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Enhancing Pavement Layer Stability with Bi-axial Geogrid: A Dual Approach Through Lab and Field Evaluation

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ABSTRACT

As on date 31st December 2024 the total completed road length in India is 6.6 milion Kms, which is second largest globally. Due to this a large amount of investment is made every year in the road network and by utilizing new technologies we can get more better results and can make some contribution in the growth of the road network. During rainy season rutting, pot holes and cracks are developed in India. These things most probably occur due to insufficient CBR of soil which is settled during rainy season. So firstly it is most important to use the soil in embankment and subgrade layer which CBR is 10% or more than that. So that bearing capacity of soil is increased in water saturated condition. If the bearing capacity of soil is increased we can use new technology like use of Bi-axial geogrid in flexible pavement design.The use of bi-axial geogrid in flexible pavement construction has gained a significant attention for improving the stability and performance of pavement layers which include subgrade, granular subbase (GSB) and wet mix macadam (WMM).The stability and performance of pavement structures are critical for the longevity and safety of roadways. This study investigates the effect of incorporating bi-axial geogrid reinforcement on the stability and mechanical behavior of pavement layers.Looking at the poor road condition of some states of India use of bi-axial geogrid is thought for road construction to improve the performance of the road. The addition of bi-axial geogrid in subgrade and granular sub-base layer can increase the bearing capacity of the subgrade and granular sub-base layer. As a result it can also reduce the total thickness of the pavement layer upto 40%. This study will have a positive impact on cost as it will reduced the total project cost as well as maintenance cost of the road. A comprehensive approach, integrating both laboratory testing and field evaluations, was adopted to assess improvements in load-bearing capacity, rut resistance, and overall structural integrity. Laboratory experiments included California Bearing Ratio (CBR), compaction testing and field trials were conducted on test sections with and without geogrid reinforcement to validate laboratory findings under actual traffic loads and environmental conditions. Results demonstrated that the inclusion of bi-axial geogrid significantly enhanced the performance of the pavement layers, reducing deformation and extending service life.

Keywords: Bi-axial geogrid, Resilient modulus, Subgrade, Reinforced GSB, Reinforced WMM

1. Introduction

In recent times, one of the primary challenges faced by highway engineers in the plains and rolling terrains of India is the presence of unsuitable or weak soil at the natural ground level. Constructing roads over such loose subgrade often necessitates the use of thicker layers of granular material to meet design requirements, immensely increasing the overall cost of construction. Attempts to reduce pavement thickness to lower costs often compromise structural integrity, leading to early pavement failure. Such premature deterioration renders the road unusable shortly after its completion. These issues are further exacerbated by inadequate or non-existent drainage, a common problem in several high-rainfall regions of India. Many states facing heavy monsoon conditions suffer from both poor drainage and weak subgrade soils, contributing significantly to the widespread occurrence of severely damaged road infrastructure. Given these challenges, the incorporation of bi-axial geogrids in road construction emerges as a viable and cost-effective solution to enhance pavement performance. Bi-axial geogrids, a type of geosynthetic product made from polymers, are specifically designed to improve the structural capacity of pavement systems.Within a pavement structure, bi-axial geogrids primarily serve two functions: reinforcement and, to a lesser extent and separation. However, this separation function is considered secondary and is typically outside the scope of standard specifications for pavement materials.

2. Literature Review

A study by Sharbaf and Ghafoori (2021): The performance of flexible pavement reinforced with two types of punched and drawn geogrids in thickness of base course and sub-base course. Six laboratory tests were conducted using a cylindrical steel mould. Instrumentation included pressure cells positioned at multiple locations within the test sections, along with a LVDT placed at top of the system. A hydraulic actuator applied a cyclic load of 40 kN (9 kips) through a 305 mm (12 in) diameter circular steel plate at a frequency of 0.77 Hz. The results demonstrated that incorporating either geogrid type into the pavement structure effectively reduced surface rutting and vertical stresses at the subgrade–base interface. Based on rutting depth measurements, geogrid reinforcement increases the number of load applications by a factor ranging from 1.5 to 7.5, depending on the test section characteristics, geogrid type, and the rutting observed at different loading intervals. Additionally, vertical stress data indicated that geogrid inclusion in strong soil conditions enabled a base course thickness reduction of approximately 7%.

A study by Tiwari and Satyam (2022) Rapid infrastructure development often faces challenges due to loose, expansive subgrades, which hinder construction. Various methods have been developed to control their swelling-shrinkage behavior, with mechanical stabilization using polypropylene fibers and geogrids proving to be sustainable solutions. While both have been individually used to enhance subgrade strength, this study evaluates their combined effect. Unconfined compressive strength (UCS) and large direct shear tests were conducted to assess the interaction between expansive soil, polypropylene fibers (12 mm length at 0.25%, 0.5%, and 1.0%), and a single layer of biaxial or triaxial geogrid placed at mid-depth. Results showed a 177% increase in shear strength and a 3.8–139.6% increase in UCS with combined reinforcement. This approach demonstrates an effective method for improving the strength and stability of expansive subgrades.

A study by Baadiga and Balunaini (2023): Geogrid reinforcement is increasingly favored over conventional stabilization methods for flexible pavement layers due to its cost-effectiveness and improved performance. However, limited experimental data on design input parameters, such as the modulus improvement factor (MIF) and layer coefficient ratio (LCR), has hindered its broader application. This study aimed to evaluate MIF and LCR for geogrid-stabilized soft subgrades under various conditions. Stabilization scenarios included: (a) subgrade only, (b) base only, and (c) subgrade, subbase, and base layers. Eighteen large-scale model pavement experiments (LSMPE) were conducted across five series (Series I–V), using biaxial (BX1, BX2) and triaxial (TX1) geogrids over subgrades with California Bearing Ratios (CBR) of 2.5% and 4%. Results showed that geogrid-stabilized subgrades increased effective CBR values from 7% to as high as 10.9%. MIF and LCR values for geogrid-reinforced granular layers ranged from 1.9–2.8 and 1.31–1.63, respectively. The study provides recommended resilient modulus values for similar reinforcement and subgrade conditions.

3. Work implementation on laboratory and field

3.1 CBR Testing of Subgrade

Subgrade material samples were collected and tested using by the soaked CBR method (Figure 1), yielding a result of 13.62%, which exceeds the required design value of 10% for flexible pavement. This confirms the material's suitability for use in the subgrade layer.

Figure 1: CBR Testing

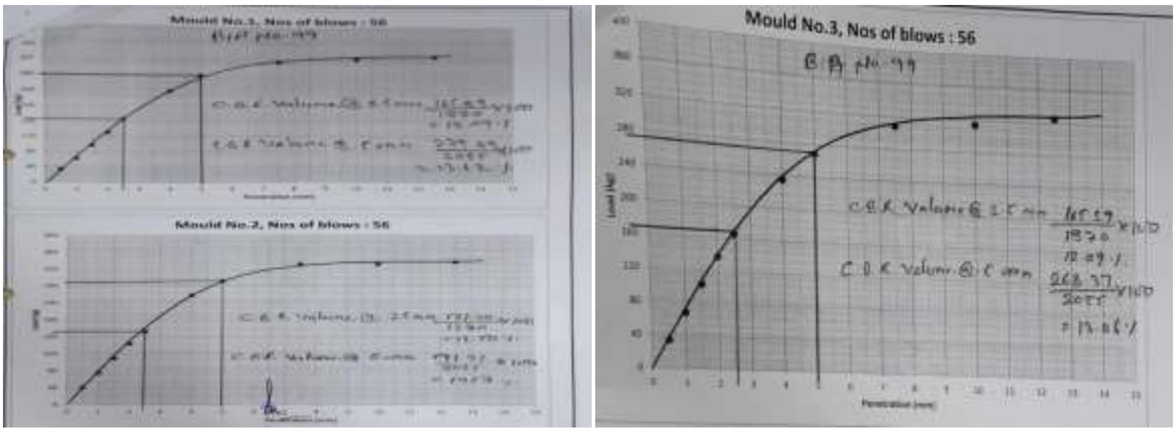

Figure 2 Figure 3

CBR Testing Graph

3.2 Resilient Modulus of Subgrade

Samples of compacted subgrade material were collected from the field for laboratory testing of the subgrade's resilient modulus. The achieved resilient modulus of subgrade layer at site is 96 MPa (Figure 4) which is greater than the required resilient modulus of subgrade layer i.e 77 Mpa.

Table 1 - Resilient Modulus Test Results

S. No.	Mix Type	No of Samples Tested	Test Result (MPa)		Limit As per IRC (MPa)
			Individual	Average	
1	Subgrade	03	96	96	Min. 77
2			95		
3			98		

—End of Report—

Figure 4: Resiliient Modulus of Subgrade

3.3 Fixing of Bi-axial geogrid over Subgrade and GSB Top layer

The bi-axial geogrid was placed and secured over the top layer of the subgrade, with careful measurement of the spacing between adjacent geogrids—300 mm in the longitudinal direction and 600 mm in the transverse direction (Figure 5).

Figure 5: Fixing of Bi-axial Geogrid Over Subgrade Top Layer

The bi-axial geogrid was placed and secured over the top layer of the Granular sub-base, with careful measurement of the spacing between adjacent geogrids—300 mm in the longitudinal direction and 600 mm in the transverse direction (Figure 6).

Figure 6: Fixing of Bi-axial Geogrid Over GSB Top Layer

3.4 Resilient modulus of GSB (with and without inclusion of Bi-axial Geogrid)

- **Resilient Modulus of GSB without inclusion of Bi-axial Geogrid**

Resilient modulus of reinforced GSB will be calculated by using the value of resilient modulus of subgrade, which has achieved from overhead testing.

As per clause no.7.2.3 of IRC 37-2018, the resilient modulus of unreinforced GSB layer shall be calculated using the equation as below:

$MR_{UNGSB} = 0.2 \text{ x } (hGSB)^{0.45} \text{ x} M_{RS}$

where,

MR_{UNGSB} = Resilient Modulus of Unreinforced GSB Layer (MPa)

M_{RS} = Resilient Modulus of Subgrade (MPa) achieved from site

h_{GSB} = Thickness of GSB Layer

for,

M_{RS} = 96 MPa

h_{GSB} = 200 mm

MR_{UNGSB} = $0.2\text{x } (200)^{0.45}\text{x } 96$ MPa = 208 MPa

- **Resilient Modulus of GSB with inclusion of Bi-axial Geogrid**

As per clause no 3.1.2.3 of IRC SP 59-2019, the improved modulus of reinforced GSB shall be calculated using following equation:

$a_3 = 0.227 \,(\log_{10} MRUNGSB) — 0.839$

Where,

a3 = Structural Layer Coefficient of unreinforced GSB layer

UN_{GSB} = Resilient Modulus of Unreinforced GSB (psi) {1MPa = 145.038psi}

for,

MR_{UNGSB} = 208 MPa = 30168 psi

a_3 = 0.227 x (log10 (30168)) — 0.839 = 0.1778

Now including Bi-axial Geogrid reinforcement into GSB layer, the improved modulus of reinforced GSB layer shall be calculated as:

$LCR_3 \times a_3 = 0.227 \times (\log_{10} \times MR_{REGSB}) — 0.839$

Where,

LCR_3 = Layer Coefficient Ratio of Bi-axial Geogrid

MR_{REGSB} = Resilient Modulus of reinforced GSB Layer (MPa)

for,

LCR_3 = 1.32

a_3 = 0.1778

MR_{REGSB} = $(10^{(((1.32 \times 0.1778) + 0.839)/0.227)})$ /145.038 = **370 MPa**

The achieved resilient modulus of unreinforced GSB layer at site is 208 MPa and unreinforced GSB is 370 MPa, which is greater than the resilient modulus of unreinforced GSB layer.

3.5 Resilient modulus of WMM (with and without inclusion of Bi-axial Geogrid)

- **Resilient Modulus of WMM without inclusion of Bi-axial Geogrid**

As per clause no. 7.2.3 of IRC 37 – 2018 the resilient modulus of unreinforced WMM layer shall be calculated using the equation as below:

MR_{UNWMM} = $0.2 \times (h_{WMM})^{0.45} \times M_{RSUPPORT}$

Where,

MR_{UNWMM} = Resilient Modulus of Unreinforced WMM layer (MPa)

$M_{RSUPPORT}$ = Resilient Modulus of Support Layer (MPa)

= Effective Modulus of Reinforced GSB and Subgrade

h_{WMM} = Thickness of WMM Layer (mm)

for,

$M_{RSUPPORT}$ = 186 MPa

H_{WMM} = 200 mm

MR_{UNWMM} = $0.2 \times (200)^{0.45} \times 186$ MPa = **403 MPa**

- **Resilient Modulus of WMM without inclusion of Bi-axial Geogrid**

As per clause no. 3.1.2.3 of IRC SP 59 – 2019, the improved resilient modulus of reinforced WMM layer shall be calculated using the equation as below:

a_2 = $0.249 \times (\log_{10} MR_{UNWMM}) - 0.977$

where,

a_2 = Structural Layer Coefficient of Unreinforced WMM Layer

MR_{UNWMM} = Resilient Modulus of Unreinforced WMM layer (MPa) {1 MPa = 145.038psi}

for,

MR_{UNWMM} = 403 MPa = 58450 psi

a_2 = $0.249 \times (\log_{10} 58450) - 0.977 = 0.2099$

Now including Bi-axial geogrid reinforcement into WMM layer, the improved resilient modulus of reinforced WMM layer shall be calculated as:

$LCR_2 \times a_2$ = $0.249 \times (\log_{10} MR_{REWMM}) - 0.977$

where,

LCR_2 = Layer Coefficient Ratio of Bi-axial geogrid

MR_{REWMM} = Resilient Modulus of Reinforced WMM Layer (MPa) for,

LCR_2 = 1.32

a_2 = 0.2099

$$\mathbf{MR_{REWMM}} = (10^{(((1.32 \times 0.2099) + 0.977) / 0.249)}) / 145.038 = \mathbf{749\ MPa}$$

The achieved resilient modulus of unreinforced WMM layer from site is 403 MPa and unreinforced WMM is 749 MPa, which is greater than the resilient modulus of unreinforced WMM layer.

4. Challenges and Future Directions

Future research on bi-axial geogrid reinforcement in pavements should focus on optimizing placement depth within pavement layers to maximize reinforcement benefits and evaluating the effectiveness of multiple layers for improved load distribution. Long-term performance and durability studies are essential to assess the effects of traffic loads, environmental conditions, and material degradation over time. Advancements in material science should aim to develop bi-axial geogrids with enhanced tensile strength and durability, while exploring hybrid reinforcement methods by combining them with geotextiles or chemical additives. Sustainability efforts should include evaluating the environmental benefits, carbon footprint reduction, and recyclability of geogrid materials. Additionally, performance under extreme conditions—such as heavy rainfall, freeze-thaw cycles, high temperatures, and seismic activity—should be investigated to ensure resilience and reliability of bi-axial geogrid-reinforced pavements..

5. Conclusion

Laboratory and field tests on the subgrade showed a California Bearing Ratio (CBR) of 13.62%, exceeding the design value of 10%, with compaction and resilient modulus results of 97.89% and 96 MPa, both higher than the design targets of 97% and 77 MPa, respectively. For the Granular Sub-Base (GSB), resilient modulus was evaluated both with and without a bi-axial geogrid (200 mm and 300 mm thickness, respectively), and the reinforced GSB showed improved performance, with a tested resilient modulus of 370 MPa and compaction of 98.86%, surpassing the design values of 277 MPa and 98%. Similarly, for the Wet Mix Macadam (WMM), geogrid reinforcement led to better results, with a resilient modulus of 749 MPa and compaction of 98.65%, exceeding the respective design values of 521 MPa and 98%. Overall, the incorporation of bi-axial geogrid in flexible pavement construction significantly enhances the overall performance, durability and cost effectiveness of the pavement structure by reducing the thickness of sub-base and base course of the pavement layer. Bi-axial geogrids improve load distribution, reduce rutting and enhance the bearing capacity of the subgrade by reinforcing the sub-base and base layers. This reinforcement minimizes differential settlement, extends pavement life period and reduces maintenance costs.

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