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Performance of Flexible Pavement Using Biaxial Geogrids: A Mechanistic Approach Using IITPAVE Software

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Abstract: ***Flexible pavements under heavy traffic must control fatigue cracking in the bituminous layer and permanent deformation in the subgrade. This study examines whether biaxial geogrid reinforcement can reduce pavement thickness for a design traffic of 175 million standard axles (msa), 9% subgrade CBR and 90% reliability.The biaxial geogrids were considered at the Base/WMM–GSB and GSB–Subgrade interfaces. A conventional section was first selected using IRC:37-2018 and checked in IITPAVE. Two reinforced alternatives were then prepared. In the Layer Coefficient Ratio (LCR) method, geogrid benefit was applied to the granular layer coefficients following the adopted design approach. In the Modulus Improvement Factor (MIF) method, the same numerical factors were applied to resilient modulus for comparison. AASHTO relationships were used to connect resilient modulus and structural layer coefficient, and IITPAVE was used to check tangential tensile strain at the bottom of the bituminous layer and vertical compressive strain at the top of the subgrade. The final unreinforced pavement was 630 mm thick. The LCR section was 480 mm thick, saving 150 mm, while the MIF section was 555 mm thick, saving 75 mm. All three final sections satisfied the adopted fatigue and rutting limits. The study shows that biaxial geogrid can reduce granular material demand, but the calculated saving depends on how reinforcement is represented in design.***

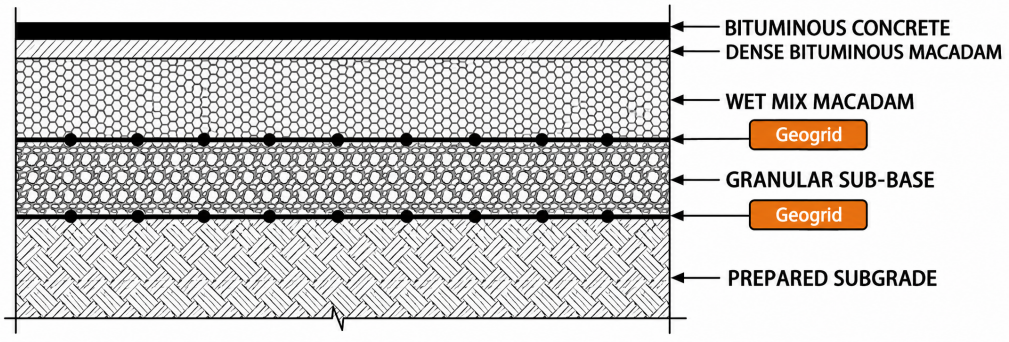
Keywords: Flexible pavement; biaxial geogrid; IITPAVE; LCR; MIF; resilient modulus; mechanistic-empirical design

I. INTRODUCTION

Flexible pavement carries wheel loads through bituminous, base and sub-base layers before the load reaches the subgrade. Repeated traffic produces tensile strain near the bottom of the bituminous layer and compressive strain near the top of the subgrade. If these responses are too high, fatigue cracking and rutting may develop. IRC:37-2018 therefore uses a mechanistic-empirical procedure in which a trial pavement is checked for critical strains rather than accepted only from a catalogue [1]. IITPAVE provides the layered-elastic response used for this check [4].

High traffic volumes usually require substantial granular thickness. Good-quality aggregate may be costly or difficult to obtain, so reducing unnecessary granular material can improve economy and construction efficiency. Biaxial geogrids are used to reinforce granular layers because aggregate particles interlock with the grid apertures. This interaction restrains lateral movement, improves confinement and can increase the effective structural contribution of the base or sub-base [2,5].

The amount of improvement is not constant for every pavement. It depends on subgrade strength, aggregate quality, geogrid stiffness and aperture geometry, reinforcement location and layer thickness. For this reason, design methods use factors such as Layer Coefficient Ratio (LCR) or Modulus Improvement Factor (MIF) instead of assuming one universal benefit [2,5].



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This paper compares one unreinforced section with two reinforced sections under the same design condition: 175 msa traffic, 9% CBR and 90% reliability. The LCR method increases the structural layer coefficient, whereas the MIF method increases resilient modulus. Because the AASHTO modulus-coefficient relation is logarithmic, the two methods do not give the same structural gain even when the same numerical factor is used [3].

The objective is to compare pavement thickness, fatigue response and rutting response for the three cases and to show the effect of the reinforcement representation. The work is analytical; no project-specific laboratory test of geogrid tensile strength or full-scale field trial was carried out. Final acceptance is therefore based on IITPAVE response checks, while the adopted geogrid factors are treated as design inputs that should be confirmed by product-specific evidence before field use.

II. RESEARCH DESIGN AND METHODOLOGY

The same traffic, subgrade and material properties were used for all pavement sections. The conventional IRC section was first checked in IITPAVE for fatigue and rutting. Geogrid reinforcement was then evaluated using the LCR and MIF methods, with reduced granular thickness estimated from Structural Number equivalency. The final sections were compared based on thickness, strain response and overall thickness saving..

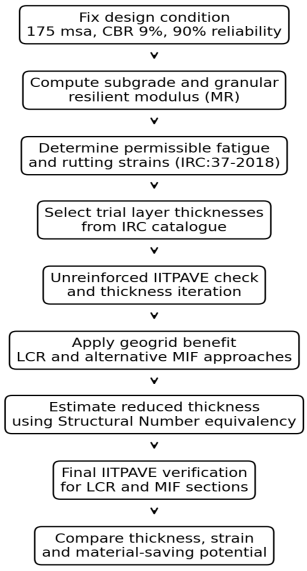


Figure 1. Research methodology adopted for the unreinforced, LCR-reinforced and MIF-reinforced pavement analyses.

III. MATERIALS AND FIXED DESIGN PARAMETERS

The pavement model has four layers: a combined bituminous layer (BC and DBM), WMM base, GSB and subgrade. VG 40 bitumen is considered, with a bituminous resilient modulus of 3000 MPa. The subgrade CBR is 9%, corresponding to a resilient modulus of 71.82 MPa in the adopted calculation. The same loading and reliability values were maintained in all three cases so that only the reinforcement representation and resulting thicknesses changed.

Parameter	Adopted value	Purpose in design
Design traffic	175 msa	Permissible fatigue and rutting response
Subgrade CBR	9%	Subgrade strength
Reliability	90%	IRC performance criterion
Bituminous resilient modulus	3000 MPa	Layered-elastic input
Bitumen grade	VG 40	Bituminous material specification
Wheel load	20,000 N	IITPAVE loading
Tyre pressure	0.56 MPa	Contact pressure
Wheel configuration	Dual wheel	Traffic loading representation

Poisson's ratio	0.35 for all layers	Elastic analysis
Base geogrid factor	1.40	LCR / MIF comparison
Sub-base geogrid factor	1.61	LCR / MIF comparison

Table 1. Fixed design parameters used throughout the study.

IV. MATERIAL PROPERTIES AND ENGINEERING ROLE OF THE BIAXIAL GEOGRID

The reinforcement considered in this study is a biaxial polymer geogrid. Its ribs act in two principal directions and its open apertures allow aggregate particles to interlock with the grid. Under repeated wheel loading, this interaction can limit lateral spreading of aggregate and improve confinement. In design, the benefit is represented as an increase in structural layer coefficient or resilient modulus rather than as a new pavement layer [2,5].

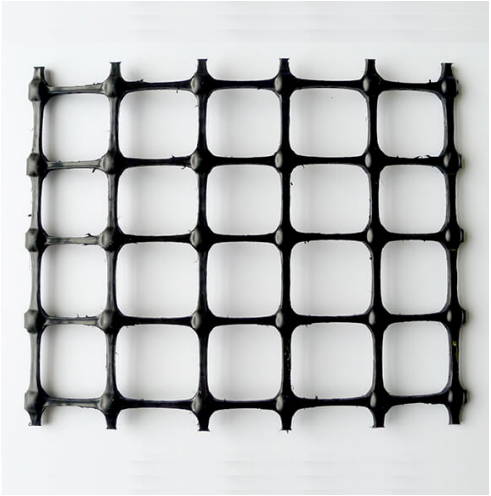


Figure 2. Typical biaxial geogrid form used to illustrate the reinforcement concept in the project report.

The project did not include laboratory measurement of tensile strength, junction efficiency, aperture size or polymer grade for a particular commercial geogrid. These values are therefore not invented here. The adopted reinforcement factors are 1.40 for the base and 1.61 for the sub-base. In the LCR method they act on layer coefficient; in the comparison MIF method the same numerical factors act on resilient modulus. Product-specific properties and certified improvement factors should be checked before construction.

Geogrid-related property	Treatment in this study	Design implication
Geogrid type	Biaxial polymer grid	Reinforcement in two principal directions
Primary mechanism	Aggregate interlock and lateral restraint	Improved confinement and load distribution
Base reinforcement factor	1.40	40% increase applied to layer coefficient in LCR method
Sub-base reinforcement factor	1.61	61% increase applied to layer coefficient in LCR method
Alternative MIF factors	1.40 and 1.61	Applied directly to MR for comparative analysis
Product tensile strength / aperture	Not independently measured	Requires product-specific verification before field application
Placement considered	Granular pavement system	Reinforcement effect represented in base and sub-base design

Table 2. Geogrid properties and design representation used in the present analytical study.

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V. IITPAVE SOFTWARE AND LAYERED-ELASTIC ANALYSIS

IITPAVE was used for the final mechanistic check. It models the pavement as elastic layers defined by thickness, resilient modulus and Poisson's ratio. The present model uses bituminous, WMM, GSB and subgrade layers. A 20,000 N wheel load, 0.56 MPa tyre pressure, dual-wheel loading and Poisson's ratio of 0.35 were used in all cases.

The program reports stresses, strains and displacement at selected depths and radial positions. Two outputs control the design: tangential tensile strain (epT) at the bottom of the bituminous layer for fatigue, and vertical compressive strain (epZ) at the top of the subgrade for rutting. The bituminous response was checked at radial distances of 0 and 155 mm, and the larger magnitude was used for comparison with the permissible limit [1,4].

VI. IITPAVE INPUTS AND OUTPUTS

The loading inputs were kept unchanged for the unreinforced, LCR and MIF sections. Only the layer thicknesses and granular moduli required by each design were changed. The input and output screens below are retained because they show the actual IITPAVE values used for final verification.

A. Common IITPAVE Input Parameters

Input	Unreinforced	LCR reinforced	MIF reinforced
Number of layers	4	4	4
Bituminous MR (MPa)	3000	3000	3000
Base MR (MPa)	374	789	523.6
Sub-base MR (MPa)	156	393	250.9
Subgrade MR (MPa)	71.82	71.82	71.82
Bituminous thickness (mm)	180	170	170
Base thickness (mm)	250	170	214
Sub-base thickness (mm)	200	140	171
Wheel load (N)	20,000	20,000	20,000
Tyre pressure (MPa)	0.56	0.56	0.56
Poisson ratio	0.35	0.35	0.35
Wheel set	Dual	Dual	Dual
Fatigue check depth (mm)	180	170	170
Rutting check depth (mm)	630	480	555

Table 3. Final IITPAVE input values for the three pavement sections.

B. Unreinforced Pavement: IITPAVE Input and Output

The unreinforced section contains 180 mm bituminous material, 250 mm WMM and 200 mm GSB, for a total thickness of 630 mm. The base and sub-base moduli are 374 MPa and 156 MPa. IITPAVE checks were made at the bottom of the bituminous layer and at the top of the subgrade.

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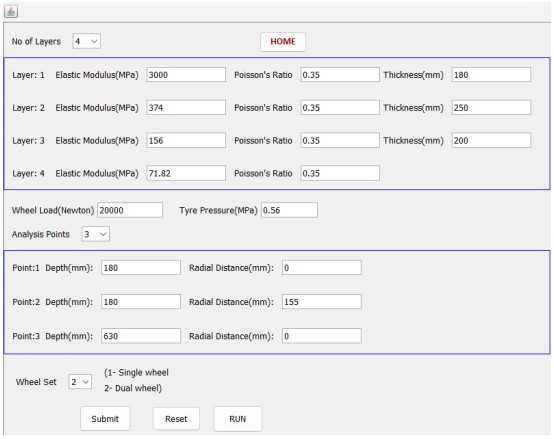


Figure 3. IITPAVE input screen for the final unreinforced pavement section.

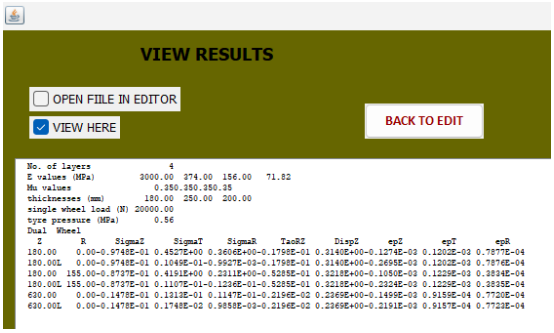


Figure 4. IITPAVE output screen for the final unreinforced pavement section.

The governing fatigue strain is 120.2 x 10^-6 and the rutting strain is 219.1 x 10^-6. Both are below the adopted limits of 124.62 x 10^-6 and 281.96 x 10^-6, so the final conventional section is acceptable.

C. LCR-Reinforced Pavement: IITPAVE Input and Output

For the LCR design, the base and sub-base coefficients increase from 0.202 and 0.149 to 0.283 and 0.240. Back-calculation gives equivalent resilient moduli of 789 MPa and 393 MPa. Structural Number equivalency was used to choose a reduced trial section, which was then checked in IITPAVE.

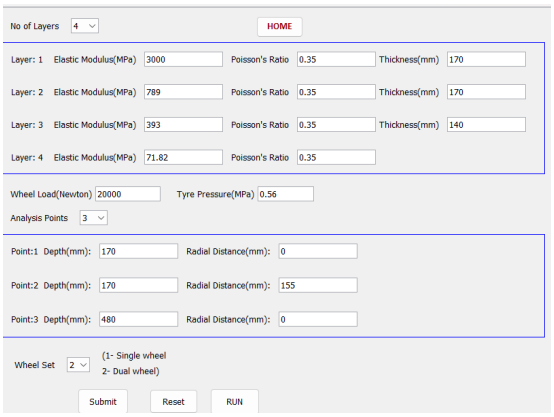


Figure 5. IITPAVE input screen for the final LCR-reinforced pavement section.

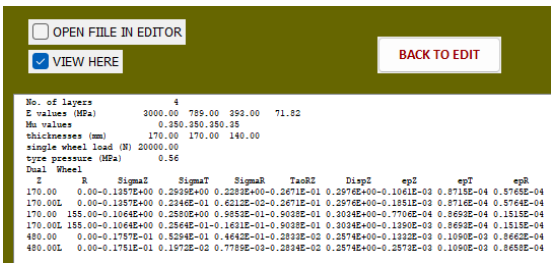


Figure 6. IITPAVE output screen for the final LCR-reinforced pavement section.

The final LCR section is 170 mm bituminous, 170 mm base and 140 mm sub-base, giving 480 mm total thickness. The fatigue strain is 87.15 x 10^-6 and the rutting strain is 257.3 x 10^-6. Both remain below the permissible limits.

D. MIF-Reinforced Pavement: IITPAVE Input and Output

For the MIF alternative, the same nominal factors are applied directly to the unreinforced granular moduli. The base modulus becomes 523.6 MPa and the sub-base modulus becomes 250.9 MPa. Structural Number equivalency gives a final trial section of 170 mm bituminous, 214 mm base and 171 mm sub-base, or 555 mm total thickness.

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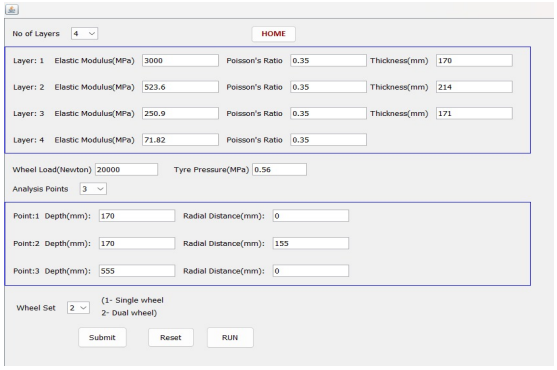


Figure 7. IITPAVE input screen for the final MIF-reinforced pavement section.

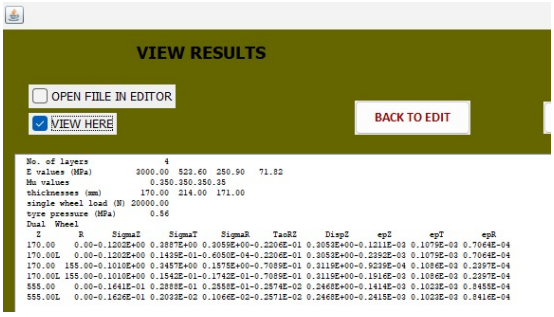


Figure 8. IITPAVE output screen for the final MIF-reinforced pavement section.

The MIF section gives a fatigue strain of 107.9 x 10^-6 and a rutting strain of 241.5 x 10^-6. Both satisfy the adopted limits. The thickness saving is 75 mm compared with the unreinforced section.

VII. RESULTS AND DISCUSSION

The final results confirm that all three pavement alternatives are safe for the adopted 175 msa design traffic and 9% subgrade CBR. However, the layer thicknesses and safety margins differ significantly. The conventional section is the thickest at 630 mm. Geogrid reinforcement reduces the thickness to 480 mm using LCR and to 555 mm using MIF. The LCR method produces the greatest reduction because the reinforcement factor is applied directly to the structural coefficient. In the MIF method the same factor is first applied to resilient modulus, and the logarithmic coefficient relation reduces the proportional gain when the modulus is converted back to a structural coefficient.

Parameter	Unreinforced	LCR reinforced	MIF reinforced
Bituminous thickness (mm)	180	170	170
Base thickness (mm)	250	170	214
Sub-base thickness (mm)	200	140	171
Total thickness (mm)	630	480	555
Base MR (MPa)	374	789	523.6
Sub-base MR (MPa)	156	393	250.9
Base structural coefficient	0.202	0.283	0.238
Sub-base structural coefficient	0.149	0.240	0.196
Fatigue strain ($\times 10^{-6}$)	120.2	87.15	107.9
Rutting strain ($\times 10^{-6}$)	219.1	257.3	241.5
Thickness saving	—	150 mm (~24%)	75 mm (~12%)
Design status	SAFE	SAFE	SAFE

Table 4. Master comparison of the final pavement designs.

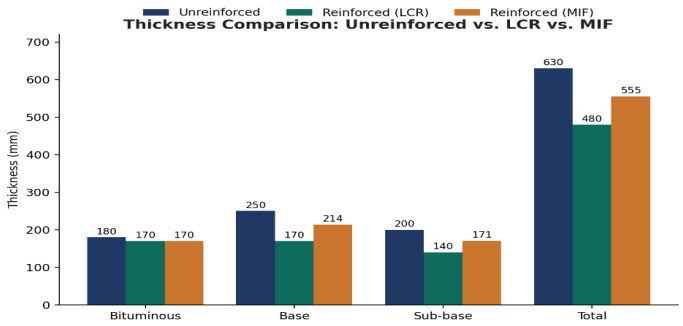


Figure 9. Layer and total thickness comparison for unreinforced, LCR and MIF designs.

The thickness comparison shows that reinforcement primarily affects the granular portion of the pavement. The bituminous thickness is reduced by only 10 mm in both reinforced designs, whereas the LCR method reduces the base by 80 mm and the sub-base by 60 mm. The MIF method provides smaller reductions of 36 mm and 29 mm in the base and sub-base. The corresponding total thickness reductions are approximately 24% and 12%. These values are analytical outcomes for the selected traffic, subgrade and reinforcement factors and should not be generalized without verification for other conditions.

A. Structural Coefficient and Resilient Modulus Response

The LCR calculation increases the base coefficient from 0.202 to 0.283 and the sub-base coefficient from 0.149 to 0.240. These are direct proportional increases of 40% and 61%. Back-calculation through the AASHTO coefficient equations produces equivalent moduli of 789 MPa and 393 MPa. In contrast, the MIF route multiplies the unreinforced moduli directly, giving 523.6 MPa and 250.9 MPa. When these MIF moduli are passed through the logarithmic AASHTO equations, the resulting coefficients are only 0.238 and 0.196. Thus, the two approaches do not produce equivalent structural capacity even though the same numerical factors are used.

This result is important for design interpretation. An improvement factor should always be applied in the manner for which it was defined and calibrated. An LCR is fundamentally a ratio of structural coefficients, whereas an MIF is a ratio of moduli. Treating the two as interchangeable can lead to different thickness reductions. The present project intentionally uses the same factor values in both formulations to demonstrate this sensitivity and then relies on IITPAVE to confirm whether each resulting section is structurally acceptable.

B. Mechanistic Performance: Fatigue and Rutting

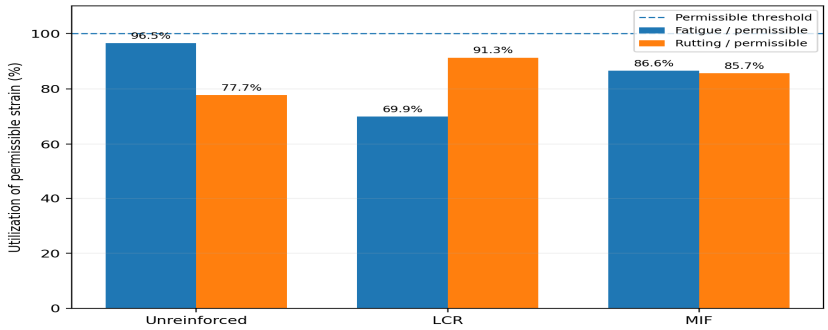


Figure 12. Percentage utilization of the permissible fatigue and rutting strain limits.

The unreinforced pavement uses about 96.5% of the allowable fatigue strain and 77.7% of the rutting limit, showing that fatigue is the more critical response. With LCR reinforcement, fatigue utilization reduces to about 69.9%, while rutting increases to about 91.3%. The MIF design gives balanced values of about 86.6% for fatigue and 85.7% for rutting.

All three designs remain within the allowable limits. The results show that geogrid reinforcement can improve fatigue performance, but reducing pavement thickness may increase the rutting response. Therefore, both fatigue and rutting should be checked when optimizing reinforced pavement thickness using IITPAVE.

VIII. PERFORMANCE OF FLEXIBLE PAVEMENT WITH BIAXIAL GEOGRID REINFORCEMENT

Biaxial geogrid improves the granular system mainly through aggregate interlock and lateral restraint. This can increase the effective support of WMM and GSB without changing the aggregate material itself.

In the present analysis, both reinforced designs remain within the fatigue and rutting limits while using less pavement thickness. The LCR section saves 150 mm and the MIF section saves 75 mm compared with the 630 mm unreinforced pavement. These savings apply only to the adopted design condition and reinforcement factors [2,5].

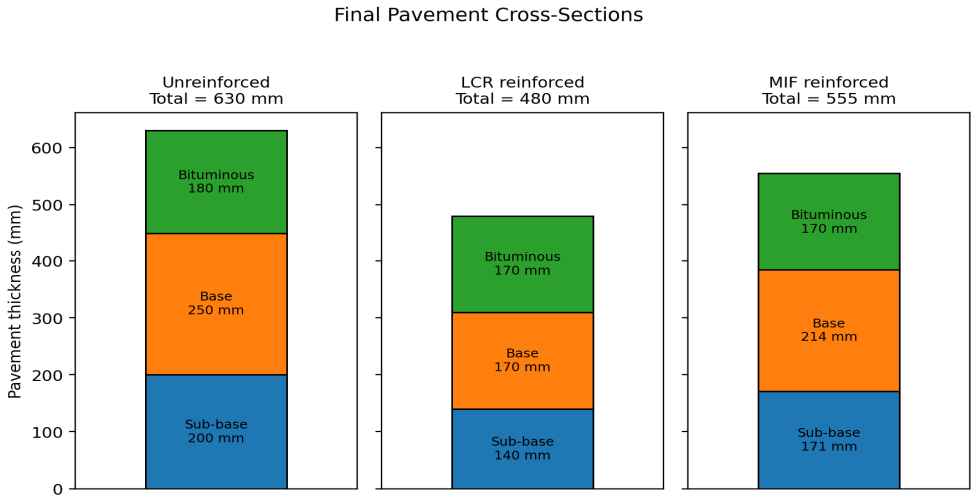


Figure 13. Corrected schematic comparison of the final pavement cross-sections

IX. PERFORMANCE OF FLEXIBLE PAVEMENT WITH GEOGRID: LCR METHOD

In the LCR method, the reinforcement benefit is applied directly to structural layer coefficient (a' = LCR x a). The base coefficient increases from 0.202 to 0.283 and the sub-base coefficient from 0.149 to 0.240. Their equivalent IITPAVE moduli are 789 MPa and 393 MPa. The final section is 170 mm bituminous, 170 mm base and 140 mm sub-base, or 480 mm overall. Fatigue strain is 87.15 x 10^-6 and rutting strain is 257.3 x 10^-6, so the section is safe and saves about 24% thickness.

X. PERFORMANCE OF FLEXIBLE PAVEMENT WITH GEOGRID: MIF METHOD

In the MIF method, reinforcement is applied to resilient modulus (MR' = MIF x MR). The base modulus increases from 373.96 to 523.6 MPa and the sub-base modulus from 155.86 to 250.9 MPa. The corresponding structural coefficients are 0.238 and 0.196. The final section is 170 mm bituminous, 214 mm base and 171 mm sub-base, giving 555 mm total thickness. Fatigue strain is 107.9 x 10^-6 and rutting strain is 241.5 x 10^-6.Both satisfy the limits, with a thickness saving of about 12%.

XI. COMPARATIVE INTERPRETATION OF LCR AND MIF RESULTS

LCR and MIF are not interchangeable. LCR changes the layer coefficient directly, whereas MIF changes resilient modulus before the AASHTO logarithmic conversion. Therefore, the same numerical factor gives different structural gains and different thickness reductions. Both final sections are acceptable after IITPAVE verification, but the LCR case gives the larger saving for this design. Improvement factors should be used only in the form for which they were developed and supported [2,5].

XII. PRACTICAL IMPLICATIONS, LIMITATIONS AND RECOMMENDED VERIFICATION

A thinner granular section can reduce aggregate use, transport and compaction, but geogrid also adds material and installation cost. This study considers one traffic level, one subgrade condition and adopted reinforcement factors. IITPAVE uses homogeneous elastic layers and does not directly model seasonal moisture, interface slip or construction defects. Before field use, the geogrid should be supported by product data or testing and installed with proper surface preparation, aggregate placement, compaction and drainage.

XIII. CONCLUSIONS

The study compared conventional and biaxial-geogrid-reinforced flexible pavements for 175 msa traffic, 9% subgrade CBR and 90% reliability. The unreinforced pavement was 630 mm thick and produced fatigue and rutting strains of 120.2 x 10^-6 and 219.1 x 10^-6. The LCR design reduced total thickness to 480 mm, saving 150 mm (about 24%), with strains of 87.15 x 10^-6 and 257.3 x 10^-6. The MIF design was 555 mm thick, saving 75 mm (about 12%), with strains of 107.9 x 10^-6 and 241.5 x 10^-6. All three final sections satisfied the adopted IITPAVE criteria.

The larger saving from LCR occurs because LCR acts directly on structural layer coefficient, while MIF acts on resilient modulus before the logarithmic AASHTO conversion.

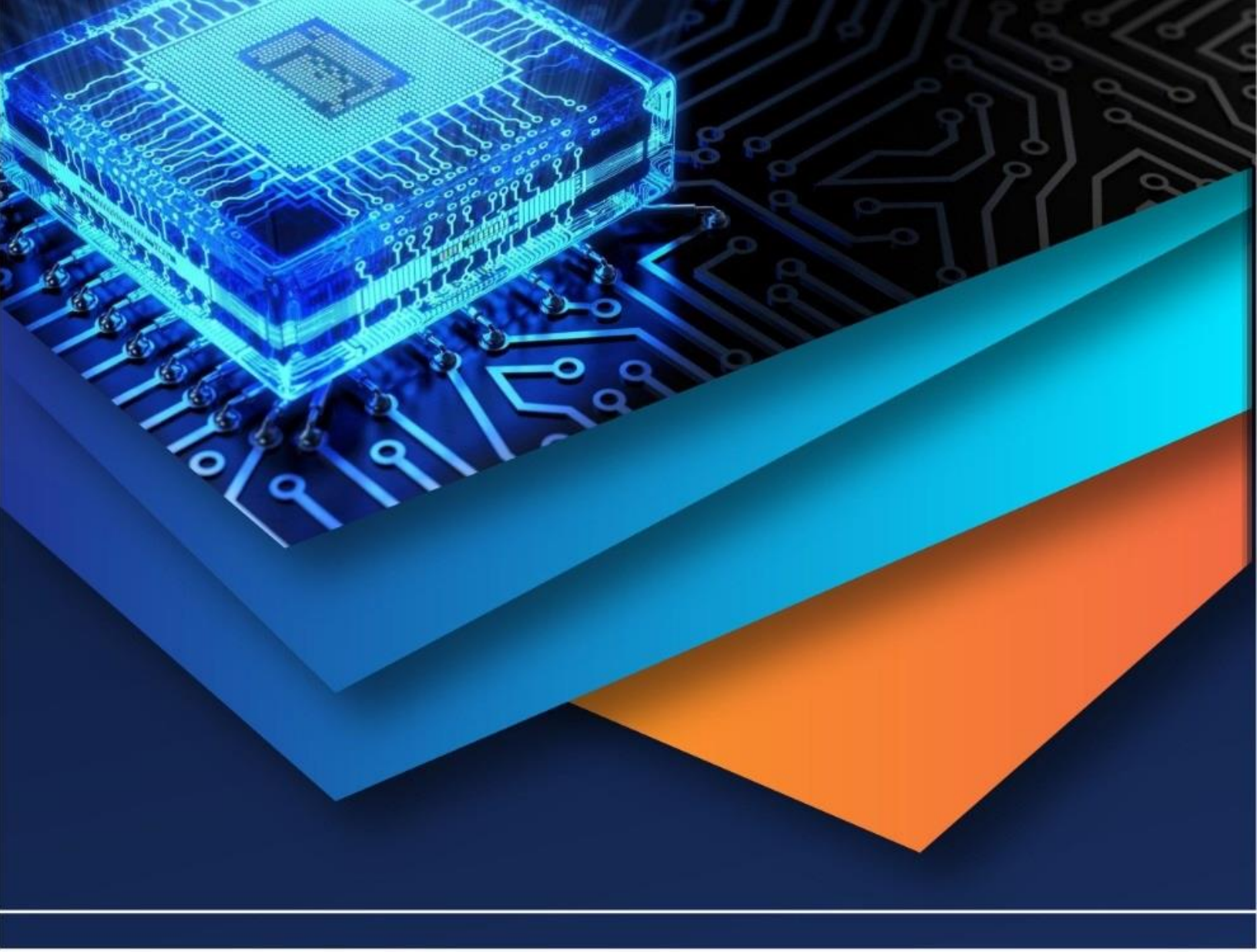
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Biaxial geogrid can therefore reduce granular material demand, but the benefit depends on the design representation and should be confirmed with product-specific evidence before field construction. Laboratory or full-scale validation and life-cycle cost assessment are recommended for future work.

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