DESIGN APPROACH FOR GEOGRID REINFORCED FLEXIBLE PAVEMENT

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ABSTRACT

Geogrids are extensively used for the stabilization of base and subbase of roads on soft soils. Since 1990's there has been a proliferation of design methods that vary between empirical to sophisticated finite element-non linear-mechanistic empirical design methods to predict performance more accurately by accommodating the new material types. This paper provides the most widely accepted method for designing the required thickness of base and/or subbase when reinforced with geogrid: the modified AASHTO 1993, an empirical method for paved roads which fully captures the benefit of geogrid in design.

This method is compared with M-E method given in IRC-37, whose application to reinforced roads is still under development. The paper emphasizes that the AAHTO 1993 and the M-E design methods are based on the same principles and that it is possible to obtain the same design layout with proper selection of the parameters.

Complete procedure is introduced for using the modified AASHTO 1993 method for designing the reinforced road section and its verification in M-E method.

Keywords : *Mechanistic Empirical, Modified AASHTO 1993*

1. INTRODUCTION

Use of geosynthetics in design and construction of pavements have gained acceptance and experience to address the functions of separation, filtration, lateral drainage, sealing, and reinforcement. In the majority of the studies reviewed, it was concluded that an appreciable increase in performance could be realised by using geosynthetic reinforcement (S.W. Perkins, 1997). The benefits of using geosynthetic reinforcement include reduction in the thickness and enhancement of performance of pavement,(Koerner, 2005, Zornberg et al 2008.). Traffic benefit ratio (TBR) is ratio of the number of load cycles on a reinforced section to the number of load cycles on an unreinforced section, with the same geometry and material constituents, to reach the same defined failure state. TBR is sometimes termed traffic improvement factor (TIF).Base course reduction (BCR) is percent reduction in the reinforced base, or subbase, thickness from the unreinforced thickness, with the same material constituents, to reach the same defined failure state. This paper focuses on use of biaxial geogrids as reinforcement with more emphasis on currently used design methodology for unreinforced flexible pavements and the modified procedure for reinforced pavement sections

incorporating the effect of geogrid based on the layer coefficient ratio (LCR). Design procedures for base & subbase reinforcement are not well documented in technical journals. Therefore, a step-by-step design procedure for base & subbase reinforcement is presented in this paper along with a solved numerical example.

1.1 Extruded Biaxial Geogrids as Reinforcement for Flexible Pavement

Geogrid have been used as reinforcement inclusions to improve pavement performance attributed to three mechanisms: (1) lateral restraint i.e. more confinement, (2) increased bearing capacity, i.e. improved load distribution area and (3) tension membrane effect.

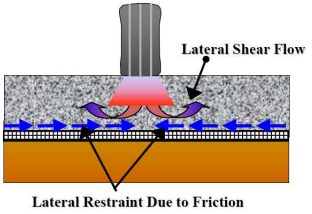

Figure 1. Lateral restraint Reinforcement Mechanism

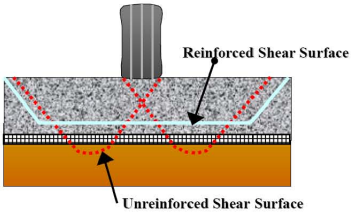

Figure 2. Improved bearing capacity reinforcement mechanism

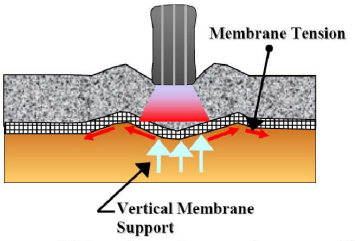

Figure 3.Tensioned membrane effect reinforcement mechanism

Extruded biaxial geogrids are geosynthetic materials formed into a grid of integrally connected tensile elements and has apertures of sufficient size to allow "strike-through" and interlocking with surrounding aggregate materials. Extruded biaxial geogrids placed either below or within the aggregate base &/or subbase layer of a pavement structure increases the stiffness and confines the unbound aggregate layers under repetitive loading. The composite section consisting of the geogrid and aggregate base/subbase is often referred to as a mechanically stabilized layer (MSL). The purposes of using extruded biaxial geogrids as reinforcement in flexible pavements have been: (1) to reduce the thickness; (2) extend a pavement's service life, or (3) to enable the construction of a pavement with a reduced quantity of base /subbase course material without sacrificing pavement performance (4) to serve as a construction aid over weak subgrade (5) to use low quality local materials as to form base and subbase of the pavement.

This improved performance of geogrids is because of its interlocking ability due to large aperture size and its role in preventing lateral spreading of unbound aggregate layers, while the degree of interlocking depends on the relationship between geogrid aperture size and aggregate particle size, the effectiveness of interlocking depends on the in-plane stiffness of the geogrid and the stability of the geogrid ribs and junctions. The torsional rigidity of the geogrid, which is governed in part by the characteristics of the junctions, is the most important factor to determine the suitability of the geogrid product.

Venkatappa Rao and Banerjee (1997) reported that bi-oriented geogrids have been successfully utilised in Maharashtra in the State Highways for strengthening road pavements in black cotton soil.

2. EXISTING DESIGN METHODS FOR FLEXIBLE PAVEMENTS

Geogrid, a type of geosynthetic reinforcement is gaining acceptance as an effective way of improving on the properties of naturally occurring soils for pavement construction for more than a decade, yet there exists no design method incorporating geogrid mechanical properties as direct design parameters. Existing design methods for flexible pavements include: empirical methods, limiting shear failure methods, limiting deflection methods, regression methods, and mechanistic-empirical methods. Of the design approaches proposed, the empirical methods of Penner et al. (1985), Montanelli et al. (1997), and Webster (1992) are limited to the experimental study. The design methods do not appear capable of accounting for the influence of wide variations in variables such as geosynthetic type, load magnitude, asphalt concrete and base layer thickness, and subgrade type. The most widely used design methods for are described below

2.1 AASHTO Method

The AASHTO guide for design of pavement structures is one of the most widely used methods for flexible pavement design (AASHTO 1993) in and around the world. The AASHTO method uses empirical equations developed from the AASHTO road tests which consider the pavement as a multi-layer elastic system with an overall structural number (SN) that reflects the total pavement thickness and its resiliency to repeated traffic loading. The AASHTO method utilizes an index termed the "structural number" (SN) to indicate the required combined structural capacity of all pavement layers overlying the subgrade. The required SN is a function of reliability, serviceability, subgrade resilient modulus, and expected traffic intensities. The actual SN must be greater than the required SN to ensure long term pavement performance.

This equation is widely used and has the following form:

$$\text{Log}_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.2 + (\log(\Delta PSI / (4.2-1.5) / (0.4 + (1094/(SN+1)^{5.19})) + 2.32 \times \log_{10}(M_R)\ 8.07 \quad [1]$$

Where:

W_{18} = predicted number of 80 KN (18 kips) ESALs

Z_R = standard normal deviate (example: Z_R = -1.645 for 95 % reliability)

S_o = combined standard error of the traffic prediction and performance prediction

SN = Structural Number (an index that is indicative of the total pavement thickness required) [inches]

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots \quad [2]$$

a_i = i^{th} layer coefficient

D_i = i^{th} layer thickness (inches)

m_i= i^{th} layer drainage coefficient

ΔPSI = difference between the initial design serviceability index, po, and the design terminal serviceability index, pt

M_R = subgrade resilient modulus (in psi)

2.2 IRC -37 Mechanistic Empirical Method

In India, IRC -37 – Guidelines for the design of flexible pavements based on Mechanistic Empirical (ME-method) approach is used in which fatigue and rutting are considered as design criteria. The cracking and rutting models were based on the findings of the research schemes of the Ministry of Road Transport & Highways, Government of India, under which pavement performance data were collected from all over India by academic institutions and Central Road Research Institute to evolve the fatigue and rutting criteria for pavement design using a semi-analytical approach.

A flexible pavement is modelled as an elastic multilayer structure. Stresses and strains at critical locations are computed using a linear layered elastic model. The Stress analysis software IITPAVE has been used for the computation of stresses and strains in flexible pavements. Tensile strain, Σ_t at the bottom of the bituminous layer and the vertical subgrade strain, Σ_v on the top of the subgrade are conventionally considered as critical parameters for pavement design to limit cracking and rutting in the bituminous layers and non-bituminous layers respectively.

Two fatigue equations were fitted, one in which the computed strains in 80 per cent and the other corresponding to 90 percent reliability level. The two equations for the conventional bituminous mixes designed by Marshall Method are as given below:

$N_f = 2.21 * 10^{-4} \times [1/\Sigma_t]^{3.89} * [1/M_R]^{0.854}$ (80 percent reliability) [3]

$N_f = 0.711 * 10^{-4} \times [1/\Sigma_t]^{3.89} * [1/M_R]^{0.854}$ (90 percent reliability) [4]

Where,

N_f = fatigue life in number of standard axles,

Σ_t = Maximum tensile strain at the bottom of bituminous layer and

M_R = resilient modulus of bituminous layer.

Like the fatigue model, rutting model also has been calibrated in the R-56 studies using the pavement performance data collected during the studies at 80 per cent and 90 per cent reliability levels. The two equations are given below:

$N = 4.1656 * 10^{-8} \times [1/\Sigma_v]^{4.5337}$ (80 percent reliability) [5]

$N = 1.41 * 10^{-8} \times [1/\Sigma_v]^{4.5337}$ (90 percent reliability) [6]

Where, N= Number of cumulative standard axles, and Σ_v = vertical strain in subgrade

2.3 Design Method for Geogrid Reinforced Flexible Pavements i.e. Modified AASHTO Method

Due to the complexity of layered pavement system and loading conditions, there hasn't been any simple design method for identifying the properties of a geogrid as direct design parameters for reinforced pavement systems. A series of performance based tests should be conducted to evaluate the structural contribution of geogrid reinforcement to pavement systems, from which design parameters could be derived and incorporated into a design methodology.

Early design approaches for flexible pavements shall be modified to reflect the benefit achieved by the addition of geogrid by a pavement reinforcement design term, LCR. LCR — Layer coefficient ratio: A modifier applied to the layer coefficient of the aggregate. This value is back-calculated, based upon the number of load cycles on a reinforced section to reach a defined failure state to the number of load cycles on an unreinforced section, with the same geometry, to reach the same defined failure state. The concept of layer coefficient ratio was introduced over a decade ago (Carroll, Walls and Haas 1987, Montanelli, Zhao, and Rimoldi, 1997) to quantify the structural contribution of a geogrid in a flexible pavement. This concept was established based on the reinforcing mechanism that geogrid provides lateral confinement to the base course material and improves the layer coefficient of the reinforced base.

- The structural contribution of a geogrid on a flexible pavement system can be quantified by the increase in the layer coefficient of the aggregate base and subbase course. Equation (2) now becomes:

  $$SN = a_1D_1 + LCR_2\, a_2D_2m_2 + LCR_3a_3D_3m_3 + \ldots \quad [7]$$

  Where, LCR is the Layer Coefficient Ratio, with a value higher than one, the design is aimed to follow the basic rules of AASHTO 1993 empirical approach.

- LCR value is determined based on the results from laboratory and extensive field testing on flexible pavement systems with and without geogrid. Layer coefficient ratio is a modifier applied to the layer coefficient of the aggregate/unbound layers of the pavement system.

- This value is back-calculated, based upon the number of load cycles on a reinforced section to reach a defined failure state to the number of load cycles on an unreinforced section, with the same geometry, to reach the same defined failure state. Agency specific evaluation of research to select appropriate LCR ratio is recommended. Performance data and analyses presented here are limited to multilayered polypropylene extruded biaxial geogrids of Maccaferri.

2.3.1 Modified AASHTO design in terms of Mechanistic Empirical Method

As already mentioned above, IRC:37 considers rutting and fatigue as design criteria, while AASHTO 1993 considers in terms of serviceability index and is given as

$$PSI - 5.02 - 1.91\log(1+SV) - 1.38RD^2 - 0.01(C+P)^{1/2} \quad [8]$$

Where SV = slope variance (X 10) (av. For both wheel paths)

RD = rut depth (inches) over 4ft span av. for both wheel paths

C= Cracking area (sq ft/1000 sq. ft of pavement)

P= Patched area (sq ft/1000 sq. ft of pavement)

Hence the Design MSA equation given by W 18 is a function of several parameters

i.e. $W18 = f(M_R, SN, Z_R, S_o, \Delta PSI)$ [9]

From the above relation it is clear that serviceability factor considers both rutting and fatigue which shows that both AASHTO 1993 and IRC : 37 are based on similar design criteria.

Equations given in IRC : 37-2012 are for unreinforced section and don't provide any criteria for incorporating the reinforcement effect. As many of the parameters used are still empirical, the equation can be modified to include the benefit of reinforcement in the pavement layers which calls for extensive research by laboratory and field testing. Hence to take the advantage of empirical and mechanistic empirical methodology reinforced pavement design shall be done in the following procedure.

3. DESIGN PROCEDURE FOR GEOGRID REINFORCED PAVEMENT

Design procedure can be subdivided into two parts:

Part 1 Determination of conventional unreinforced section from IRC:37 for the given subgrade CBR and Design traffic load and getting the same section as per AASHTO.

Part 2 Design of reinforced section and calculation of fatigue and rutting resistance of geogrid reinforced section as per the equations suggested by IRC:37

Various steps involved in the design procedure are discussed here in detail

Step 1 Determination of soaked subgrade CBR and Design Traffic Load for which the pavement has to be designed.

Step 2 Selection of conventional pavement from IRC:37 design catalogue for specific subgrade CBR and Design traffic. The thickness D_1, D_2, D_3 of surface, base and sub base layers can be defined from that analysis.

Step 3 Using equation for SN as per AASHTO 1993 method for unreinforced section, determine layer coefficients a_1, a_2, a_3, by trial and error, by substituting D1, D2, D3 of surface, base and sub base layers obtained in point 1 above. Layer coefficients a1, a2 a3 shall be chosen such that they shall correspond to the resilient modulus of aggregate layers and elastic modulus of bituminous layers as that obtained through equations and tables given in IRC:37. With these layer coefficients, unreinforced section of AASHTO 1993 method and M-E method will remain same. This completes part 1 of the design.

Step 4 since geogrid is used in base/subbase, elastic modulus/ layer coefficient shall increase due to the confinement and interlocking action of geogrid. This increase in modulus of confined layers can be computed by

applying layer coefficient ratio to the unconfined layer coefficients defined in the above steps.

i.e. improved layer coefficient of base $a2' = LCR_2 X a_2$

Improved layer coefficient of Subbase $a3' = LCR_3 X a_3$

This LCR has very crucial role in design and must be evaluated from the field and laboratory testing. LCR depends on Geogrid material, its aperture size, different fill material. Precise LCR can be taken from the geogrid Manufacturer based on their field and laboratory testing.

Step 5 Based on this increased layer coefficient, determine the reinforced section. For the reinforced section obtained from AASHTO 1993, calculate the critical tensile and compressive strains at bottom of surface course and top of subgrade respectively from equations suggested by IRC:37. This process insures the completion of part 2 of design.

In this way the advantages of both M-E method (for unreinforced road design) and modified AASHTO 1993 method (for reinforced road design) are considered. Since the LCR values are obtained through extensive laboratory and field tests, with the application of hundred thousand or even million ESAL load cycles, the above procedure allows to take profit of the invaluable information provided by LCR charts for each specific geogrid and CBR value of the layer below.

4. SOLVED DESIGN EXAMPLE

An illustrative example for designing geogrid reinforced flexible pavement with the above said methods is given below.

A pavement carrying traffic of 150 MSA needs to be designed for a 20 year life with the design subgrade CBR 3% Conventional Pavement Section for CBR 3 and 150MSA is shown in Table 1.

Layer	BC	DBM	Base Layer(d_2)	Subbase(d_3)
Thickness (mm)	50	170	250	380

Table 1 Conventional Pavement Design (from IRC:37-2012 Design Catalogues)

By trial and error the appropriate layer coefficients for base and subbase are chosen so that unreinforced section of AASHTO and ME method will be equivalent. Layer coefficients a1, a2 and a3 corresponding to elastic modulus values are tabulated below using equations 1 & 2 by assuming the following parameters

Initial service index, Po = 4.2

Terminal service index, Pt = 2.5

Reliability Level, R = 90%

Combined standard error, So= 0.45

Drainage Coefficients $m_2=m_3=1$

Layer	Surface Layer (BC+DBM)	Base Layer	Subbase Layer
Layer Coefficient	$a_1=0.55$	$a_2=0.14$	$a_3=0.10$
Elastic Modulus (Mpa)	3000	210	90

Table 2 Layer coefficients and Corresponding Elastic Modulus considered in the analysis

Increased modulus and layer coefficient is applicable for stabilised zone/ layer only. Here let us consider geogrid reinforcement in both base and subbase with Maccaferri extruded geogrids MacGrid EG40S. From the figure 4 layer Coefficient ratios for MacGrid EG 40S for base and subbase are 1.4052 and 1.7372 respectively.

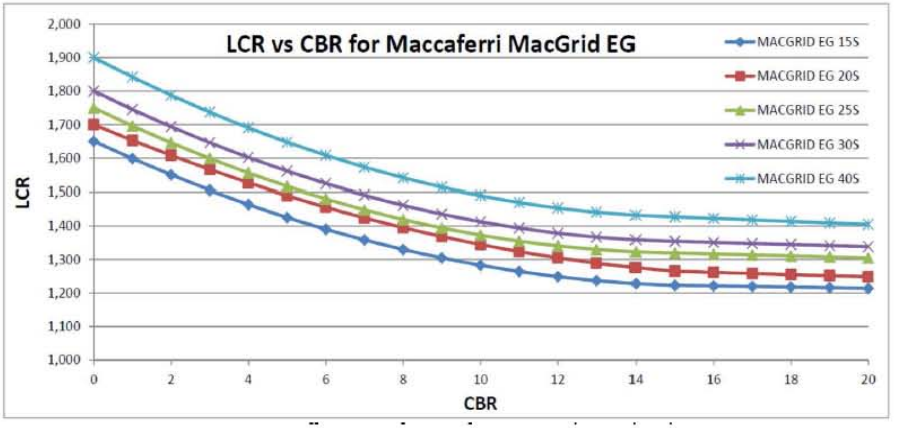

Figure 4 Layer Coefficient Ratio for Maccaferri EG Geogrids vs. CBR of layer

For these layer coefficient ratios, corresponding improved layer coefficients and elastic modulus are tabulated below

Table 3 Layer coefficients and Corresponding Elastic Modulus considered in the analysis

Layer	Surface Layer (BC+DBM)	Base Layer	Subbase Layer
Layer Coefficient	$a_1=0.55$	$a_2=0.225$	$a_3=0.226$
Elastic Modulus (Mpa)	3000	462	335

Table 4 Geogrid Reinforced pavement section

Layer	BC	DBM	Base Layer (d_2)	Subbase(d_3)
Thickness (mm)	50	170	180	220

(Analysis has been done based on the performance tests data of Maccaferri extruded biaxial geogrids MacGrid EG).

By putting the above improved parameters in equations 2, 4 and 6 we get SN N_F and N_R to determine the structural number, fatigue and rutting resistance of reinforced pavement.

Maximum tensile strain at bottom of surface layer= 86 micro strains

Corresponding N_F= 423 MSA>150MSA

Maximum compressive strain at top of subgrade = 291 micro strains

Corresponding N_R = 151 MSA>150MSA

cross-section of conventional and reinforced section are shown in the figures 5 and 6

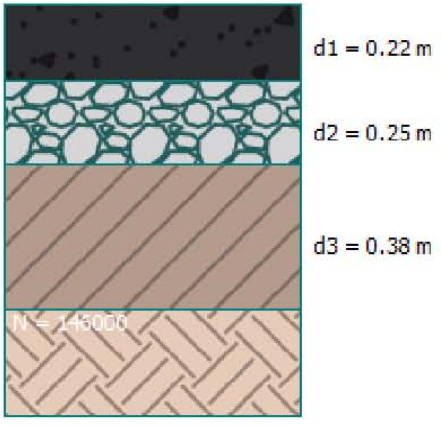

Figure 5 Unreinforced Pavement Section

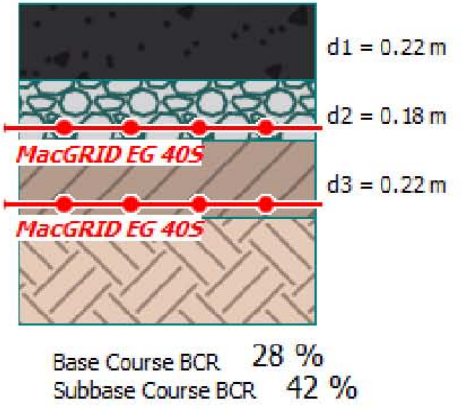

Figure 6 Reinforced Pavement Section

5. CONCLUSION

Geogrid when used in flexible pavements shall yield a significant reduction in aggregate layers and thus can reduce the overall cost of pavements. However a proper and well established design procedure is must to utilize the

benefit of this technology. By modifying the existing AASHTO Structural Number (SN) equation with the reinforcement index LCR, design of geogrid reinforced pavement can be standardised. Obtained reinforced sections can be checked in Mechanistic Empirical approach by back calculating the material properties i.e. resilient modulus and layer coefficients and determining the critical strains to satisfy rutting and fatigue resistance criteria followed in IRC 37.

Beside the initial cost savings, overall construction time saving because of reduced thickness and long service life are other important aspects of this technology which has not been quantified in this paper.

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