JOURNAL OF APPLIED ENGINEERING SCIENCES
ISSN: 2247-3769 / e-ISSN: 2284-7197

VOL. 13(26), ISSUE 2/2023
ART.NO. 372, pp. 175-182

DESIGN OF GEOTEXTILE REINFORCED GRAVEL ROADS USING GIROUD AND HAN APPROACH FOR INDIAN CONDITION

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Received: 17.08.2023 / Accepted: 05.09.2023 / Revised: 07.09.2023 / Available online: 15.12.2023

DOI: 10.2478/jaes-2023-0022

KEY WORDS: Gravel road, Geotextile, Aggregate thickness, California Bearing Ratio, Unique equation, Allowable Rut Depth

ABSTRACT:

Sustainable pavement is the need of the hour using the mechanistic and robust pavement design approach, eliminating empiricism in the present IRC SP 72-2015 design guidelines, if any. Giroud and Han (2004) (GH) approach has confirmed existing empiricism in IRC SP 72-2015 design guidelines and permits the use of locally available material, thus saving transportation costs and reducing air pollution. IRC SP 72 – 2015 recommends design thickness only for the unreinforced condition in gravel roads for the maximum rut of 50mm. This paper presents the comparative study of an unreinforced and geotextile-reinforced gravel road design for Indian conditions with the rut as a vital design parameter using the GH method for subgrade classes with 2% to 5% CBR and the maximum traffic count of 100,000. The proposed unique equation provides Allowable Rut Depth (ARD) based aggregate thickness for 10,000 to 100,000 traffic count apart from simplifying the complex procedure of the GH approach for IRC SP 72-2015 data. The unique equation's result reveals an increase of 22.65% in aggregate thickness is attributed to the increase in ARD of 30mm using locally available poor aggregates. This confirms the practical relevance of ARD in pavement design that may help in planning maintenance programs and road rehabilitation strategies. The results obtained from the unique equation match 85 to 100% with GH results. Saving up to 36.5% to 76.9% of costly aggregate is found in the case of geotextile-reinforced gravel roads in Indian conditions.

1. INTRODUCTION

1.1 Gravel Roads

In general, unpaved roads are low-volume aggregate or gravel-surfaced rural roads, commonly known in India as Water-Bound Macadam (WBM) roads (IRC, 2015). A gravel layer with surface screenings of medium to hard clayey gravel overlaid over subgrade is typical in WBM construction. The aggregate layer reduces the intensity of vertical stress to the subgrade layer, allowing vertical deformation at the design-acceptable limit by spreading the wheel load to a broader area. In this paper, the maximum traffic considered for WBM roads is up to a cumulative 100,000 Equivalent Single Axle Load (ESAL) repetitions (AASHTO, 1993, IRC, 2012, 2015). However, the unpaved road length in India constitutes less than half the total road length (IRC, 2008, 2015, Jayalakshmi, 2023). According to road statistics in India, out of the total rural roads, 13.7% (331,552 km) are WBM roads. Unpaved roads in India are suitable for average daily traffic of 200 vehicles per day (IRC, 2008). The access to habitats is improved with the emerging aggregate surface road as an economical option (IRC, 2008).

Since 1970, research has acknowledged that geosynthetic inclusions in weak subgrade layers improve road performance to a greater extent (Singh, 2020), tolerate deeper ruts (Cuelho, 2017), allow the use of locally available material towards achieving sustainability (Singh, 2020, The best performance indicator in road evaluation is the rutting behavior and the rate of the rut with traffic (AASHTO, 1993, Giroud, 2004a, 2004b, Hammit, 1970, Perkins, 2012). The 75 mm rut depth is typical for unpaved roads (Hammit, 1970). The Tensioned Membrane Effect (TME) in geosynthetic reinforced roads is mobilized at a deeper rut (Milligan, 1989), and lateral constraint is developed at a smaller rut to improve the road performance (Ingle, 2017, Jayalakshmi, 2021). Early design methods rely on historical road design data (Barenberg, 1975). The empirical design approaches (Barenberg, 1975, IRC, 2015, 1984, Sellmeijer, 1982, 1983) and the quasi-static semi-empirical design approach (Giroud, 1981) developed design equations and charts. The mechanistic-based approach is encouraged in road design after Giroud and Han (GH) (Giroud, 2004a, 2004b, Tingle, 2003). The methodology of reinforcing pavement with geosynthetics proves the exceptional performance of pavement, delays rut formation, reduces permanent surface deformation (Tingle, 2007), reduces gravel layer thickness by approximately 30% (Perkins, 2012), facilitates compaction, offers sustainable benefits (Singh, 2020), extends service life and the influence of geosynthetic tensile stiffness is efficient (Hufenus, 2006) satisfies economic and ecological aspects (Hufenus, 2006), mainly when the subgrade California bearing Ratio (CBR) is less than 3% (Cuelho, 2017, Jayalakshmi, 2021, Hufenus, 2006). The design equations for determining stress distribution angle in roads are available in the GH approach (Giroud, 2004a, Burmister, 1958).

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The geosynthetic inclusion in a weak subgrade improves the subgrade bearing capacity and base reinforcement (Giroud, 1985, Haas, 1988, Milligan, 1986, Christopher, 1991, Barksdale, 1989, Al-Qadi, 1994, Collin, 1996) prevents lateral spreading, vertical displacement of the loaded area is reduced by 15% to 20% (Dondi, 1994). Maximum benefits are achieved when the geosynthetic is placed at the upper one-third depth of the base layer (Baadiga, 2021).

1.2 Giroud and Han Approach 2004

Giroud and Han (GH) developed a generic equation for aggregate thickness, which applies to reinforced and unreinforced conditions. The design parameters involved are limited modulus ratio, wheel load, tyre radius, bearing capacity factor, aperture modulus, Allowable Rut Depth (ARD), subgrade CBR, and the number of standard axle passes. In the GH design philosophy, ARD is the serviceability criteria that do not relate to the base or subgrade failure. The primary parameter is the stresses developed at the aggregate subgrade interface. The approach is limited to subgrade CBR of less than 5 and valid for 50 to 100mm rut depth. GH considers the limited modulus ratio with a maximum limit of 5, attributed to the subgrade and aggregate layer subgrade CBR.

1.3 Design Approaches in India

Indian Roads Congress (IRC) is an autonomous body of the Ministry of Road Transport and Highways, Government of India, which provides guidelines and design approaches for roads in India. IRC road design approaches are mostly empirical-based and semi-mechanistic-based methods. IRC 37 (1984, 2012) provides the guidelines for flexible pavement. Indian Roads Congress Special Publication (IRC SP) 72-2015 provides guidelines for gravel/unpaved roads, which is the focus of this paper. In India, the aggregate thickness for gravel roads depends on serviceability loss over the design life. IRC SP 72 is a performance-based design that limits ARD from exceeding 50mm for the design catalogs data of gravel roads. IRC SP 72 design catalogs present the pavement composition and thickness for design traffic and subgrade strength. IRC SP 72 depends on exhaustive research data from AASHTO (1993) guidelines. IRC SP 72 does not provide design details of geosynthetics-reinforced unpaved roads and does not provide information on mechanics arriving at the data presented in the design catalog for unreinforced unpaved roads. This paper presents geotextile-reinforced road design using the GH approach for IRC SP 72 data.

2 PRESENT INVESTIGATION

2.1 Water Bound Macadam

The present analytical investigation follows GH's comprehensive generic design equations in Table 1 to arrive at equation (1).

Parameter	Equation
Equivalent tyre contact area (r)	$r = \sqrt{\frac{P}{\pi\rho}}$
California bearing ratio for subgrade soil (CBR sg)	$C_u = f_c\, CBR_{sg}$
Allowable bearing capacity of subgrade soil without reinforcement ($P_{h=0}$)	$P_{h=0} = \left(\frac{s}{f_s}\right) \pi r^2\, N_c\, f_c\, CBR_{sg}$
Limited modulus ratio (R_E)	$R_E = \min\left(\frac{3.48\, CBR_{bc}^{0.3}}{CBR_{sg}}, 5.0\right)$
Modulus ratio factor (f_E)	$f_E = 1 + 0.204\,(R_E - 1)$
Bearing capacity mobilization factor (m)	$m = \left(\frac{s}{f_s}\right)\left[1 - \varepsilon\, exp^{-\omega\left(\frac{r}{h}\right)^n}\right]$

Table 1. Giroud – Han's generic design equations

In this paper, the IRC SP 72 data is superimposed in the GH approach in developing a unique equation for unreinforced aggregate thickness. The aggregate saving in geotextile-reinforced conditions is estimated for the Indian condition.
The comprehensive equation is given in equation (1)

$$h = \frac{0.868 + \left(0.661 - 1.006 J^2\right)\left(\frac{r}{h}\right)^{1.5} logN}{1 + 0.204[R_E - 1]}\left[\sqrt{\frac{\frac{P}{\pi r^2}}{\left(\frac{s}{f_S}\right)\left[1 - 0.9e^{-\left(\frac{r}{h}\right)^2}\right] N_c f_C CBR_{sg}}} - 1\right] r \quad (1)$$

where: h = aggregate thickness (m); P = wheel load (kN); N = design traffic of standard axle load; J = geogrid aperture stability modulus, (J as 0 for geotextile reinforced and unreinforced state); r = radius of equivalent tire contact area; R_E = limited modulus ratio for base and subgrade layer; s = allowable rut depth (mm); f_S = factor equal to 75 mm; N_c = bearing capacity factor; f_C = factor equal to 30 kPa; CBR_{sg} = subgrade CBR.

2.2 Serviceability Criteria

The present investigation considers the rut formation as serviceability criteria, and the rut between 50 to 100mm, as suggested by GH, is applied. Rut depth is the maximum vertical deformation measured at the road surface. A typical Allowable Rut Depth (ARD) is 75mm (Cuelho, 2017, Giroud, 2004a, 2004b). In the GH approach, the aggregate thickness is more if the selected allowable rut is small and vice-versa. If pavement design limits the rut to 13 to 75mm (AASHTO, 1993), it mobilizes reinforcement benefit in the form of only lateral constraints, where the Tensioned Membrane Effect (TME) is negligible (Giroud, 2004a, 2004b). When the rut depth exceeds 75mm, TME becomes predominant with ensured additional reinforcement benefits.

2.3 IRC SP 72 – 2015 data for the present study

The present investigation considers IRC SP 72 data only for traffic categories T1, T2, and T3, where T1 is for 10,000-to-30,000, T2 for 30,000-to-60,000, and T3 for 60,000-to-100,000-wheel passes. Based on CBR values of 2%, 3-4%, and 5%, the first three IRC SP 72 categories of subgrade classes S1, S2, and S3, respectively, are only considered because the GH approach is applicable for the subgrade CBR up to 5%.

3 ANALYSIS USING THE GH APPROACH

3.1 Unreinforced pavement

The typical aggregate thickness obtained using the GH approach for Indian traffic T1, T2, and T3 under the unreinforced condition for subgrade having 3% CBR by varying rut depth (r) from 50 to 100mm is given in Figure 1.

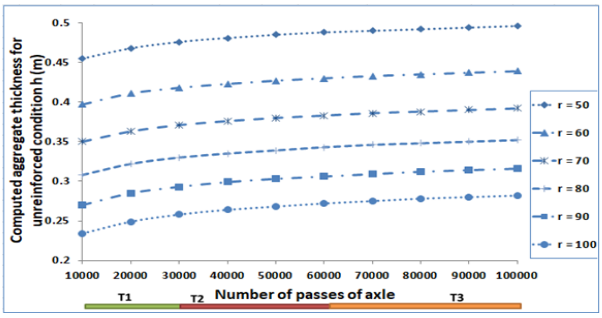

Figure 1. Typical curve for subgrade CBR 3% and Indian traffic T1, T2, T3 for the unreinforced road from 50 to 100 mm rut (r)

From Figure 1, for design traffic of 10,000 with a rut depth of 70mm, the computed aggregate thickness is 0.35m. This proves the need for reinforcement in the pavement layer as an economical solution to achieve sustainability. For a typical case of 100,000 traffic, the aggregate thickness varies from 0.282m to 0.496m for rut depths of 100mm to 50mm, respectively. Hence the required aggregate thickness decreases for the same traffic with the increase of ARD.

The IRC aggregate thickness for 10,000 to 100,000 traffic for subgrade CBR of 2%, 3%, 4%, and 5% increases by 25%, 62.5%, again 62.5%, and 57.1%, respectively. When the allowable rut increases for 4% and 5% subgrade CBR, the required aggregate thickness becomes negligible and sometimes negative. Hence the resistance to rut improves as subgrade CBR increases. The aggregate thickness computed by the GH approach for 10,000 to 100,000 traffic with ARD 50mm shows variations by 3%, 4%, 5%, and 6% for subgrade CBR of 2%, 3%, 4%, and 5%, respectively. Figure 2 shows the increase in the aggregate layer thickness with traffic as per the GH approach for ARD 50mm, along with the aggregate thickness suggested by IRC SP 72.

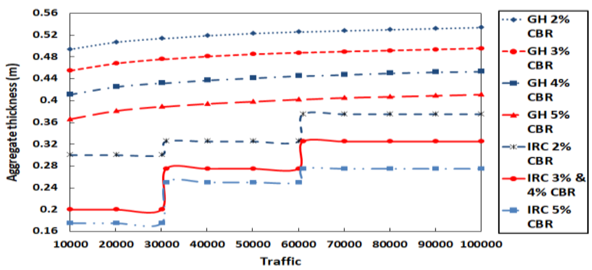

Figure 2. Traffic-wise aggregate thickness by GH and IRC SP 72 catalog with ARD 50mm for 2% to 5% subgrade CBR

As indicated in Figure 2, the aggregate thicknesses of the IRC SP 72 remain constant for each traffic category, with an abrupt rise at 30,000 and 60,000 traffic. For example, for 3% CBR with the same 60,000 traffic, the aggregate thickness for the T2 category is 0.275m, and T3 is 0.325m. Hence, in Figure 2, the vertical line is observed at 30,000 and 60,000 traffic, with two points showing two IRC aggregate thicknesses for two traffic categories for the given subgrade CBR.

The aggregate thickness observed for all the subgrade CBR in GH approach is higher than those suggested by IRC SP 72. This may be attributed to the lesser ARD considered by IRC SP 72. Superimposing the IRC SP 72 recommended unreinforced aggregate thickness data in Figure 1 enables us to arrive at the Allowable Rut Depth for Unreinforced (ARD_{UR}) for the Indian condition. Figure 3 displays the magnified view of the IRC curve intersecting the other rut curves of the GH approach. A similar approach can plot the curves for the CBR range of 2% to 5% for T1, T2, and T3 traffic.

In Figure 3, the horizontal line showing the IRC SP 72 recommended thickness of 0.325m for T3 traffic lies between rut depths of 85mm to 87mm computed for a typical 3% subgrade CBR by GH approach for the unreinforced unpaved road for Indian conditions.

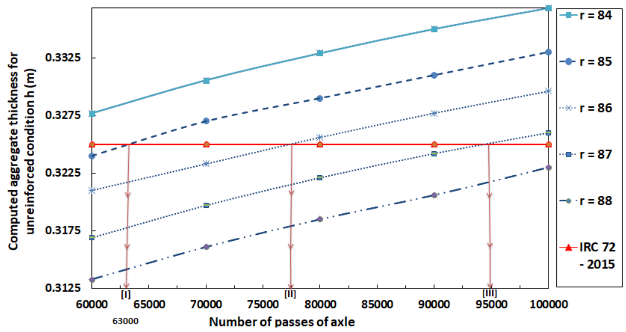

Figure 3. Typical curve for observed allowable rut by GH approach for Indian T3 traffic with 3% CBR subgrade for unreinforced condition

Hence, GH permits the higher allowable rut of 35 to 37mm for the same aggregate thickness, compared to IRC SP 72 ARD of 50mm. In other words, ARD of 85mm, 86mm, and 87mm suggests allowable traffic of 63,000; 77,500; and 95,000, respectively, for the constant aggregate thickness of 0.325m given by IRC SP 72 for a single wide traffic range of 60,000 to 100,000. Hence it may be concluded that IRC SP 72 approach is conservative and thus uneconomical based on ARD.

Hence Figure 3 depicts the methodology adopted to bring in a mechanistic approach in IRC SP 72 by superimposing the two existing design procedures. The superimposition is valid as both the existing approach has a common reference of using AASHTO (1993) in their design procedures for achieving their respective aggregate thickness. GH referred to AASHTO (1993) for obtaining information on the resilient modulus of the aggregate layer to derive a correlation between the modulus and CBR. IRC SP 72 approach used the extensive experimentation experience of AASHTO (1993) in developing the design chart.

4 UNIQUE EQUATION

Development of a unique equation embodying the mechanistic approach of GH with non-mechanistic-based IRC SP 72 -2015 for unreinforced conditions is attempted. The proposed unique equation derived from specific ARD GH curves, which fall in the IRC SP 72 trend line. As per the GH limitation, the zone from 50mm to 100mm rut is not considered. Figure 4 shows the IRC SP 72 trend line for subgrade CBR of 3%, which falls in three GH curves with ARD 80, 90, and 100mm. The linear equations of these three GH curve with R^2 = 0.89 is considered for 3% subgrade CBR. Similarly, the linear equations are obtained for 2%, 4%, and 5% subgrade CBR from their respective GH curves of ARD ranging from 70mm to 100mm in IRC SP 72 trend line to derive a unique equation. The ten linear equations are obtained for the S1, S2, and S3 subgrade classes having CBR 2%, 3-4%, and 5%, respectively, for traffic T1, T2, and T3, by selecting the respective GH curves on the IRC SP 72 trend line.

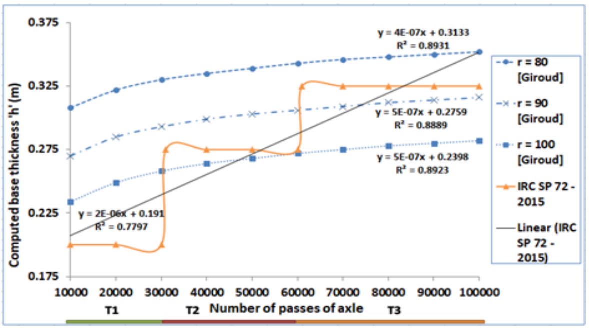

Figure 4. Typical curve for observed allowable rut by GH approach for Indian T3 traffic with 3% CBR subgrade for unreinforced condition

Table 2 shows above mentioned equations. The equations are simplified further to obtain the unique equation for subgrade CBR 2% to 5%, as given below in equation (2).

Subgrade CBR /class	Allowable Rut Depth (mm)	Linear equations For 10000 to 100000 traffic
2% S1 subgrade class	80	0.0000004x + 0.3608
	90	0.0000004x + 0.3288
	100	0.0000004x + 0.3004
3% S2 subgrade class	80	0.0000004x + 0.3133
	90	0.0000005x + 0.2759
	100	0.0000005x + 0.2398
4% S2 subgrade class	80	0.0000005x + 0.2549
	90	0.0000006x + 0.2001
5% S3 subgrade class	70	0.0000005x + 0.2449
	75	0.0000006x + 0.2073

Table 2. Set of linear equations showing details of subgrade CBR, traffic, and ARD

$$Y = 0.00000048x + C \quad (2)$$

where:

Y = Aggregate layer thickness (mm)
X = Design traffic (10,000 to 100,000)
C = Y-intercept, the aggregate layer thickness (mm) for 10,000 traffic.

Figure 5 is plotted to find the value of C in equation (2) for the unique equation for subgrade CBR 2% to 5% by extrapolating forward and backward from the ARD point of passing the IRC SP 72 trend line to cover the rut from 50mm to 100mm. The unique equation computes the GH thickness for the Indian condition by following equations in Table 1 and equation (1).

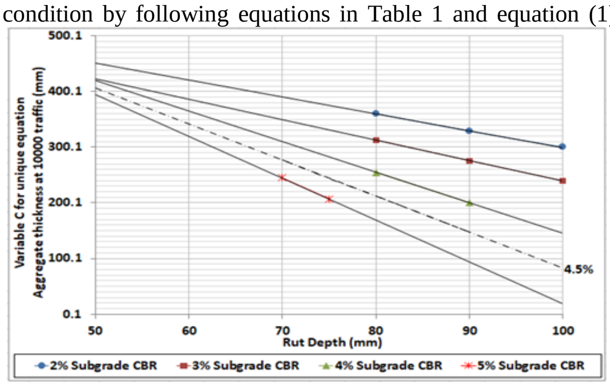

Figure 5. Graph showing y-intercept with ARD 50mm to 100mm for subgrade CBR 2% to 5% to apply in the unique equation

The observation from Figure 5 is that the value of the C variable decreases as the rut value increases. The design examples illustrated below demonstrate the use of the unique equation developed in this article and compare the result with GH and IRC SP 72.

4.1 Design Example

Compute aggregate layer thickness for subgrade CBR of 4.5% with ARD 50mm for design traffic 100,000.

4.1.1 Solutions

As a preliminary step, the value of C = 408.1mm, obtained from Figure 5 for given ARD = 50mm and CBR = 4.5%, is used in equation (2) to obtain aggregate thickness.
Result for aggregate layer thickness from:
(a) Unique equation = 456.1mm
(b) GH approach = 471mm
(c) IRC SP 72 recommended thickness = 432mm
Unique equation result summary:
(i) Decrease in thickness with reference to GH result =3.2%
(ii) Increase in thickness with reference to IRC SP 72 thickness = 5.5%

Hence the unique equation provides the approximately average thickness of the two approaches and ARD-based aggregate thickness in comparison to IRC SP 72 approach, suggesting a unique rut of 50mm for a wide range of traffic. The increase of 22.65% in aggregate thickness is attributed to the increase in ARD of 30mm. This confirms the practical relevance of ARD in pavement design that helps in planning maintenance programs and road rehabilitation strategies.

From the design example, it is prudent that this unique equation simplifies the use of the GH approach, and with reference to IRC SP 72, it is not too conservative, but it allows more ARD than the recommended 50mm by IRC SP 72. For the typical case of subgrade CBR of 3%, the aggregate layer results from the GH approach and unique equation for traffic 10,000 to 100,000 decrease in the range of 0.26% to 3.3% for ARD 80mm, 0.16% to 4% for ARD 90mm, and 0.07% to 4.5% for ARD 100mm.

The aggregate thickness value from the unique equation for 100,000 traffic with ARD 50mm is 15%, 7%, and 4% less than the GH approach thickness for 2-3%, 4%, and 5% subgrade CBR, respectively. But the unique equation aggregate thickness is 20%, 30%, and 44% more than IRC recommended thickness for 2%, 3- 4%, and 5% subgrade CBR, respectively.

5 GEOTEXTILE REINFORCED PAVEMENT

As a typical case, aggregate thickness for the geotextile reinforced condition using the appropriate parameters like J =0 and N_c = 5.14 for subgrade CBR 3% is shown in Figure 6. From Figure 6, the range of aggregate thickness for the geotextile-reinforced case for IRC SP 72 traffic is observed from 0.031m to 0.345m for the rut range of 90mm to 50mm, respectively.

Figure 1 and Figure 6 results reveal that for the same rut of 50mm and traffic of 100,000, the aggregate thickness is reduced due to geotextile inclusion, from 0.496m to 0.345m.

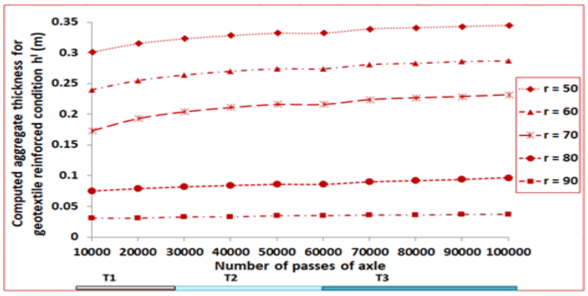

Figure 6. Typical curve for subgrade CBR 3% and Indian traffic T1, T2, T3 for geotextile reinforced unpaved road

From Figure 6, the observed rut for the aggregate thickness of 0.3m at 10,000 traffic for the geotextile-reinforced case is 50mm, and from Figure 3, for the unreinforced case is 82mm. Hence, rut reduction is due to geotextile inclusion at the aggregate-subgrade interface for the given aggregate thickness.

The aggregate thickness for geotextile-reinforced gravel roads by the GH approach for 2%, 3%, 4%, and 5% subgrade CBR confirms that the required aggregate thickness reduces as the allowable rut increases. It also confirms that the need for reinforcement diminishes as the subgrade CBR increases with the reduction in the allowable rut range (Giroud, 2004a, 2004b).

The typical case shown in Figure 1 and Figure 6 indicates the range of Allowable Rut Depth for Unreinforced (ARD_{UR}) and Geotextile Reinforced (ARD_{GR}) cases of 50 to 100mm and 50 to 90mm, respectively. Table 3 shows the allowable rut range for the unreinforced condition and geotextile reinforced condition of subgrade class S1 to S3 for T1, T2, and T3 traffic.

Subgrade CBR (%)	Unreinforced ARD_{UR} (mm)	Geotextile Reinforced ARD_{GR} (mm)
2	50 - 100	50 - 100
3	50 - 100	50 - 90
4	50 - 100	50 - 65
5	50 - 85	50 - 55

Table 3. Summary for the allowable rut range observed in the GH approach for subgrades classes S1, S2 and S3

The aggregate thickness for the ARD, different from the range given in Table 3, becomes invalid because the GH equation gives a negative value of aggregate thickness beyond a certain magnitude of the rut. Henceforth, this rut magnitude is called critical rut depth (CRD).

The critical rut for unreinforced and geotextile-reinforced cases is abbreviated as CRD_{UR} and CRD_{GR}. If ADR_{UR} is more than CDR_{UR}, provide a bare minimum aggregate thickness to avoid the deterioration of the subgrade. The minimum thickness may vary based on aggregate gradation, which in the case of IRC is 75mm. If ARD_{UR} is less than CRD_{UR}, the required aggregate thickness from the GH approach must be provided for the given traffic (Giroud, 2004a, 2004b).

6 RESULTS AND DISCUSSION

6.1 Geotextile Reinforced Gravel Road

The IRC SP 72 code only gives aggregate/macadam thickness of unreinforced conditions. It does not provide a design chart for geotextile-reinforced conditions.

Hence this paper presents aggregate thickness for the geotextile-reinforced condition for Indian roads by following the GH approach. Figure 7 shows the superimposition of intersection points from Figure 3 in Figure 6 for the predicted allowable rut range for the geotextile reinforced case for 3% subgrade CBR and T3 traffic. To compute the aggregate thickness required for geotextile reinforced unpaved road for Indian conditions point of intersection [I] from Figure 3 for 63,000 traffic with ARD 85mm is projected in Figure 7 and is observed to be 0.051m.

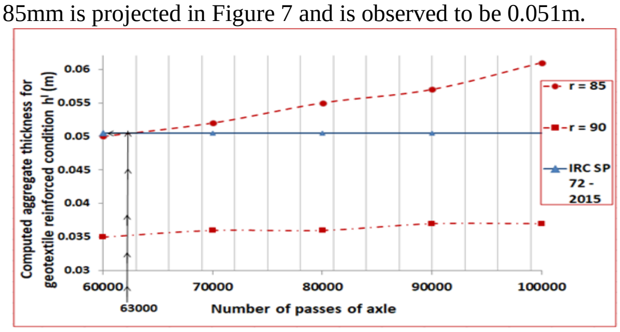

Figure 7. T Typical curve by GH approach for Indian T3 traffic and 3% CBR for geotextile reinforced condition

Since the IRC aggregate thickness for the unreinforced condition is 0.325m, the aggregate saving for T3 traffic for subgrade CBR 3% is 84.31% in the geotextile-reinforced condition. Similarly, the aggregate thickness for other CBR classes and traffic categories is computed for geotextile-reinforced conditions using the above-mentioned methodology.

6.2 Benefits of geotextile reinforced unpaved road for Indian condition

The comprehensive data of saving in aggregate thickness for S1, S2, and S3 subgrade classes and T1, T2, and T3 traffic categories is given in Table 4, Table 5, and 6.

CBR (%)	IRC SP 72 - 2015 unreinforced thicknesses h (mm)	Geotextile reinforced aggregate thicknesses h (mm)		
	T1	T1		
2	300	# 143		
3	200	#(-39)	** 75	* 100
4	200	#(-84)	** 75	* 100
5	175	#(-147)	** 75	* 100

Table 4. Saving in natural aggregate for geotextile reinforced unpaved road for T1 traffic up to 30000 cycles

CBR (%)	IRC SP 72 - 2015 unreinforced thicknesses h (mm)	Geotextile reinforced aggregate thicknesses h (mm)		
	T2	T2		
2	325	# 172		
3	275	# 15	** 75	* 100
4	275	# (-16)	** 75	* 100
5	250	# (-94)	** 75	* 100

Table 5. Saving in natural aggregate for geotextile reinforced unpaved road for T2 traffic up to 60,000 cycles

CBR (%)	IRC SP 72 - 2015 unreinforced thicknesses h (mm)	Geotextile reinforced aggregate thicknesses h (mm)		
	T3	T3		
2	375	# 238		
3	325	# 51	** 75	* 100
4	325	# 23	** 75	* 100
5	275	# (-81)	** 75	* 100

Table 6. Saving in natural aggregate for geotextile reinforced unpaved road for T2 traffic up to 60,000 cycles

Theoretical thickness as per GH equation
* Minimum aggregate thickness recommended by GH as well as Grade I macadam of IRC
**Minimum aggregate thickness as per Grading II and III macadam of IRC

Tables 4 to 6 show that for the given subgrade CBR, the percentage saving of natural aggregate decreases with the increase in traffic. While for the given traffic, the percentage saving in aggregate decreases with the increase in subgrade CBR. Thus, it may be concluded that geotextile reinforcement is more beneficial in poor subgrade because of saving in costly natural resources apart from other associated benefits, viz, use of locally available resources with saving in transportation cost with pollution reduction. It also provides durable and economical pavement based on the designed life cost.

The state of limit equilibrium of the subgrade is reached when the mobilization factor (m) becomes one. In other words, when the deflection at the interface is equal to ARD. When 'm' is more than one, the computed aggregate thickness becomes more than the minimum thickness to safeguard the subgrade from shear failure (Giroud, 2004a, 2004b). The computed negative aggregate thickness value for the geotextile-reinforced condition shown in Tables 4 to 6 indicates no need for an aggregate layer for that subgrade. From a practical standpoint for computed negative aggregate thickness, GH and IRC suggest 100mm and 75mm as minimum thicknesses, respectively, not only to protect the subgrade but also to prevent wear and tear of reinforcement from exposed direct traffic and to get the added benefit of mobilization of geotextile reinforcement mechanism.

6.2.1 Minimum Aggregate Thickness and its CBR

Aggregate gradation is the key parameter deciding minimum thickness. IRC recommends grading II (63mm – 45mm) and III (53mm– 22.4mm) for Water Bound Macadam (WBM) layer with the minimum aggregate compacted thickness of 75mm. GH recommends a minimal aggregate thickness of 100mm.

The minimum aggregate thickness may differ if the aggregate gradation is based on locally available material. The GH approach considers the limited modulus ratio with a maximum value of 5, as shown in Table 1. Equation (3) is obtained, considering the limited modulus ratio with a maximum value of 5 to compute aggregate CBR.

$$CBRbc = ((5 * CBR_{sg})/3.48)^{3.33} \quad (3)$$

where: $CBRbc$ = California Bearing Ratio of the base course;

$CBRsg$ = California Bearing Ratio of the subgrade;

Aggregates/Macadam having CBR value equal to or more than given by Equation (3) is suitable per the GH approach. Equation (3) permits using locally available aggregate/macadam with CBR even less than 15% against the recommendation of IRC SP 72. Figure 8 depicts the variation of aggregate thickness with CBR of aggregate layer for unreinforced case, by GH approach and IRC SP 72, for ARD 50mm and typical subgrade CBR of 3%. The IRC SP 72 aggregate thicknesses remain constant for every traffic category, irrespective of the increase in the aggregate CBR value against the decrease in aggregate thickness as per the GH approach. The saving in aggregate thickness for the GH approach is 21% for T1, T2, and T3 traffic over a range of aggregate CBR from 20% to 100%.

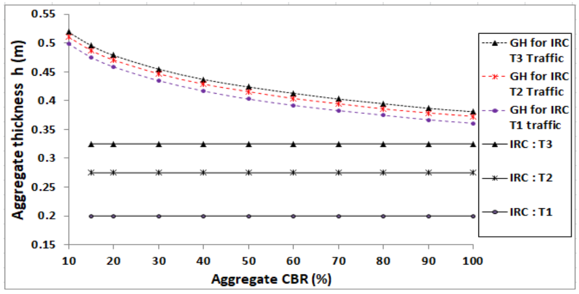

Figure 8. Variation of aggregate thickness by GH approach and IRC SP 72, for ARD 50mm and subgrade CBR of 3%

IRC SP 72 recommended aggregate thickness is lower by 56% for T1 traffic, 42% for T2 traffic, and 32% for T3 traffic than the GH approach for typical aggregate CBR of 20%. Regarding 100% aggregate CBR, IRC SP 72 design thickness is lower by 45% for T1, 26% for T2, and 15% for T3. This may be attributed to GH's robust mechanistic design approach, validation possible using Full Scale Accelerated Pavement Testing Setup (Ingle, 2017), indigenously designed and developed at COEP Technological University.

6.2.2 Subgrade CBR

Figure 9 shows the variation of aggregate thickness for unreinforced and geotextile reinforced conditions computed by the GH approach for traffic count (N) of 10,000 to 100,000 and ARD of 50mm with subgrade CBR.

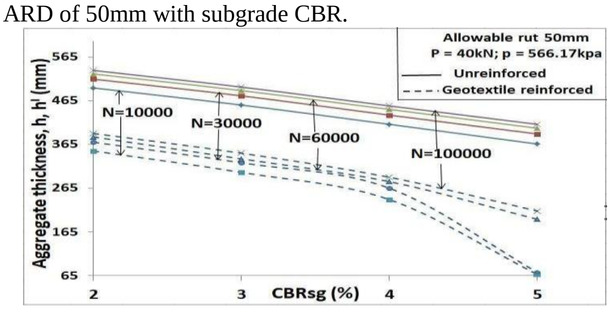

Figure 9. Variation of aggregate thicknesses by GH approach for both geotextile reinforced and unreinforced conditions with ARD 50 mm for traffic 10,000 to 100,000

Figure 9 shows the variation of aggregate thickness for unreinforced and geotextile reinforced conditions computed by the GH approach for traffic count (N) of 10,000 to 100,000 and ARD of 50mm with subgrade CBR. A drop in thickness for 5% subgrade CBR confirms the sensitivity of the GH approach to mobilization factor (m).

Figure 10 shows the variation of aggregate thickness towards the CBR of the subgrade layer for unreinforced (h) and geotextile reinforced ($h^{|}$) cases for Indian conditions using the GH approach after superimposing the IRC SP 72 data.

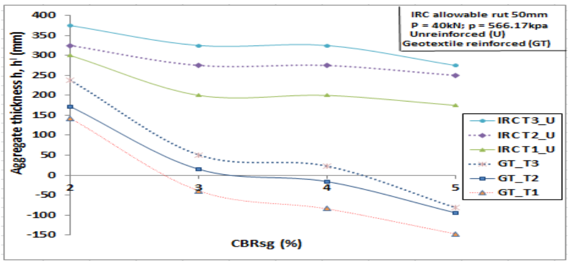

Figure 10. Variation of aggregate thickness with subgrade CBR for unreinforced (h) and geotextile reinforced (h|) cases for Indian Conditions using the GH approach after superimposing the IRC SP 72 data

The geotextile reinforcement benefit in pavement design is the aggregate layer thickness reduction, which is observed in Figure 10. Negative values of aggregate thickness mean practically zero aggregate thickness for geotextile-reinforced roads. However, to avoid damage to the subgrade and for the safety of geotextile reinforcement, a minimum aggregate thickness of 75mm is provided.

6.2.3 Practical Application

The practical application of the present work includes:

a) The upgradation in the Indian gravel road design by diminishing the existing empiricism with the superimposition of the robust mechanistic approach. From the results, using low-quality locally available material with a CBR of less than 15% is also allowed for aggregate layer in road construction in India.

b) Applying the proposed unique equation to compute aggregate layer thickness simplifies the design procedure with significant accuracy.

c) Due to the non-availability of design charts in Indian design guidelines for geotextile reinforced conditions, the computed aggregate thickness for the reinforced condition in the present work enhances the construction quality. It prioritizes saving natural aggregate to achieve sustainability.

d) The present results apply to different serviceability conditions for road usage for the rut ranging from 50mm to 100mm.

e) The result reveals that applying geotextile reinforcement in Indian gravel road design exhibits the predominant advantage over the general practice of rural road construction in India.

7. CONCLUSIONS

The following conclusions are drawn from the above results and discussion:

- IRC SP 72-2015 is used in India for designing gravel/roads. Very high growth in road construction and associated infrastructure in India have exponentially increased the demand for good quality natural resources. Hence, sustainable pavement is highlighted with a mechanistic and robust pavement design approach to eliminate existing empiricism. IRC SP 72-2015 approach, in the use of locally available material, thus ensuring to be conservative and uneconomical based on ARD while it is under-designed for a given ARD with the increase in traffic, with the possibility of failure before the design period.
- The proposed unique equation provides ARD-based aggregate thickness for 10,000 to 100,000 traffic count, compared to the IRC SP 72 approach suggesting a unique rut of 50mm. The increase of 22.65% in aggregate thickness is attributed to the increase in ARD of 30mm. This confirms the practical relevance of ARD in pavement design that helps in planning maintenance programs and road rehabilitation strategies. The proposed unique equation simplifies the complex procedure of the GH approach for IRC SP 72-2015 data. The results obtained from the unique equation match 85 to 100% with GH results.
- The GH approach allows allowable rut greater than 50mm for the IRC SP 72 thickness catalog, which differs based on traffic category and subgrade class. For the typical case for T3 traffic with 3% subgrade CBR, GH aggregate thickness agrees with the IRC SP catalog data for ARD 85 to 87mm against 50mm ARD of IRC SP 72. Though the aggregate thickness by the GH approach is higher than the thickness specified by IRC SP 72 for the same traffic and subgrade data, GH allows higher ARD against 50mm considered by IRC SP 72.
- This paper presents aggregate thickness for the geotextile reinforced condition for Indian roads by following the GH approach. Geotextile reinforcement is beneficial because of saving costly natural resources apart from other associated benefits, using locally available resources and durable and economical pavement based on the designed life cost on the poor subgrade. The results reveal that geotextile reinforcement for typical 2% subgrade CBR reduction in aggregate thickness is 36.5%, 47.1%, and 52.3% for traffic count T3, T2, and T1, respectively.

Abbreviation

The following abbreviations are used in this paper.
ARD_{GR} = Allowable Rut Depth for Geotextile Reinforced;
ARD_{UR} = Allowable Rut Depth for Unreinforced;
CBR = California Bearing Ratio;
CRD_{GR} = Critical Rut Depth for Geotextile Reinforced;
CRD_{UR} = Critical Rut Depth for Unreinforced;
ESAL = Equivalent Single Axle Load; GH = Giroud and Han;
IRC = Indian Roads Congress;
IRC SP 72-2015 = Indian Roads Congress Special Publication 72-2015;
km = Kilometer;
m = Mobilization coefficient;
MSA = Million Standard Axle;
S1 = Subgrade Class 1 having CBR of 2%; S2 = Subgrade Class 2 having CBR of 3-4%; S3 = Subgrade Class 3 having CBR of 5%;
T1 = Traffic 1 of count 10,000 to 30,000;
T2 = Traffic 2 of count 30,000 to 60,000;
T3 = Traffic 3 of count 60,000 to 100,000;
TME = Tensioned Membrane Effect;
WBM = Water Bound Macadam.

Acknowledgment

I am grateful to Prof. Sudhir Agashe, Vice Chancellor, COEP Technological University, Government of Maharashtra, Pune, Maharashtra State, India, for supporting this research.

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