

Planar Reinforcements for Flexible Pavements

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Abstract— Base and subbase layers, forming a major portion of a pavement, are constructed using crushed aggregates. In order to reduce the consumption of huge quantities of aggregates in large-size projects, it is essential to adapt and utilize alternate materials and design methods in building sustainable road ways. Reinforcing flexible pavements is one of the ways to improve the performance or to reduce the pavement thickness. Many researchers conducted experiments to quantify the benefit of reinforcing flexible pavements in terms of traffic benefit ratio (TBR). In this study, Large Scale Model Experiments (LSME) are conducted to investigate the settlement behaviour of unpaved pavement system against static loading. The design of reinforced unpaved roads is carried out using Giroud and Han method with reinforcement in the form of geogrids having aperture stability modulus of 0.32 N-m^0 and 0.65 N-m^0 . The design of reinforced paved roads is carried out using AASHTO guidelines with the selected TBR values equal to 3 and 6. From the LSME conducted on the unreinforced and reinforced unpaved pavement system, it is observed that inclusion of planar reinforcement in the form of geogrid or steel-wire-mesh within the aggregate layer resulted in load improvement factor ranging from 1.1 to 1.9. Based on the design carried out using the proposed methods on paved and unpaved reinforced roads, it is possible to reduce the pavement thickness from 20% to 70% depending on the type of geogrid and subgrade strength.

Keywords—*planar reinforcement, geogrid, hexagonal steel-wire-mesh, load improvement factor, traffic benefit ratio, base course reduction factor*

I. INTRODUCTION

In many highway projects, contractors are forced to procure aggregates from far away distances to meet the required quality and quantities for construction of pavements. It is essential to look for alternate materials to conserve naturally available materials and to meet the increasing demand of construction. In some cases, substandard materials may be used with provision of additional thickness of the layer to cater to the designed axle load passes before reaching terminal rut depth and fatigue cracking.

According to Indian Road Congress manual [16] on design of flexible pavement structure overlying subgrade, the quantity of crushed aggregates for granular base and sub base layers alone varies from 75% to 88% corresponding to

150 million standard axles (MSA) to 2 MSA of traffic, respectively. It is paramount to reduce the quantity of aggregates in the construction of a flexible pavement base/subbase layer particularly for low-volume pavements. Large-scale model experimental (LSME) studies are used to study the performance of reinforced and unreinforced pavements. LSME is devised to model a pavement structure (or parts of it) at prototype scale in a manner that replicates field conditions as closely as practical.

Pavements are reinforced using two-dimensional or planar reinforcement, or three-dimensional (geocell) reinforcement, or combination of both planar and geocell in the form of basal reinforcement to improve the performance or to reduce the base layer thickness without compromising the required level of service [25]. Load improvement factor equal to 1.5 for geocell reinforced system was reported by [10] at settlement ratio of about 5%. Reference [19] reported a load improvement factor equal to 3.0 at a settlement ratio of 5%. Seven fold improvement in bearing capacity was observed for geocell reinforcement with basal geogrid [25].

Use of planar reinforcement (geosynthetic or steel-wire mesh) in unbound granular base layers has several benefits: (a) increases the load bearing capacity of the pavement structure, (b) increases the resistance to permanent deformation of the granular layer and subgrade, and (c) increases the fatigue resistance of asphalt concrete layers. The amount of improvement in pavement performance with the inclusion of planar reinforcement in base layers depends on many factors, including the strength of subgrade, reinforcing material properties, location of reinforcement in pavement, thickness of base layer and wearing course, etc.

Geogrid belongs to the family of extensible geosynthetic reinforcement commonly used to reinforce unpaved and paved roads. It can be placed within a base course or at the interface of base and subgrade to improve the subgrade and/or reinforce the base course. Geogrid offers resistance through interlocking between aggregates and its apertures to form a confined zone [11, 12].

Steel wire mesh is a type of inextensible planar reinforcement used to reinforce flexible pavements. It consists of a double-twist, hexagonal shaped mesh with variable dimensions, which is transversally reinforced at regular intervals with steel wires inserted in the double

twist. The new generation of steel-wire-mesh reinforcement consists of unwelded galvanized steel wire that is protected against corrosion by a zinc coating. It can offer high tensile strength at low strains required to resist rutting caused by heavy vehicular loading.

In the present study, the results of large-scale model tests conducted on unreinforced, geogrid-, and steel-wire-mesh- reinforced pavement systems are reported. In addition, reduction in base layer thickness using two methods used for reinforced pavement design, namely Giroud and Han method and modified AASHTO method, is provided. Accordingly, this study is divided into two parts- Part (A) Investigation of reinforced unpaved pavements from LSME testing, and Part (B) Design of reinforced roads based on Giroud and Han’s design method and AASHTO method considering Indian conditions.

II. PART (A) EXPERIMENTAL STUDY

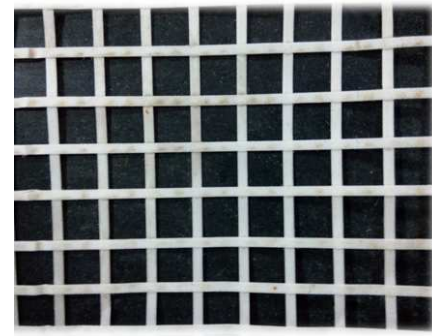
A. Materials used

In this study, unpaved pavement structure overlying medium-stiff subgrade is considered. Locally available river sand was used for testing. Grain-size distribution, the maximum density, and the minimum density for this sand were obtained according to [4, 5, and 6] respectively. The maximum density of sand was found to be equal to 1.78 g/cc using vibratory method. The coefficient of uniformity, Cu, and the coefficient of curvature, Cc, were equal to 1.89 and 1.13, respectively. It is classified as poorly-graded sand (SP) as per the Unified Soil Classification System (USCS). To prepare a strong aggregate layer overlying a sand layer, locally available aggregates of average size equal to 6mm were used above the sand layer. Table 1 presents the physical properties of the geogrid (make: NAUE-Secugrid 40/40) and steel wire mesh (make: Maccaferri-Road mesh) used in the study. Fig. 1 shows a photograph of the two reinforcement types considered.

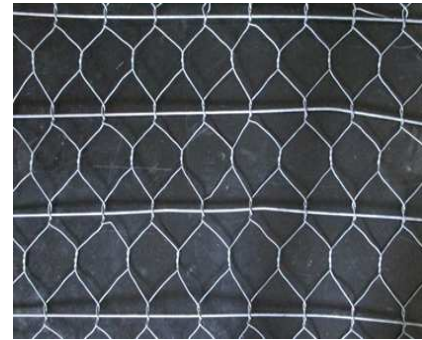
Table 1 Properties of geogrid and steel wire mesh

Property	Geogrid	Steel wire mesh
Raw materials	Polypropylene (PP)	Steel galvanized
Maximum tensile strength	40 kN/m	380-550 kPa*
Tensile strength at 2% / 5% elongation	16/32 kN/m	-
Aperture/ Opening (D) size	31 x 31 mm	105mm
Rib thickness	0.85 mm	
Diameter of steel mesh wire/transverse rod	-	2.4/4.4mm
Spacing between transverse rods	-	175 mm

*As per manufacturers data sheet



(a)



(b)

Figure 1 Photographs of reinforcement types used in the experimental study: (a) geogrid, and (b) steel wire mesh.

B. LSME setup and results

Figs. 2 and 3 show the photograph of experimental test set up and a schematic view of reinforced pavement structure prepared in the laboratory, respectively. The thickness of top aggregate layer (H1) was kept as 100mm and the thickness of sandy soil (H2) was equal to 800mm. Tests were performed under displacement-controlled mode with a displacement rate of 1mm/minute, and the static test loading was terminated at a displacement equal to 50mm. The load-displacement response was obtained for the following test cases: a) Unreinforced aggregate layer overlying a sandy soil subgrade, b) Geogrid-reinforced aggregate layer overlying a sandy soil subgrade, and c) Steel-wire-mesh reinforced aggregate layer overlying a sandy soil with reinforcement placed at optimum dr/B



Figure 2 Photograph showing main components of experimental test set-up

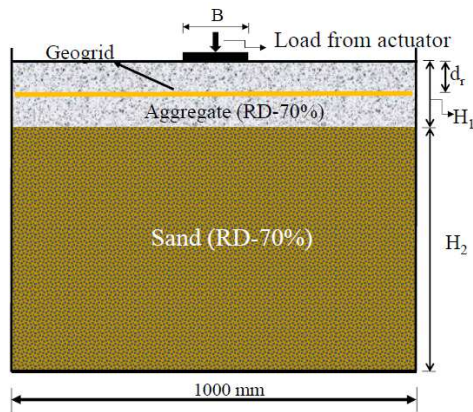


Figure 3 Schematic of the test bed

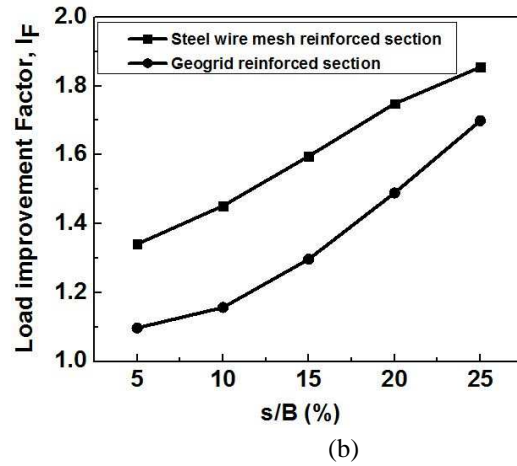
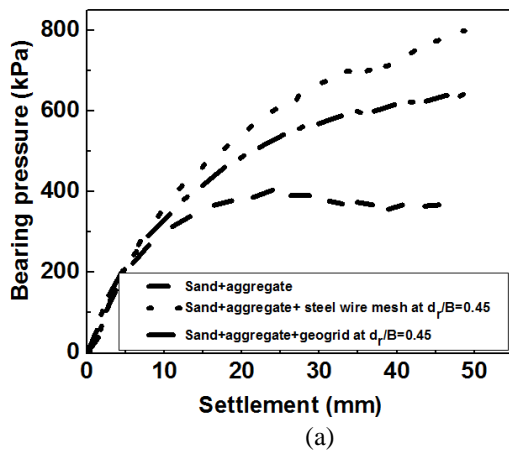


Figure 4 (a) Effect of reinforcement types for $H_1/B=0.66$, and $d_r/B=0.45$: Variation of bearing pressure with settlement, and (b) variation of load improvement factor with settlement ratio

Load improvement factors are obtained for reinforced layered system corresponding to various settlement ratios. Load improvement factor (I_f) is defined as

$$I_f = \frac{q_r}{q_0} \quad (1)$$

where, q_r is the bearing pressure under the footing resting on reinforced layered system at a given settlement, s , and q_0 is the bearing pressure under the footing resting on unreinforced layered system at the same footing settlement

Fig. 4(a) shows the variation of bearing pressure under the circular plate with respect to the settlement for the three cases, one with unreinforced section and with geogrid- and steel-wire-mesh- reinforced pavement sections. For the case of unreinforced pavement section, a peak bearing pressure equal to 403kPa is reached within footing settlement of 25mm followed by a plateau in the load-settlement behaviour. While no such peak behaviour in the load-settlement behaviour was noticed for the reinforced pavement sections (both geogrid and steel-wire-mesh) and the load was found to increase continuously with the settlement for footing settlements within 50mm. Fig. 4(b) shows the variation in load improvement factor with respect to different settlement ratios for both geogrid and steel-wire-mesh reinforcements. The improvement was found to be higher at higher settlement ratios for both the reinforcement types confirming the mobilization of reinforcing effect at higher pavement rut depth. Load improvement factor ranges from 1.4 to 1.9 and 1.1 to 1.7 for steel-wire-mesh and geogrid reinforced pavement sections, respectively. Abu-Farsakh, Akond, and Chen [2] performed studies on pavement sections reinforced with single layer of reinforcement and reported that load improvement factors ranged from 1.04 to 1.28 at a settlement ratio of 26% for different types of geogrids considered in their study. The findings from the present study indicate that steel-wire-mesh reinforcement can also be a potential material to contribute towards the reduction in the pavement crust thickness, construction, rehabilitation, and maintenance costs of

asphalt pavement layers, leading to provision of sustainable road infrastructure.

III. PART (B) DESIGN OF REINFORCED ROADS

A. Geogrid reinforced pavements

American Association of State Highway and Transportation Officials flexible pavement design method [3] is one of the most widely used methods to design paved roads with geogrids for base reinforcement. Giroud and Han [7, 8] have proposed a recent method to design unpaved roads. To study and quantify the potential reduction in granular base course thickness of flexible pavements, the above mentioned two methods are used to design geogrid reinforced unpaved and paved roads.

B. Reinforced unpaved road design - Giroud and Han method [10,11]

Researchers Giroud and Han have developed a theoretically based and experimentally calibrated design method for geogrid-reinforced unpaved roads. To serve a traffic of 10,000 ESALs with 40 kN wheel load, three cases of unpaved unreinforced roads having subgrade CBR equal to 1%, 3% and 5%, and six cases of reinforced unpaved roads with two types of geogrids having aperture stability modulus 0.32 N-m⁰ and 0.65 N-m⁰ available in the market are selected to design unpaved roads. Granular layer thickness was determined considering a rut depth of 75mm and 50mm. Reference [15] recommends to use a rut depth of 50mm. According to this method of pavement design, Eq. 2 is used to determine the required granular layer thickness, h, for each of the unreinforced and reinforced cases.

$$h = \frac{0.066 + (0.661 - 1.005 J^2) \left(\frac{f_s}{s}\right)^{0.2} \log N}{1 + 0.204 (R_E - 1)} \left[\sqrt{\frac{\frac{P}{rc^2}}{f_s \left(1 - 0.9 \exp\left[-\left(\frac{P}{N_c}\right)^2\right]\right) N_c f_c CBR_{sg}} - 1} \right] \quad (2)$$

- where, h = required base course thickness (m)
- J = aperture stability modulus in metric units (N-m/degree)
- P = wheel load (kN)
- r = radius of tire print (m)
- N = number of axle passes
- R_E = modulus ratio = 3.28 CBR_{bc}^{0.3} / CBR_{sg} ≤ 5
- CBR_{bc} = aggregate base course CBR = 30%
- CBR_{sg} = subgrade CBR
- f_s = rut depth factor 0.075m
- s = maximum rut depth (m)
- N_c = bearing capacity factor = 3.14 for unreinforced roads = 5.71 for geogrid reinforced roads
- f_c = factor relating subgrade CBR to undrained cohesion, c_u = 30 kPa

In order to calculate a required thickness using Eq. 2, it is necessary to iterate the thickness, h, until both sides of the equation are numerically the same. The base course reduction factor (BCR) is defined as the percent reduction in the base-course thickness due to an addition of geosynthetic reinforcement (T_r) in relation to the thickness of the flexible

pavement with the same materials but without reinforcement (T_u) to reach the defined failure state. BCR is calculated using Eq. 3. A summary of thickness obtained using Giroud and Han method of pavement design along with BCR values are presented in Table 1. BCR ranges from 31% to 60% depending on subgrade CBR for an aperture stability modulus of 0.32 N-m⁰, while it varies from 44% to 70% for an aperture stability modulus of 0.65 N-m⁰. A minimum granular layer thickness of 150mm is kept to function as cover aggregate in reinforced pavement to meet construction survivability criterion for new construction as recommended by geosynthetic materials association (GMA).

$$BCR = \frac{(T_u - T_r)}{T_u} \times 100 \quad (3)$$

where, T_u = thickness of granular layers (GB+GSB) of unreinforced pavement

T_r = thickness of granular layers (GB+GSB) of reinforced pavement

TABLE II SUMMARY OF UNPAVED ROAD THICKNESSES USING GIROUD AND HAN METHOD FOR SELECTED DESIGN PARAMETERS

CBR	Rut depth, mm	Unreinforced granular layer thickness (mm)	Reinforced granular layer thickness, mm			
			J = 0.32 N-m ⁰	BCR (%)	J = 0.65 N-m ⁰	BCR, %
1	75	690	455	34	329	52
1	50	860	590	31	478	44
3	75	376	150	60	150	60
3	50	504	286	43	150	70
5	75	293	150	49	150	49
5	50	433	150	65	150	65

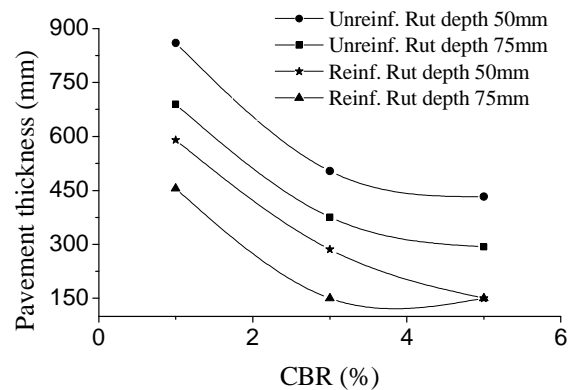


Figure 5 Variation of pavement thickness with CBR for unreinforced and reinforced pavements (with geogrid aperture stability modulus, J=0.32 N-m⁰) corresponding to different rut depths

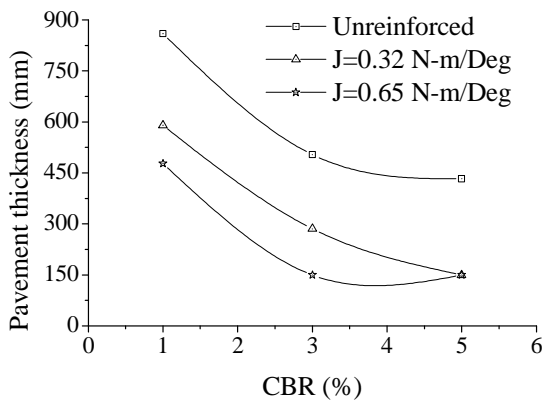


Figure 6 Variation of pavement thickness with CBR for unreinforced and reinforced cases corresponding to two different J values at a rut depth of 50mm

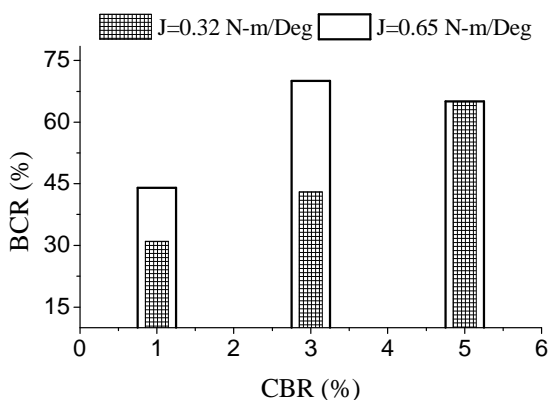


Figure 7 Variation of BCR with CBR corresponding to two different J values at a rut depth of 50mm

C. Reinforced paved road design-Empirical Design Method from AASHTO R50 (2009)

Guidelines given in [1] for design of geogrid-reinforced base courses in flexible pavements are empirical in nature. Design steps followed in this method were initially reported by Berg, Christopher & Perkins (2000). Reference [3] pavement design is based on serviceability criterion of the pavement system expressed through measurements of roughness and different types of distress (cracking, rutting, etc.). The load carrying capacity of a pavement is expressed with the number of equivalent standard axial loads (ESALs) at which the permanent deformation on the surface reaches specific value (allowable rut depth equal to 25mm). The number of ESALs is calculated using Eq. 4.

$$\log(W_{18}) = Z_R S_0 + 9.36 \log_{10}(SN + 1) - 0.2 + \frac{\log_{10} \left[\frac{\Delta PSI}{2.0} \right]}{0.4 + \frac{1.624}{SN + 1}} + 2.32 \log_{10} M_R - 8.02 \tag{4}$$

where, W_{18} =Number of Equivalent Standard Axle Load (80kN) passes
 Z_R = Standard Normal Deviate= -1.282 for a reliability of 90%
 S_0 = Standard Deviation = 0.49

SN = Structural Number
 ΔPSI = Change in Present Serviceability Index = 4.2 – 2.0 = 2.2
 M_R = Resilient Modulus of subgrade (psi)

Kwon, Tutumluer, & Al-Qadi [20] states that the effectiveness of geogrid reinforcement appears to be more pronounced when used in roads designed for low to moderate traffic volumes (less than 2,000 average daily traffic), especially when the pavement structure consists of a thin (40-100mm) hot-mix asphalt (HMA) layer on top of an unbound aggregate granular base/sub base layer. The unreinforced pavement structure was selected from [16] for a traffic of 10 million standard axle passes for three types of subgrades with CBR 3%, 5% and 8%. Table 3 gives the unreinforced pavement thickness. Resilient modulus of subgrade soil is calculated using Equations 5 or 6 based on the CBR value.

$$M_r = 10CBR \tag{5} \text{ for CBR up to 5\%}$$

$$M_r = 17.6 CBR^{0.64} \tag{6} \text{ for a CBR of 8\%}$$

TABLE III UNREINFORCED PAVEMENT LAYER DETAILS FOR A TRAFFIC OF 10MSA AS PER [16]

Subgrade CBR	Pavement layers	Thickness, mm
3%	Bituminous wearing course	40
	Bituminous base course	90
	Granular base	250
	Granular sub-base	380
5%	Bituminous wearing course	40
	Bituminous base course	70
	Granular base	250
	Granular sub-base	300
8%	Bituminous wearing course	40
	Bituminous base course	60
	Granular base	250
	Granular sub-base	200

The AASHTO method utilizes an index term the “structural number” (SN) to indicate the required combined structural capacity of all pavement layers overlying the subgrade. SN is calculated for selected pavement based on AASHTO recommended values of layer coefficients and drainage coefficients using Eq. 7.

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \tag{7}$$

where, SN = structural number
 a_1, a_2 and a_3 are surface, base and sub-base layer coefficients
 D_1, D_2 and D_3 are surface, base and sub-base layer thickness
 m_1 and m_2 are drainage coefficients for base and sub-base layers

Equation 4 is used to calculate number of standard axle (W_{18}) passes (N_u). The efficiency of the geosynthetic as a reinforcement in a road can be quantified by the Traffic

Benefit Ratio (TBR), defined as the ratio of the number of load cycles to reach a defined failure state for a reinforced section to the number of cycles to reach the same failure state for an unreinforced section. Table 4 presents TBR reported from various studies in the literature.

$$TBR = \frac{N_r}{N_u} \dots \dots \dots (8)$$

where, N_r = number of load passes on reinforced road
 N_u = number of load passes on unreinforced road

TABLE IV LIST OF RESEARCHERS WITH WORK DESCRIPTION AND REPORTED TBR VALUES FOR GEOGRID REINFORCED PAVEMENTS FROM LITERATURE

S.No	Reference	Work description	Reported TBR value
1	Webster (1993)	Full scale field instrumented test sections with subgrade CBR 3%, 5% and 8%	0.9 to 22.4
2	Chen, Abu-Farsakh, & Tao (2009)	cyclic plate load tests in test tank 2mX2mX1.7m with silty clay sub grade	3 to 19
3	Latha, Nair, & Hemalatha (2010)	Instrumented Field tests for biaxial geogrid and subgrade CBR 1%	6.5
4	Palmeira & Antunes (2010)	cyclic plate load tests in test tank 1.6mX1.6mX1.2m with subgrade CBR 8%	7 to 9
5	Jie Gu (2011)	Analysis of finite element results based on the mechanistic empirical approach	3.4
6	Jersey et al. (2012)	full scale field tests with subgrade CBR 2-3%	12+
7	Qian, Han, Pokharel, & Parsons (2013)	cyclic plate load tests in test tank 2mX2.2mX2m with subgrade CBR 2% triangular aperture geogrid	13

In this study, TBR values of 3 and 6 are considered to calculate number of standard axle passes, N_r , for a reinforced pavement using Eq. 8. SN of reinforced pavement is calculated using Eq. 4 by inputting the calculated N_r . Difference in SN of reinforced and unreinforced pavement is considered as equivalent SN of geogrid. SN of base and sub-base layers is reduced by changing the thickness to the extent of SN of geogrid and BCR is calculated using Eq. 3 with reinforced and unreinforced base and sub-base layer thicknesses. Table 3 presents summary of the selected and calculated values of granular base (GB) and granular sub-base (GSB) layer thicknesses and BCRs for different subgrade CBRs and TBRs. It is observed that for a TBR of 3, BCR ranges from 22% to 29% whereas for TBR of 6, it goes up to 45%.

TABLE V SUMMARY OF UNREINFORCED AND REINFORCED PAVED ROAD DESIGN BASE AND SUB-BASE THICKNESSES WITH SELECTED SUBGRADE CBR AND TBR (AASHTO METHOD)

CBR	SN of Unreinforced pavement	Unreinforced granular layer thickness (GB+GSB), mm	TBR	Equivalent SN of geogrid	Reinforced granular layer thickness (GB+GSB), mm	BCR, %
3	5.29	250+380=630	3	0.81	200+250 = 450	29
5	4.65	250+300 = 550		0.74	200+200 = 400	27
8	4.04	250+200 = 450		0.67	150+200 = 350	22
3	5.29	250+380 = 630	6	1.37	150+200 = 350	44
5	4.65	250+300 = 550		1.25	150+150 = 300	45
8	4.04	250+200 = 450		1.13	125+125 = 250	44

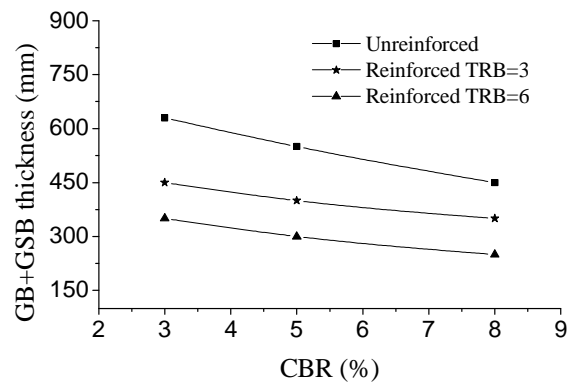


Figure 8 Variation of granular base and sub-base thickness with CBR for unreinforced and reinforced cases

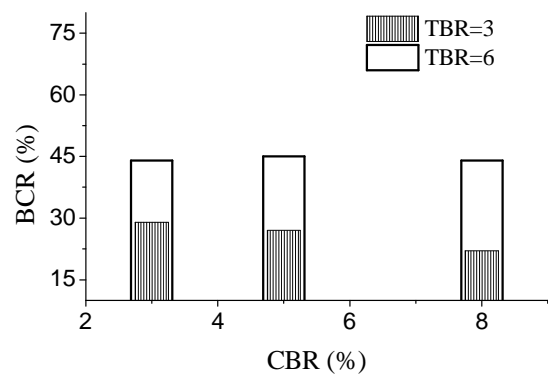


Figure 9 Variation of BCR with CBR for two different TBRs

IV CONCLUSIONS

(a) From the LSME studies conducted on the unreinforced and reinforced unpaved systems, it is concluded that inclusion of reinforcement in the form of geogrid and steel-wire-mesh reinforcements within the aggregate layer resulted in load improvement factor ranging from 1.1 to 1.7

and 1.4 to 1.9 at various settlement ratios of the footing respectively.

(b) Based on unpaved road design method given by Giroud and Han, it is possible to reduce the pavement thickness by 44% to 70% depending on the type of geogrid and subgrade strength.

(c) Based on paved road design based on AASHTO guidelines, the thickness of granular material can be reduced by 22% to 45%.

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