2012)	Geogrids	Biaxial & triaxial (polypropylene)	Base-subgrade interface Upper one third of base course and Middle of the base layer
John R. Bowman (2012)	Geogrids	Extruded biaxial and triaxial (Polypropylene)	Base-subgrade interface
Yu Qian et.al (2013)	Geogrids	Triaxial (Polypropylene)	Base-subgrade interface
Sireesh Saride et.al (2015)	Geocell	High-Density Polyethylene (HDPE)	Variable height

Table 4: Measurement of Various Parameters from Test Sections

Researcher (Year)	Surface of test Section	Base and Subbase Layers	Geosynthetics	Subgrade
Perkins (1999)	Surface deformation	Radial strain	strain	Vertical stress and strain and radial strain
Leng et.al (2002)	Surface deformation	Surface contours	None	Vertical stress, permanent deformation
Tanyu et.al (2003)	Surface deflection	None	strain	Vertical deformation
Bhosale S.S. et.al (2008)	Surface deformation	Vertical deformation	None	Vertical deformation
Abu Farsakh et.al (2012)	Surface deformation	None	strain	Vertical stress and strain
John R. Bowman (2012)	Surface deflection	Vertical displacement	strain	Vertical displacement
Yu Qian et.al (2013)	Surface deformation	None	None	Vertical stress
Sireesh Saride et.al (2015)	Surface deformation	None	None	Vertical deformation

Except, Perkins (1999) no other investigators observed the strain developed in the asphalt concrete layer.

Table 5: Summary of the Major Finding of Each Study and Comparison with Field Studies of Similar Nature

Researcher (Year)	Performance Criteria	Effect of Geosynthetics type	Effect of Geosynthetics Location	Subgrade Strength & Stiffness Characteristics	Base course layer Equivalency	Other Observations including Field studies of same nature
Perkins (1999)	Permanent surface deformation	Between the two geogrid, the stiffer one exhibited better performance. While both geogrids performed better than geotextile	Better performance was observed when the geogrid was elevated in the base (100mm up to the base layer for 300 mm thick.) as compared to subgrade-base course interface	Geogrid showed substantial improvement for pavement built over a subgrade of CBR 1.5%, while little improvement was found for strong CBR of 20%.	The reinforcement allows for at least a 20% reduction in base thickness	Reinforced test sections having a 300 mm-thick base with an unreinforced test section having a 375 mm-thick base showed better performance. A.V.S.R. Murty et.al [17] carried out a field performance study of geotextile reinforced low volume road from December 1988 to February 1992. The performance study shows that, geotextile reinforced road are having lesser distresses as compared to control section. The type /variety of geotextile is not having any significance on performance
Leng et.al (2002)	Vertical surface deformation	Higher modulus geogrids provided a better stress attenuation effect compared to lower modulus geogrids	NA	NA	NA	The stress distribution at subgrade level is lesser for higher thickness (245mm) of base course as compared to lower thickness (152mm). Al-Qadi I.L.et.al [18] in their eight year field performance studies observed same kind of results, that the geosyntheics stabilized pavement extends the service life. However this increase in service life is reduced for stronger pavements (Higher base thickness)

Tanyu et.al (2003)	Rut depth	The difference in geocell geometry (diameter and cell height) did not show any significant differences in rutting behavior.	NA	NA	Geocell reinforcement effect was more evident in thinner (225 mm) sections than in thicker (450 mm)	The presence of geocells improved the resilient modulus by 40 to 50% in both 225 mm and 450 mm thick sections.
Bhosale S.S. et.al (2008)	Rut depth	Membrane effect of geotextile will be mobilized lesser and lesser for the geotextile of lower grab/tensile strength	NA	NA	NA	The higher the stiffness of the geotextile with assured interface friction the better will be the triggering up of membrane action at an early stage of deformation
Abu Farsakh et.al (2012)	Permanent deformation	Traffic Benefit Ratio(TBR) increased from 5.5 for the biaxial geogrid to 6.4 for the triaxial geogrid at 19mm rut depth)	Better performance was observed when the geogrid was placed within the upper one third of the base aggregate layer as compared to the base-subgrade interface or at the middle of the base	The geogrid can significantly reduce the rut depth and extend the service life of pavement sections which built on weak subgrades (CBR $\leq$ 1%)	NA	The construction method can have a significant effect on mobilizing the interaction between the geogrid and base course aggregates
John R. Bowman (2012)	Rut depth	The extruded geogrid performed consistently better than the non-extruded geogrids	NA	NA	NA	Largest tensile strains developed directly beneath the center of the cyclic loading plate and became negligible at a 1.5 D distance from the loading plate
Yu Qian et.al (2013)	Permanent deformation	The permanent deformation for heavy-duty geogrid, was lesser as compared to medium and light duty geogrid	NA	NA	The stress distribution angle increased with the increase of the base thickness.	Andrus Aavik et. al [19] carried out a field performance study from 2009-2013 for geosynthetic Reinforced road constructed in swampy area in Estonia. The performances of field trials were measured in the form of International Roughness Index (IRI). The IRI values for geosynthetics sections are in average about 6.4 % bigger than IRI values of sections without geosynthetics.
Sireesh Saride et.al (2015)	Permanent deformation	A TBR of as high as 23 was observed for h/D = 1.0 and b/D = 4.33	NA	NA	NA	Avinash Unni [21] carried out a field performance study of geocell pavement at Govind Dairy Farm in Phaltan, India.

4. Concluding remark and issue to be addressed

1) Most of the above laboratory model studies have shown that appreciable reduction in surface deformation can be realized by keeping geosynthetics within the upper one third of the base course aggregate layer of a flexible pavement. This reduction was found to increase with stiffness of geogrid. It was also observed that geogrids performed better than geotextile.
2) The test box (pavement section) size varies from 3.0m x 3.0m x 3.0m [11] to 0.45m x 0.25m x 0.15m [12] where the pavement sections are confined in a box, have a scaling effect. Application of results of small scale laboratory simulation to the field condition found to have limitations.
3) Majority of the studies [3], [13], [14], [15] simulated a half axle load of 40 kN, while mobilization of geosynthetics reinforcement mechanism under the half axle load may differ as compared to the full scale standard axle load on field.
4) Most of the researchers considers the influence of geosynthetics properties mainly geogrid aperture size and stiffness on reinforced mechanism, but in practice other parameter such as geogrid rib strength, junction strength etc. will also contribute for reinforcement mechanism.

The following areas have been identified, through the re-viewed literature that needs further studies

1) Development of full scale laboratory test for which pavement section can simulate the field condition by constructing the unconfined asphalt layer and is to be tested under standard axle load.
2) The combined effect of geogrid rib strength, junction strength and base course aggregate properties on reinforcement mechanism using full scale model, needs to be studied.

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