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Design Approach for Geogrid Reinforced Base and Subbase Layers in Flexible Pavement

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Abstract

Geogrids are commonly used for pavement layer reinforcement and to build a construction platform over weak subgrade soils to carry equipment and facilitate construction of pavement without excessive deformations in the subgrade. Geogrid reinforcement is used in permanent paved roadways in two major application areas – base reinforcement and subgrade stabilization. The present study applied the AASHTO (1993) (Guide for Design of Pavement Structures), IRC: 37 (2018) (Guidelines for the design of flexible pavements) and IRC: SP: 59 (2019) (Guidelines for use of geosynthetics in road pavements and associated works) methods for design of geogrid-reinforced pavements using 20-year design life. Relevant design data were obtained to design the pavement, and a comparison was made between different design results.

Keywords: geogrid; flexible pavement; pavement design; reinforced base; reinforced subbase

1. Introduction

ASTM D4439 (ASTM, 2006) defines a geosynthetic as a planar product manufactured from a polymeric material and used with soil, rock, earth, or other geotechnical materials as an integral part of a civil engineering project, structure, or system. Geogrids have been used for reinforcing aggregate layers within the pavement system since their introduction in the early 1980s. Geogrids are formed by a regular network of tensile elements with apertures of sufficient size to interlock with the surrounding fill material. The efficiency of the geogrid-aggregate interlock depends on the relationship between aperture size and aggregate particle size, and the in-plane stiffness of the geogrid ribs and junctions. The predominant reinforcing mechanism associated with this application is providing lateral restraint to pavement base course. The lateral restraint develops through interlock between the aggregate, soil and the geogrid due to four reinforcement effects: (i) prevention of lateral spreading of aggregate, (ii) aggregate confinement resulting in increased strength/stiffness of aggregate in the vicinity of the geogrid, (iii) reduction of vertical stresses on top of the subgrade, and (iv) reduction of shear stress on the subgrade. The two important factors that govern pavement design are soil sub-grade strength and traffic loading. Both factors affect the layer thicknesses of flexible as well as rigid pavements. A concise introductory discussion is now provided for design methods of unreinforced and geosynthetics reinforced flexible pavements.

2. Design Methods for Geogrid-Reinforced Flexible Pavements

Geogrid, a type of geosynthetic reinforcement, has been gaining popularity as a reliable way to enhance the characteristics of naturally occurring soils for the construction of pavements. However, there is no design method that directly takes into account the mechanical properties of geogrid. Empirical approaches, limiting shear failure methods, limiting deflection methods, regression methods, and mechanistic-empirical methods are some of the design techniques in use for flexible pavements. The empirical methods of Penner et al. (1985), Montanelli et al. (1997), and Webster (1992) are restricted to the experimental studies. The design processes do not seem to be able to consider the effects of significant differences in factors such subgrade type, load magnitude, asphalt concrete and base layer thickness, and geosynthetic type. The following is a description of the most popular design approaches for geogrid-reinforced pavements.

2.1. AASHTO Method

One of the most popular approaches for designing flexible pavements is the AASHTO guide for design of pavement structures (AASHTO, 1993). The AASHTO method employs empirical equations developed from AASHO road tests that consider the pavement as a multi-layer elastic system with an overall structural number (*SN*) that represents the entire pavement thickness and its resilience to repeated traffic loading. *SN* is a numerical index representing the total structural capacity that all pavement layers overlying the subgrade must be able to support. Reliability, serviceability, subgrade resilient modulus, and predicted traffic intensities influence the required *SN*. To ensure long-term pavement performance, the actual *SN* must be higher than the required SN. Equation (1) shows the basic design equation for flexible pavement design as per AASHTO (1993):

$$\log_{10}(W_{18}) = Z_R \times S_0 + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07 \quad (1)$$

where, W_{18} =predicted number of 80 kN (18 kip) ESALs; Z_R = standard normal variate (example, Z_R = –1.646 for 95% variability); S_0 = combined standard error of the traffic prediction and performance prediction; *SN* = Structural Number (an index that is indicative of the total pavement thickness required) (inch); ΔPSI = difference between the initial design serviceability index, p_0, and the design terminal serviceability index, p_t; M_R = subgrade resilient modulus (in psi). The structural number (*SN*) is given by the following equation:

$$SN = a_1 * D_1 + a_2 * D_2 * m_2 + a_3 * D_3 * m_3 + ... \quad (2)$$

where, a_i = i^{th} layer coefficient; D_i = i^{th} layer thickness (inch); and m_i = i^{th} layer drainage coefficient.

2.2. IRC:37 Method

Fatigue and rutting are considered while designing flexible pavements in India according to IRC: 37 method (IRC, 2018) based on the mechanistic-empirical (ME) approach. The cracking and rutting models were developed using a semi-analytical approach from the results of research projects funded by the Ministry of Road Transport & Highways, Government of India. An elastic multilayer structure is used to model a flexible pavement. Using a linear layered elastic model, stresses and strains are calculated at critical points in the pavement structure. The computer program IITPAVE is employed for computing stresses and strains in flexible pavements. In order to reduce cracking and rutting in the bituminous layers and non-bituminous layers, respectively, conventionally considered key parameters for pavement design include tensile strain ε_t at the bottom of the bituminous layer, and vertical subgrade strain ε_v, on top of the subgrade. Two fatigue equations were developed with a reliability level of 80% [Equation (3)] and 90% reliability level [Equation (4)]:

$$N_f = 2.21 \times 10^{-4} \times [1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \quad (3)$$

$$N_f = 0.711 \times 10^{-4} \times [1/\varepsilon_t]^{3.89} \times [1/M_R]^{0.854} \quad (4)$$

where, N_f = fatigue life in number of standard axles; ε_t = maximum tensile strain at the bottom of bituminous layer; and M_R = resilient modulus of bituminous layer.

Similar to fatigue equations, two equations for rutting were developed at 80% [Equation (5)] and 90% reliability level [Equation (6)]:

$$N = 4.1656 \times 10^{-8} \times [1/\varepsilon_v]^{4.5337} \quad (5)$$

$$N = 1.41 \times 10^{-8} \times [1/\varepsilon_v]^{4.5337} \quad (6)$$

where, N = number of standard axles; and ε_v = vertical strain at the top of subgrade.

2.3. Modified AASHTO Method for Geogrid-Reinforced Flexible Pavement

There has not been a convenient design method that uses characteristics of a geogrid as direct design parameter for reinforced pavement systems owing to the complexity of layered pavement systems and loading conditions. The structural contribution of geogrid reinforcement to pavement systems should be evaluated using a series of performance-based tests, from which design specifications could be derived and incorporated into a design methodology. The benefits of incorporating geogrid should be included in early design approaches for flexible pavements by using the pavement reinforcement design term: layer coefficient ratio (LCR). LCR is a modification made to the aggregate's layer coefficient. Based on the number of load cycles required for a reinforced section to reach a given failure state and the number of load cycles required for an unreinforced section with the same geometry to reach the same defined failure state, the LCR is back-calculated.

The LCR was developed to measure the structural contribution of a geogrid in a flexible pavement (Carroll et al., 1987; Montanelli et al., 1997). LCR reflects the geogrid's lateral confinement of base course material and improvement in the reinforced base's layer coefficient as a reinforcing mechanism. The increase in the layer coefficient of the aggregate base and subbase course can be used to measure the structural contribution of a geogrid in a flexible pavement system. Equation (2) is now modified to:

$$SN = a_1 * D_1 + LCR_2 * a_2 * D_2 * m_2 + LCR_3 * a_3 * D_3 * m_3 + ... \quad (7)$$

where, LCR = layer coefficient ratio with a value higher than unity. LCR value is established based on the results of extensive laboratory and field testing on flexible pavement systems with and without geogrid. The aggregate/unbound layer coefficient of the pavement system is modified by the LCR. This value is back-calculated based on how many load cycles must be applied to a reinforced section before a defined failure occurs. An unreinforced section with the same geometry and number of load cycles is required to achieve the same determined failure condition. It is advised to evaluate studies on an agency-specific basis to choose the suitable LCR value.

2.4. Mechanistic-Empirical Method Modified AASHTO Design

AASHTO (1993) considers the present serviceability index (PSI) as shown in Equation (8):

$$PSI = 5.03 - 1.91 * \log(1 + SV) - 1.38 * (RD)^2 - 0.01\sqrt{C + P} \quad (8)$$

where, SV = slope variance; RD = rut depth (inch); C = cracking area; P = patched area. Hence, the design traffic in Equation (1) is a function of several parameters: $W_{18} = f(M_R, SN, Z_R, S_0, \Delta PSI)$.

The above relationship makes it obvious that the serviceability index takes rutting and fatigue into account and shows that the design standards used by AASHTO (1993) and IRC: 37 (IRC, 2012) are similar. IRC:37 equations (3-

6) are for unreinforced sections, and they do not include any guideline to account for the reinforcing effect. The equation can be modified to account for the advantage of geogrid reinforcement in the pavement layers, but this requires extensive study involving laboratory and field testing because many of the values employed are still empirical. Therefore, the following approach must be followed in order to build reinforced pavement while employing empirical and mechanistic empirical methods.

3. Geogrid-Reinforced Pavement Design Procedure

The design process consists of two stages:

- *Stage 1:* Identifying the conventional unreinforced section from IRC: 37 for the specified subgrade CBR in according to AASHTO, design traffic load and obtaining the same portion.
- *Stage 2:* Design of reinforced sections and using IRC: 37 recommended equations for calculating the fatigue and rutting resistance of geogrid reinforced sections.

The steps involved in the design process are presented as follows:

- *Step 1:* Calculate the design traffic and soaked subgrade CBR for which the pavement must be designed.
- *Step 2:* Choose a conventional pavement composition from the IRC: 37 design template library for a certain subgrade CBR and design traffic. Hence, the thickness D_1, D_2, D_3 of the surface, base, and subbase layers can be determined.
- *Step 3:* Obtain layer coefficients a_1, a_2, a_3 via trial and error by substituting D_1, D_2, D_3 into the equation for SN as per AASHTO (1993) technique for unreinforced section. Layer coefficients a_1, a_2, a_3 must be selected so that they match the elastic modulus of bituminous layers and the resilient modulus of aggregate layers as determined by the equations and tables provided in IRC: 37. The unreinforced portion of the AASHTO (1993) approach and the ME method will remain the same with the use of these layer coefficients. The design's first stage is now complete.
- *Step 4:* Since geogrid is used in base and subbase, its confinement and interlocking properties will cause the elastic modulus and layer coefficient to increase. It is possible to calculate this change in the modulus of confined layers by applying LCR to the unconfined layer coefficients defined in the above steps, i.e., improved layer coefficient of base $a_2' = LCR_2 \times a_2$, and improved layer coefficient of subbase $a_3' = LCR_2 \times a_3$. The LCR is highly important to the design process and needs to be assessed by field and lab testing. LCR is influenced by the geogrid's material, aperture size, and fill type. Based on their field and laboratory tests, the geogrid manufacturer can provide precise LCR.
- *Step 5:* Determine the reinforced section using the enhanced layer coefficients. Calculate the critical tensile and compressive strains at the bottom of the surface course and the top of the subgrade, respectively, for the reinforced section obtained from AASHTO (1993) using the IRC: 37 equations. The design's second stage is now complete.

With the proposed design methodology, the benefits of the modified AASHTO (1993) method for reinforced pavement design as well as the ME method for unreinforced pavement design are utilized. The above procedure enables taking advantage of the information offered by LCR charts for each unique geogrid and CBR value of the layer below because the LCR values are obtained through extensive laboratory and field tests.

4. Design Data Input

A pavement with a design traffic of 20 msa (million standard axles) needs to be designed for a design life of 20 years with 8% subgrade CBR. The main design parameters of pavement structural layers are determined through comprehensive analysis. Table 1 shows the summary of design parameters. By trial and error, the layer coefficients of base and subbase are chosen so that the unreinforced and reinforced sections of AASHTO and ME will be equivalent. Layer coefficients a_1, a_2 and a_3 corresponding to modulus values are obtained using Equations (1) and (2) by assuming the parameters.

Table 1: Assumed values of layer coefficient for materials

Parameter	Value
Layer coefficients	
Dense graded bituminous concrete surface course, a_1	0.44
Crushed stone / WMM base course, a_2	0.14
Sandy gravel sub-base course, a_3	0.11
Drainage coefficients	
Drainage coefficients for base, m_2	1
Drainage coefficient for subbase, m_3	1
Other parameters	
N_s	20×10^6
CBR	8%
Reliability (R)	90%
S_0	0.45
Z_R	-1.282
ΔPSI	4.2 – 2.5 = 1.7

The estimated future traffic in terms of ESALs for the design period (W_{18}) was 20 million. The required structure number (SN) was 4.84 against 8% subgrade CBR, which has been fulfilled by providing an adequate pavement structure. The proposed pavement design of new construction is shown in Table 2.

Table 2: Proposed design thickness calculations as per Equation (1)

Equation component	Expression	Value
LHS	$\log_{10}(N_s)$	7.30130
	For SN = 4.68	
RHS	$Z_R * S_0$	-0.5769
	$9.36* \log_{10}(SN+1)$	6.72979477
	$0.2* \log_{10}(\Delta PSI/(4.2-1.5))/(0.4+(1094/(SN+1)^{5.19}))$	-0.41191446
	$2.32*\log_{10}(M_R) – 8.07$	1.393700491

For N_s = 20 million and using the AASHTO design equation, the required SN is calculated as 4.68. The calculation of actual SN is shown as follows:

SN = 0.44*(BC+DBM thickness in inch) + 0.14*1*(WMM thickness in inch) + 0.11*1*(GSB thickness in inch)

SN=0.44*(0.05+0.10)/0.0254+0.14*1*(0.125+0.125)/0.0254+0.11*1*(0.10+0.10)/0.0254 = 4.84

Since the actual SN (4.84) is greater than the required SN (4.68), the design is safe. The pavement composition is shown in Table 3.

Table 3: Thickness of crust

Layer	Thickness
Bituminous concrete (BC)	50 mm
Dense bituminous macadam (DBM)	100 mm
Wet mix macadam (WMM) 1st layer	125 mm
Wet mix macadam (WMM) 2nd layer	125 mm
GSB 1st Layer	100 mm
GSB (Drainage layer)	100 mm
Total	600 mm

Now, assuming new thicknesses of granular layers, let the thickness of GSB = 160 mm, and thickness of base = 150 mm. As per IRC: SP: 59 (IRC, 2019), the layer coefficient ratio for geogrid used in GSB is 1.61 and that used in base layer is 1.40. The resilient modulus of base and subbase are revised by back calculations to yield the value of 323.6 MPa for base and 406.88 MPa for subbase. The actual strain values obtained from IITPAVE computer program are checked and found within the permissible limits, hence the design of reinforced section is safe.

Reduced thicknesses of subbase and base are calculated as follows:

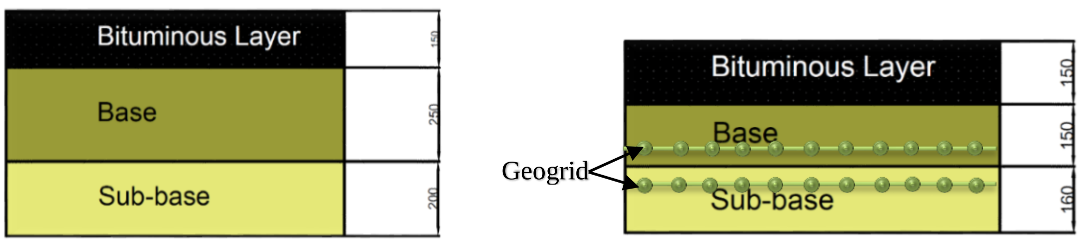
Reduction in thickness of GSB subbase = 200 – 160 = 40 mm

Reduction in thickness of base = 250 – 150 = 100 mm

Percent reduction in the thickness of GSB = (40/200) × 100 = 20%

Percent reduction in the thickness of base = (100/250) × 100 = 40%

Figure 1 shows the comparison of pavement composition with and without geogrid reinforcement.



(a) **(b)**

Fig. 1. Comparison of pavement composition without (a) and with (b) geogrid reinforcement (all thickness values are in mm)

5. Conclusions

This study proposed a design methodology for design of flexible pavement composition with geogrid reinforcement in base and subbase layers. A design example was also presented which showed that subbase thickness reduced by 20% and the base thickness reduced by 40% in the geogrid reinforced pavement compared to the unreinforced composition for the same traffic and design life. The use of geogrid reinforcement will help in conserving natural resources like aggregates used in the pavement construction. Overall, introducing geogrid to the base and subbase layer ensures that loads are distributed evenly, reduces rut depth, and offers an affordable and long-term alternative to current procedures.

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