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Design of Flexible pavement using IITPAVE as per IRC-37-2018 and minimize the pavement thickness by using Geogrid

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Abstract – The main purpose of the designing the Flexible pavement with Geogrid is to reduce the thickness of pavement layer thicknesses by providing the geosynthetics on base or subbase courses. With this analysis using relevant Indian road congress (IRC) standards we may reduce the bituminous layer thickness or overall pavement thickness of roads and highways having high traffic volume compared to the conventional method as per IRC 37.

***Key Words*:** Geogrid, IITPAVE, Flexible Pavement, Geosynthetics, IRC 37, Highways.

1.INTRODUCTION

An important factor in a nation's overall development is its transportation system. Highways and roads serve as the main modes of transportation. Since flexible pavement can be gradually strengthened and enhanced to accommodate increasing traffic, it is preferred over cement concrete roadways. This report is to design the flexible pavement in conventional method and comparison of reduced thickness of flexible pavement by providing geogrid in base and/or subbase with the help of IRC guidelines IRC SP 59-2019 & IRC 37-2018 for major highways/expressways using IITPAVE software.

In recent times, as per the suggestions of NHAI (National Highways Authority of India) and MoRT&H (Ministry of Road Transport and Highways) officials, the major highway projects with high-capacity traffic volume in terms of commercial traffic has to be constructed for the maximum design speed for 120kmph for expressways and 100kmph for the National Highways by keeping the view of substantial growth of commercial vehicles, speed improvement and to reduce the travel time. The relevant Indian roads congress (IRC) special publications guidelines has to be followed for designing of the project, for example IRC SP 99-2013 for expressways design and IRC SP 87-2019 for six lane National Highways etc.

In this paper, I have provided the analysis and comparison between flexible pavement thicknesses without geogrid and the design of flexible pavement by providing the geogrid in base and subbase courses for the design traffic 130 MSA with design CBR 13%. The analysis of tensile strains of bituminous and vertical compressive subgrade strains has been evaluated by using IITPAVE software.

2. Literature Review

The subgrade soil strength and the traffic volume are two key factors that affect flexible pavement design. Rutting deformation, fatigue, cracking and are the main causes for failures of bitumen. Pavement design is also influenced by a number of other parameters, including wheel load, subgrade strength, climate, stress distribution, and material properties. In India, the pavement design is carried out in accordance with Indian road congress (IRC) regulations. An elastic multilayer structure is useful for flexible pavement. When calculating stresses and strains at crucial areas, a linear layered elastic model can be useful. Stress analysis software can be used to compile the tension and stress in the flexible pavement. IITPAVE is an enhanced version of FPAVE is called IITPAVE software. According to IRC 37 2018 recommendations, a multilayer analysis software is used for the analysis and design of flexible pavement.

The process of reinforcing various pavement layers is known as pavement reinforcement. Geosynthetics/Geogrid included to reinforce the subbase or/and base also to provide subgrade restraint during road construction over the weak condition of subgrade.

IRC SP:59 proposes the LCR (Layer coefficient ratio method) and MIF (Modulus Improvement Factors) method for granular layers reinforced with geosynthetic materials. These methods are to be used to evaluate the modulus value improvement in the granular layer owing to geosynthetic reinforcement. As mentioned in IRC SP:59, these values must be established through thorough field and laboratory experiments. It recommends estimating modulus values of unreinforced granular subbase and base layers independently. Then, obtain the moduli of the reinforced granular layers (subbase and base) by applying the applicable modification factors.

The indicative range of LCR values given below as per IRC:SP:59-2019

Table-1 LCR Values (Indicative Range)

S. No.	CBR Value	LCR* for geogrid (Indicative range)
1	<3%	1.2-1.8
2	>3%	1.2-1.6

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The indicative range of MIF values given below as per IRC:SP:59-2019

Table2 MIF Values (Indicative Range)

S. No.	CBR Value	MIF* for geogrid (Indicative range)
1	<3%	2-2.75
2	>3%	1.4-2.0

IITPAVE software was created to examine the liner elastic layered pavement structures. The strains, stresses, and deflection that a uniformly distributed single load applied over a circular contact area at the pavements surface will cause different spots in the pavement can be calculated using the software.

The required pavement inputs are the thickness of all layer (except from the subgrade) and the elastic characteristics (elastic/resilient moduli and Poisson's ratio values) of all pavement layers. Pavements of up to 10 layers, including the subgrade, can be analysed using the current version of the software.

The inputs and analysis of Flexible pavement without Geogrid/Geosynthetics provided below Table-5 .

Table-5 Flexible Pavement Design Analysis Report Without Geogrid

S.No.	Description	Value
1	Design CBR in (%)	13
2	Thickness of Bituminous Concrete (in mm)	80
3	Thickness of Dense Bituminous Macadam (in mm)	110
4	Thickness of Bitumen Layer (BC+DBM) (in mm)	190
5	Thickness of WMM Layer (in mm)	250
6	Thickness of GSB Layer (in mm)	200
7	Thickness of Granular Layer (WMM+GSB) (h in mm)	450
8	Resilient Modulus for Subgrade (Mpa), $M_R = 17.6*(CBR)^{0.64}$	90.87
9	Resilient Modulus for Granular Layer (Mpa) = $0.20*(h)^{0.45}*M_{R(Subgrade)}$	284.06
10	Pavement Temperature (°C)	35°C
11	Binder (Since MSA More than 30)	VG 40 Bitumen
12	Resilient Modulus of Bituminous Mixes (Mpa)	3000
Determination of Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model)		
$N_f = 0.5161*C*10^{-04}*(1/€_t)^{3.89}*(1/M_R)^{0.854}$		
Where, $C=10^M$		
$M = 4.84 * \{ [V_b/(V_a+V_b)]-0.69 \}$		
{for 90% Reliability}		
13	Fatigue life in number of Standard Axles = Nf = 130.00 MSA	130000000
14	V_a = Per cent Volume of Air Voids (in %)	3.5
15	V_b = Per cent Volume of bitumen in a given volume of bituminous mix (in %)	10.75
16	$M = 4.84 * \{ [V_b/(V_a+V_b)]-0.69 \}$	0.31
17	$C=10^M$	2.05
18	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$	0.0001345
19	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$ (in Micro Strain)	134.52
20	Horizontal Tensile Strain on Bituminous Layer as per The computed strains From IIT PAVE software (in Micro Strain)	128.60
	Check	**Hence, Safe**
Determination of Vertical Compressive Strain on the top of Subgrade (Rutting)		
$N = 1.4100*10^{-08}*(1/€v)^{4.5337}$		
{for 90% Reliability}		
21	Number of Standard Axles = Nf = 130.00 MSA	130000000
22	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = $€_v$	0.000301061
23	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = €v (in Micro Strain)	301.06
24	Vertical Compressive Strain on Subgrade Layer as per The computed strains From IIT PAVE software (in Micro Strain)	205.70
	Check	**Hence, Safe**

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The inputs and analysis of Flexible pavement with Geogrid (Layer coefficient ratio, LCR method) provided below Table 4.

Table -4 Flexible Pavement Design Analysis Report With Geogrid (LCR Method)

S.No.	Description	Value
1	Design CBR in (%)	13.000
2	Thickness of Bituminous Concrete (in mm)	40
3	Thickness of Dense Bituminous Macadam (in mm)	50
4	Thickness of Bitumen Layer (BC+DBM) (in mm)	90
5	Thickness of WMM Layer (in mm)	230
6	Thickness of GSB Layer (in mm)	200
7	Thickness of Granular Layer (WMM+GSB) (h in mm)	430
8	Resilient Modulus for Subgrade soil (Mpa), $M_R = 17.6*(CBR)^{0.64}$	90.873
9	Resilient Modulus for Granular Layer (Mpa) = $0.20*(h)^{0.45}*M_{R(Subgrade)}$	278.309
10	Pavement Temperature (°C)	35°C
11	Binder (Since MSA More than 30)	VG 40 Bitumen
12	Resilient Modulus of Bituminous Mixes (Mpa)	3000
Determination of Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model)		
$N_f = 0.5161*C*10^{-04}*(1/€_t)^{3.89}*(1/M_R)^{0.854}$		
Where, $C=10^M$		
$M = 4.84 * \{ [V_b/(V_a+V_b)]-0.69 \}$		
{for 90% Reliability}		
13	Fatigue life in number of Standard Axles = Nf = 130.00 MSA	130000000
14	V_a = Per cent Volume of Air Voids (in %)	3.500
15	V_b = Per cent Volume of bitumen in a given volume of bituminous mix (in %)	10.750
16	$M = 4.84 * \{ [V_b/(V_a+V_b)]-0.69 \}$	0.312
17	$C=10^M$	2.049
18	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$	0.0001345
19	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$ (in Micro Strain)	134.518
Determination of Vertical Compressive Strain on the top of Subgrade (Rutting) $N = 1.4100*10^{-08}*(1/€v)^{4.5337}$ {for 90% Reliability}		
21	Number of Standard Axles = Nf = 130.00 MSA	130000000
22	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = $€_v$	0.000301061
23	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = €v (in Micro Strain)	301.061
	Layer Coefficient Ratio of Layers *(Layer coefficient for geogrid is taken on the basis on the laboratory tests/filed tests; or it can be provided by the manufacturer)*	
24	Layer coefficient for ratio for base layer (LCR_{base})	1.200
25	Layer coefficient ratio for subbase layer ($LCR_{subbase}$)	1.000
	Subbase and base layer thickness values	
26	Layer Thickness for Base (mm)	230
27	Layer Thickness for Subbase (mm)	200
	MR Values for Subgrade, base and sub base	
28	Resilient Modulus of Subgrade soil (Mpa), MR = 17.6*(CBR)0.64	90.873
29	Resilient Modulus of subbase Layer (MR_subbase, Mpa), $M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$, (h= thickness of granular sub-base layer, mm)	197.210
30	M_{R_GSB} in Psi	28603.008
31	Resilient Modulus of base Layer (MR_base, Mpa) $M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$ (h= thickness of granular base layer, mm)	455.761
32	M_{R_GB} in Psi	66102.705
	Calculation of Effective Modulus of Subgrade + Subbase	
33	Contact Pressure (p)	0.560
34	Radius of circular contact area (a)	150.800
35	Poisson's Ratio	0.350
36	Deflection in mm (From IITPAVE)	1.090
37	Effective Modulus of Subgrade & Subbase, Eq. 6.3 of IRC 37-2018	135.969

38	Modified MR values for Base Layer (Mpa), Eq. 7.1 of IRC 37-2018	314.230
39	*Structural layer coefficient of each layer* (The equations given in AASTHO 1993	
40	Layer coefficient for bituminous layer (a_1) = 0.171 x (LN (MR))-1.784 0.171 x (LN (435102))-1.784	0.436
41	Layer coefficient of Base layer (a2)= 0.249 (log10 $M^1{}_{R\_GB}$) – 0.977	0.223
42	Layer coefficient of Subbase layer (a3)= 0.227 (log10 $M^1{}_{R\_GSB}$) – 0.839	0.173
	Modified layer thickness values for reinforced sections by IITPAVE	
43	Modofied thickness of sub base layer	200.000
44	Modofied thickness of base layer	230.000
45	Modofied Resilient Modulus of subbase Layer ($MR\_{subbase}$, Mpa), $M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$, (h= thickness of granular sub-base layer, mm)	197.210
46	Modofied M_{R_GSB} in Psi	28603.008
47	Modofied Resilient Modulus of base Layer (MR_base, Mpa) $M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$ (h= thickness of granular base layer, mm)	455.761
48	Modofied M_{R_GB} in Psi	66102.705
	Modified Structural layer coefficient of each layer (The equations given in AASTHO 1993	
49	Layer coefficient for bituminous layer (a_1) = 0.171 x (LN (MR))-1.784 0.171 x (LN (435102))-1.784	0.436
50	Layer coefficient of Base layer (a_2)= 0.249 (log10 $M^1{}_{R\_GB}$) – 0.977	0.223
51	Layer coefficient of Subbase layer (a_3)= 0.227 (log10 $M^1{}_{R\_GSB}$) – 0.839	0.173
52	Modified Layer Coefficient for Surface Layer (a'_1)	0.436
53	Modified Layer Coefficient for Base Layer ($a_{2'}$) = $LCR_{base} \times a_2$	0.268
54	Modified Layer Coefficient for Subbase Layer ($a_{3'}$) = $LCR_{Subbase} \times a_3$	0.173
55	*With the improved layer coefficients, improved elastic modulus of respective layers shall be back calculated using below equations for IIT Pave*	
56	Modified elastic Moduli for Base layer ($MR\_{GB'}$) in Psi = 10^((a_2'+0.977)/0.249)	99890.485
57	$MR\_{GB'}$ in Mpa (for IIT pave input)	688.719
58	Modified elastic Modulii for Subbase layer ($MR\_{GSB'}$) in Psi = 10^((a_2'+0.839)/0.227)	28603.008
59	$MR\_{GSB'}$ in Mpa (for IIT pave input)	197.210
	Using above improved elastic modulus corresponding improved layer coefficients, reinforced layer thickness shall be determined	
60	Surface layer (BC	40.00
61	Surface layer (DBM)	50.00
62	Reinforced base layer thickness (WMM+Geogrid)	230.00
63	Reinforced subbase layer thickness (GSB)	200.00
	Comparison of Revised Strains	
64	Permissible Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) for given design traffic = €t (in Micro Strain)	134.518
65	Maximum Induced tensile strain (from IIT Pave)	127.500
	Check Tensile Strain at the Bottom of Bituminous	**Hence, Safe**
66	Permissible Vertical Subgrade Strain on the top of Subgrade (Rutting Model) for given design traffic = €v (in Micro Strain)	301.061
67	Maximum induced vertical Strain (from IIT Pave)	282.000
	Check of Vertical Subgrade Strain	**Hence, Safe**

The inputs and analysis of Flexible pavement with Geogrid (Modulus improvement factor, MIF method) provided below in Table-6.

Table -6 Flexible Pavement Design Report with Geogrid (MIF method)

S.No.	Description	Value
1	Design CBR in (%)	13.000
2	Thickness of Bituminous Concrete (in mm)	40
3	Thickness of Dense Bituminous Macadam (in mm)	50
4	Thickness of Bitumen Layer (BC+DBM) (in mm)	90
5	Thickness of WMM Layer (in mm)	250
6	Thickness of GSB Layer (in mm)	200
7	Thickness of Granular Layer (WMM+GSB) (h in mm)	450

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8	Resilient Modulus for Subgrade soil (Mpa), $M_R = 17.6*(CBR)^{0.64}$	90.873
9	Resilient Modulus for Granular Layer (Mpa) = $0.20*(h)^{0.45}*M_{R(Subgrade)}$	284.061
10	Pavement Temperature (°C)	35°C
11	Binder (Since MSA More than 30)	VG 40 Bitumen
12	Resilient Modulus of Bituminous Mixes (Mpa)	3000
Determination of Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model)		
$N_f = 0.5161*C*10^{-04}*(1/€_t)^{3.89}*(1/M_R)^{0.854}$		
Where, $C=10^M$		
$M = 4.84 * \{[V_b/(V_a+V_b)]-0.69\}$		
{for 90% Reliability}		
13	Fatigue life in number of Standard Axles = Nf = 130.00 MSA	130000000
14	V_a = Per cent Volume of Air Voids (in %)	3.500
15	V_b = Per cent Volume of bitumen in a given volume of bituminous mix (in %)	10.750
16	$M = 4.84 * \{ [V_b/(V_a+V_b)]-0.69 \}$	0.312
17	$C=10^M$	2.049
18	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$	0.0001345
19	Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) = $€_t$ (in Micro Strain)	134.518
Determination of Vertical Compressive Strain on the top of Subgrade (Rutting)		
$N = 1.4100*10^{-08}*(1/€v)^{4.5337}$		
{for 90% Reliability}		
21	Number of Standard Axles = Nf = 130.00 MSA	130000000
22	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = $€_v$	0.000301061
23	Vertical Subgrade Strain on the top of Subgrade (Rutting Model) = €v (in Micro Strain)	301.061
	Modulus Improvement factor of Layers (The indicative range of MIF values for geogrid to be used in the design shall be 1.2 to 2)	
24	Modulus Improvement factor for base layer (MIF_{base})	1.400

25	Modulus Improvement factor for subbase layer ($MIF_{subbase}$)	1.000
	Subbase and base layer thickness values	
26	Layer Thickness for Base (mm)	250
27	Layer Thickness for Subbase (mm)	200
	MR Values for Subgrage, base and sub base	
28	Resilient Modulus of Subgrade soil (Mpa), MR = 17.6*(CBR)0.64	90.873
29	Resilient Modulus of subbase Layer (MR_subbase, Mpa), $M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$, (h= thickness of granular sub-base layer, mm)	197.210
30	M_{R_GSB} in Psi	28603.008
31	Resilient Modulus of base Layer (MR_base, Mpa) $M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$ (h= thickness of granular base layer, mm)	473.187
32	M_{R_GB} in Psi	68630.112
	Calculation of Effective Modulus of Subgrade + Subbase	
33	Contact Pressure (p)	0.560
34	Radius of circular contact area (a)	150.800
35	Poisson's Ratio	0.350
36	Deflection in mm (From IITPAVE)	1.090
37	Effective Modulus of Subgrade & Subbase, Eq. 6.3 of IRC 37-2018	135.969
38	Modified MR values for Base Layer (Mpa), Eq. 7.1 of IRC 37-2018	326.244
39	*Structural layer coefficient of each layer* (The equations given in AASTHO 1993	
40	Layer coefficient for bituminous layer (a_1) = 0.171 x (LN (MR))-1.7840.171 x (LN (435102))-1.784	0.436
41	Layer coefficient of Base layer (a2)= 0.249 (log10 $M^1_{R\_GB}$) – 0.977	0.227
42	Layer coefficient of Subbase layer (a3)= 0.227 (log10 $M^1_{R\_GSB}$) – 0.839	0.173
	Modified layer thickness values for reinforced sections by IIT PAVE	
43	Modofied thickness of sub base layer	200.000
44	Modofied thickness of base layer	250.000
45	Modofied Resilient Modulus of subbase Layer ($MR_{subbase}$, Mpa), $M_{R\_GSB} = 0.2 \times h^{0.45} \times M_{R\_subgrade}$, (h= thickness of granular sub-base layer, mm)	197.210
46	Modofied M_{R_GSB} in Psi	28603.008

47	Modofied Resilient Modulus of base Layer (MR_base, Mpa) $M_{R\_GB} = 0.2 \times h^{0.45} \times M_{R\_GSB}$ (h= thickness of granular base layer, mm)	473.187
48	Modofied M_{R_GB} in Psi	68630.112
	Modified Structural layer coefficient of each layer (The equations given in AASTHO 1993	
49	Layer coefficient for bituminous layer (a_1) = 0.171 x (LN (MR))-1.784 0.171 x (LN (435102))-1.784	0.436
50	Layer coefficient of Base layer (a_2)= 0.249 (log10 $M^1{}_{R\_GB}$) – 0.977	0.227
51	Layer coefficient of Subbase layer (a_3)= 0.227 (log10 $M^1{}_{R\_GSB}$) – 0.839	0.173
52	Modified Layer Coefficient for Surface Layer (a'_1)	0.436
53	Modified Layer Coefficient for Base Layer ($a_{2'}$) = $LCR_{base} \times a_2$	0.273
54	Modified Layer Coefficient for Subbase Layer ($a_{3'}$) = $LCR_{Subbase} \times a_3$	0.173
55	*With the improved layer coefficients, improved elastic modulus of respective layers shall be back calculated using below equations for IIT Pave*	
56	Modified elastic Modulii for Base layer (MR_$_{GB'}$) in Psi = 10^((a_2'+0.977)/0.249)	104490.954
57	MR_$_{GB'}$ in Mpa (for IIT pave input)	720.438
58	Modified elastic Modulii for Subbase layer (MR_$_{GSB'}$) in Psi = 10^((a_2'+0.839)/0.227)	28603.008
59	MR_$_{GSB'}$ in Mpa (for IIT pave input)	197.210
	Using above improved elastic modulus corresponding improved layer coefficients, reinforced layer thickness shall be determined	
60	Surface layer (BC	40.00
61	Surface layer (DBM)	90.00
62	Reinforced base layer thickness (WMM+Geogrid)	250.00
63	Reinforced subbase layer thickness (GSB)	200.00
	Comparison of Revised Strains	
64	Permissible Tensile Strain at the Bottom of Bituminous Layer (Fatigue Model) for given design traffic = €t (in Micro Strain)	134.518
65	Maximum Induced tensile strain (from IIT Pave)	121.100
	Check Tensile Strain at the Bottom of Bituminous	**Hence, Safe**
66	Permissible Vertical Subgrade Strain on the top of Subgrade (Rutting Model) for given design traffic = €v (in Micro Strain)	301.061
67	Maximum induced vertical Strain (from IIT Pave)	244.400
	Check of Vertical Subgrade Strain	**Hence, Safe**

3. CONCLUSIONS

From the analysis of flexible pavement without Geogrid as per IRC-37-2018, the summary of pavement thickness below in given in Table-7

Table -7 Summary of pavement without Geogrid

Description	Thickness (mm)
BC with modified bitumen (VG40)	80
Dense Bituminous Macadam (VG40)	110
Granular Base Layer without Geogrid	250
Granular Subbase Layer	200
Subgrade	500

From the analysis of flexible pavement with geogrid considering LCR factor 1.2 and MIF factor 1.4 the pavement thickness provided below in Table-8

Table -8 Summary of pavement witho Geogrid

Description	Thickness with LCR Method (mm)	Thickness with MIF Method (mm)
BC with modified bitumen (VG40)	40	40
Dense Bituminous Macadam (VG40)	50	50
Granular Base Layer with Geogrid	230	250
Granular Subbase Layer	200	200
Subgrade	500	500

The Geogrid layer shall be provided over the compacted layer of subbase below the carriageway in this case.

After the results of pavement design analysis without using geogrid and with geogrid presented in summary table 7 & table 8, it is recommended to adopt the pavement layer thickness as per LCR method as summarized in Table 8.

REFERENCES

1. IRC:37-2018 Guidelines for the Design of Flexible Pavements (Fourth Revision) published by Indian Roads Congress
2. IRC:SP:59-2019 Guidelines for use of Geosynthetics in Road Pavements and associated works published by Indian Roads Congress