Design and Performance of Highway Pavement Reinforced with Geo-synthetic

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Abstract. Soft soil particularly clayey soil has a very low value of California bearing ratio (CBR). As the CBR value is low the thickness of the granular layer is more, which is resulting in the higher cost of pavement. To overcome this issue, geosynthetics (geogrids) are mainly used in the granular layer of pavement as reinforcement. For cost-effectiveness and durability of pavement, geosynthetics are used from last 2-3 decades but still, there is no proper design philosophy available for use of geogrid in the flexible pavement. To quantify the benefits of geogrid reinforcement, field studies were conducted on the geogrid reinforced test section constructed on Mandvi-Serulla state highway by using falling weight deflectometer (FWD). Results of FWD data confirmed that the modulus value of geogrid reinforced layer is increased by 1.40 times than that of the unreinforced granular layer. A finite element model was also developed in PLAXIS 2D to justify the benefits of geogrid reinforcement against fatigue and rutting failure.

Keywords: Low CBR, Geogrid, PLAXIS 2D, FWD, etc

1 Introduction

The demand for new roads and widening of the existing road is increasing day by day as the traffic is increasing drastically in the last few decades. In order to fulfill the demand for construction of new highways and expressway, enough quantity of good quality granular material is required for the construction of the same. It creates a harsh impact on the environment as we mainly obtained good quality granular material by cutting and excavating the hills made up with the good quality rock. In the current study, the attempt was made to reduce down the thickness of granular material required for base or subbase layer of the road by using high strength geogrid reinforcement.

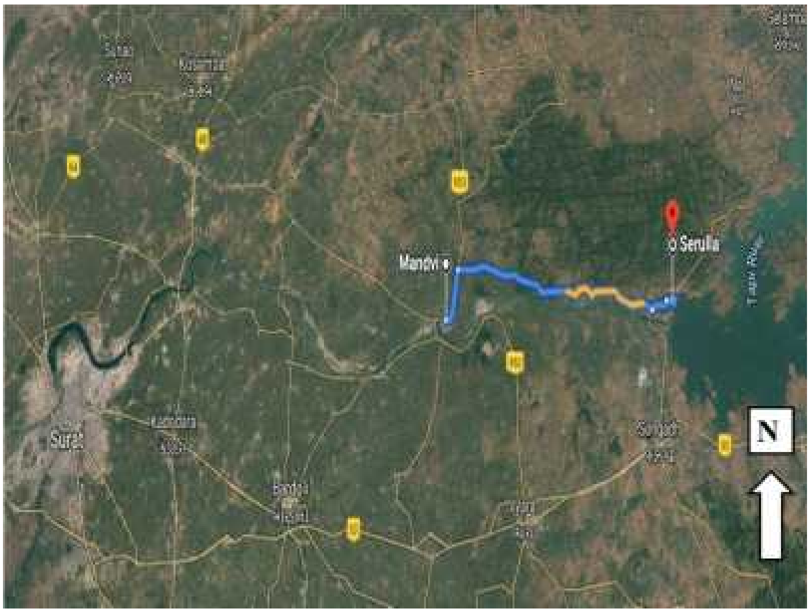


Fig. 1. Location of Mandvi-Serulla State Highway

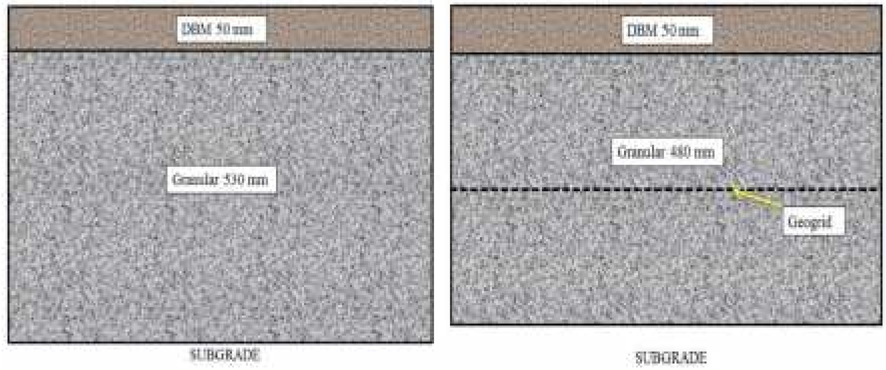
1.1 The objective of this study

The objective of the current study is to evaluate the performance of geogrid reinforced pavement by conducting falling weight deflectometer (FWD) test on the test section constructed on Mandavi-Serulla highway. In the current study finite element analysis was also carried out to quantify the benefits of geogrid reinforcement.

2 Details of Section and Field Study

In view of objectives of this study, two sections are constructed on Mandavi-Serulla state highway as a part of widening portion consisting of one geogrid reinforced section and one is control section (unreinforced) for comparison purpose. Location of test section on Mandvi-Serulla state highway is given in figure 1. Control section comprised 50 mm of dense bituminous macadam (DBM) layer and 530 mm of the granular layer. Geogrid section comprised 50 mm DBM layer and 480 mm of the granular layer with 40 kN/m of geogrid placed at the center of the granular layer. The cross-section for control and geogrid reinforced section are given in figure 2.

Field evaluation of test sections was carried out by using falling weight deflectometer (FWD). Control and geogrid reinforced section are constructed at chainage from 20.87 km to 22.81 and 23.05 km to 25.28 km respectively. The length of control and geogrid reinforce section is 1.94 km and 2.23 km resp.



(a) (b)

Fig. 2. The cross-section for (a) Control Section and (b) Geogrid Reinforced Section of Mandavi-Serulla State Highway

2.1 FWD Data collection and analysis

Performance of flexible pavements can be evaluated by applying loads on the pavements that simulate the traffic loading, recording the response to such loading by measuring the elastic deflection under such loads, and analyzing these data duly considering the factors influencing the performance such as subgrade strength, thickness and quality of each of the pavement layers, drainage conditions, pavement surface temperature etc.

Falling Weight Deflectometer (FWD) is an impulse-loading device shown in figure 3 and 4 in which a transient load is applied to the pavement and the deflected shape of the pavement surface is measured. The resulting load-deflection data can be interpreted through appropriate analytical techniques, such as back-calculation technique, to estimate the elastic moduli of the pavement layers [1].

Results of deflection data obtained from FWD testing is given in Table 1 and 3 for control and geogrid reinforced section resp. Modulus values for the individual layer are determined by using a back-calculation technique for that ELMOD software was employed. Modulus value for each layer are given in table 2 and 4 for control and geogrid reinforced section resp. Chainage wise back-calculated modulus for control and geogrid reinforced section is shown in figure 5.

Average Modulus value for a granular layer of the control section is 171 MPa and the geogrid reinforced granular layer is 240 MPa. Modulus improvement factor (MIF) for geogrid is obtained by using the following equation (1) and it is given by Kief O. et al. [2].

$$MIF = \frac{Ebc\ (Reinforced)}{Ebc\ (Unreinforced)} \tag{1}$$

Where, E_{bc} = Resilient modulus for the granular layer (MPa)

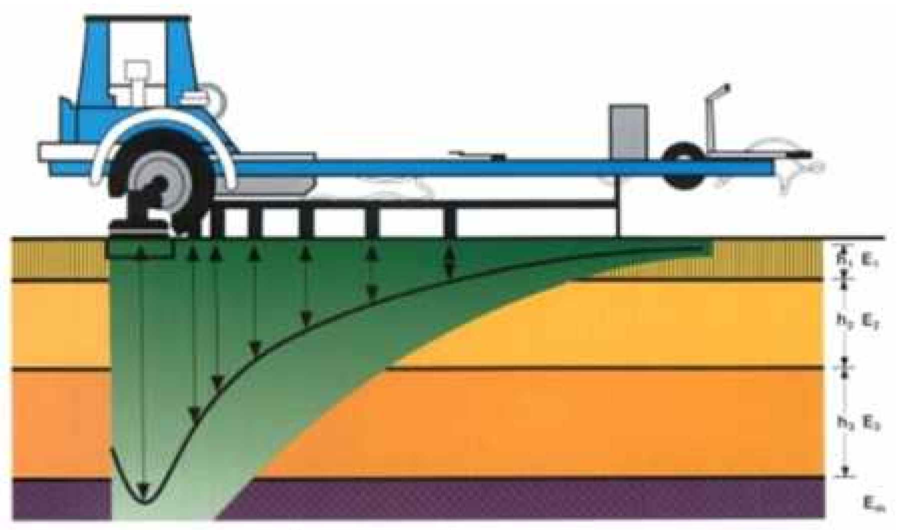


Fig. 3. Schematic of Falling Weight Deflectometer (FWD)

Fig. 4. DYNATEST Falling Weight Deflectometer (FWD)

By putting value E_{bc} of Reinforced layer as 252 MPa and Ebc of the unreinforced layer (control section) as 178 MPa in equation 1, MIF value obtained for 40 kN/m of geogrid is 1.40. From the field study and FWD testing, it is observed that modulus value for the geogrid reinforced granular layer is increased by 1.40 times compared to control (unreinforced section). In the current study thickness of the geogrid reinforced granular layer is 50 mm less compared to the thickness of the granular layer of the control section. It is observed that the higher value of improvement factor will be possible by keeping the same thickness of the granular layer for both reinforced and unreinforced section.

Table 1 Deflection Data from FWD Test for Control Section

Sl. No.	Chain-age (km)	Location	T_{pav} (^0C)	Deflection observed (microns) at radial distances (mm)						
				0	300	600	900	1200	1500	1800
1	20.87	Left	54	845.3	423.9	210.3	132.7	95.5	71.9	48.7
2	21.11	Right	54	839.8	418.0	171.1	115.7	87.2	63.8	52.0
3	21.28	Left	54	627.8	303.0	146.4	100.3	77.3	60.4	51.2
4	21.40	Right	54	748.8	344.4	179.7	118.0	85.2	62.8	51.8
5	21.82	Left	54	701.9	318.2	99.3	52.8	35.0	26.6	20.2
6	22.11	Right	54	718.8	299.3	141.3	88.8	63.1	43.4	38.4
7	22.37	Left	54	915.8	503.4	229.0	140.0	97.5	66.5	50.3
8	22.81	Right	54	793.3	252.1	99.2	70.9	62.2	39.7	52.0

Table 2 Back Calculated Moduli (MPa) for Control Section

Sl. No.	Chainage (km)	Location	T_{pav} (^0C)	Back Calculated Moduli (MPa)		
				Bitumen*	Granular	Subgrade
1	20.87	Left	54	2819	163	76
2	21.11	Right	54	3226	171	86
3	21.28	Left	54	3490	191	96
4	21.40	Right	54	2789	187	98
5	21.82	Left	54	3273	169	89
6	22.11	Right	54	2836	180	79
7	22.37	Left	54	2991	178	82
8	22.81	Right	54	2647	185	88
Average				**3009**	**178**	**87**

* Modulus values obtained after temperature correction

3 Finite Element (FE) Analysis by PLAXIS 2D

A two-dimensional finite element (FE) model was developed in PLAXIS 2D to quantify the benefits of geogrid reinforcement in flexible pavement. 15 noded triangular elements were used to model the pavement layers. Instead of using inbuilt geogrid element of PLAXIS 2D, modulus improvement factor of 1.4 was considered for geogrid reinforced layer, which was obtained from field study conducted on test section by FWD. Linear elastic model was considered for all the layers and input properties for all the layers are given in Table 5. Finite element model for both control and geogrid reinforced section (with 530 and 480 mm granular layer thickness) are shown in figure 6. A 565 kPa and 709 kPa tire pressure correspnding to 40 kN and 50 kN single wheel load were applied on the FE model having loading radius of 150 mm.

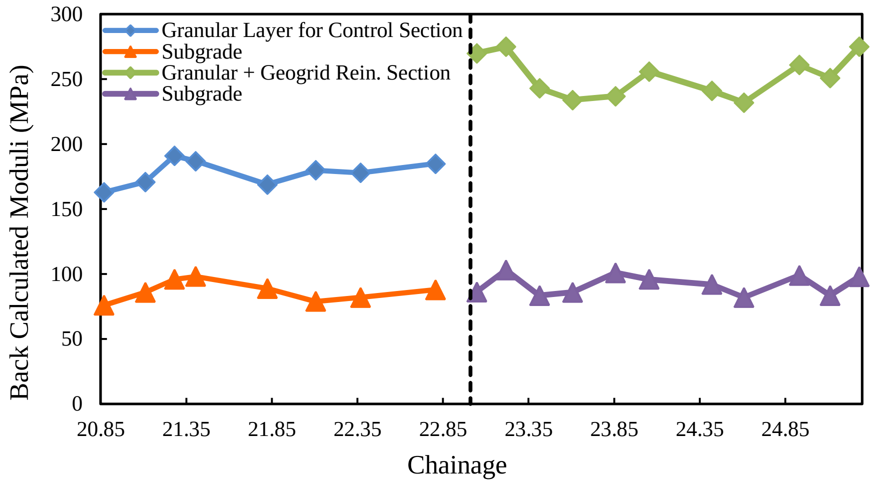


Fig. 5. Back Calculated Moduli (MPa) against chainage for Control and Geogrid Reinforced Section

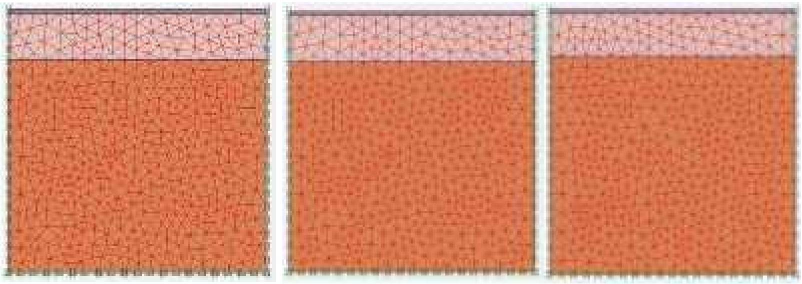
Table 3 Deflection Data from FWD Test for Geogrid Reinforced Section

Sl. No.	Chainage (km)	Location	T_{pav} (^{0}C)	Deflection observed (microns) at radial distances (mm)						
				0	300	600	900	1200	1500	1800
1	23.05	Left	54	818.8	414.3	175.1	97.7	64.1	45.6	34.8
2	23.22	Right	54	620.3	301.3	146.1	95.2	64.1	50.9	36.2
3	23.41	Left	54	989.7	486.1	174.3	87.5	55.4	40.4	28.5
4	23.61	Right	54	664.2	337.3	178.4	113.1	82.5	63.3	50.2
5	23.86	Left	54	978.7	484.6	191.7	112.0	78.6	61.4	50.6
6	24.05	Right	54	889.6	403.6	177.6	116.4	84.7	60.6	51.5
7	24.42	Right	54	927.9	362.8	133.4	89.9	65.9	49.5	44.7
8	24.61	Left	54	672.6	288.0	136.1	73.5	41.4	24.2	18.5
9	24.93	Right	54	755.1	296.4	124.3	81.5	57.6	43.9	34.0
10	25.11	Left	54	783.7	395.6	193.2	118.8	78.9	62.3	50.5
11	25.28	Right	54	920.4	435.0	172.7	110.5	79.2	58.5	45.7

Table 4 Back Calculated Moduli (MPa) for Geogrid Reinforced Section

Sl. No.	Chainage (km)	Location	T_{pav} (^0C)	Back Calculated Moduli (MPa)		
				Bitumen*	Granular	Subgrade
1	23.05	Left	54	3542	270	86
2	23.22	Right	54	2803	275	103
3	23.41	Left	54	3274	243	84
4	23.61	Right	54	3216	234	86
5	23.86	Left	54	3126	237	101
6	24.05	Right	54	2365	256	96
7	24.42	Right	54	2428	241	92
8	24.61	Left	54	1527	232	82
9	24.93	Right	54	2521	261	99
10	25.11	Left	54	3305	251	84
11	25.28	Right	54	3119	275	98
Average				**2839**	**252**	**92**

* Modulus values obtained after temperature correction



(a) (b) (c)

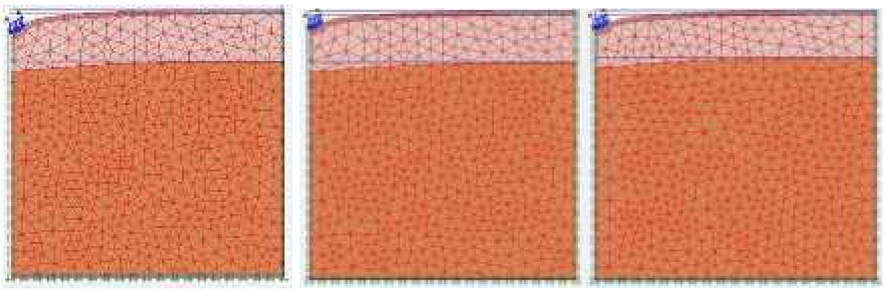
Fig. 6. Finite Element Model of (a) Control Section (b) Geogrid Reinforced Section with 530 mm Granular Layer and (c) Geogrid Reinforced Section with 480 mm Granular Layer

Deformed shape of pavement model for both control and geogrid reinforced section are shown in figure 7. Results of tensile strain and compressive strain in pavement models are shown in figure 8 and 9 resp. Tensile strain at bottom of bituminous layer and vertical compressive strain at top of subgrade were determined for all the sections from finite element analysis. Results of tensile strain and compressive strain observed in pavement models are mentioned in Table 6. From figure 8 and 9 it is observed that tensile and compressive strains are distributed on wider area due to improved modulus of geogrid reinforced layer.

Table 5 Properties of Pavement Material Consider for Finite Element Analysis in PLAXIS 2D

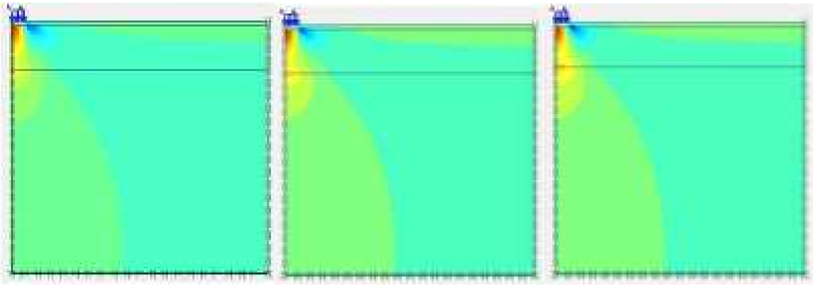
Material	Modulus of Elasticity (MPa)	Poisson's Ratio	Thickness (mm)
Bituminous	1000	0.35	50
Granular Layer	269	0.35	530
Granular Layer + Geogrid	378*	0.35	530
Granular Layer + Geogrid	378*	0.35	480
Subgrade	80	0.35	-

* Improved modulus for geogrid reinforced layer



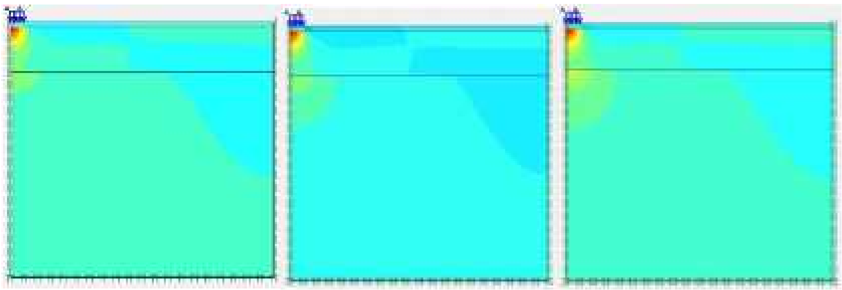
(a) (b) (c)

Fig. 7. Deformed Shape of (a) Control Section (b) Geogrid Reinforced Section with 530 mm Granular Layer and (c) Geogrid Reinforced Section with 480 mm Granular Layer



(a) (b) (c)

Fig. 8. Tensile Strain of (a) Control Section (b) Geogrid Reinforced Section with 530 mm Granular Layer and (c) Geogrid Reinforced Section with 480 mm Granular Layer



(a) (b) (c)

Fig. 9. Compressive Strain of (a) Control Section (b) Geogrid Reinforced Section with 530 mm Granular Layer and (c) Geogrid Reinforced Section with 480 mm Granular Layer

Table 6 Result of Finite Element Analysis for Critical Strain in Test Section

Section	DBM (mm)	Granular (mm)	Tire Pressure (kPa)	PLAXIS	
				Tensile Strain (ϵ_t)	Compressive Strain (ϵ_v)
Control Section	50	530	565	315.5	387
Geogrid Reinforced Section	50	530	565	215.3	330.9
Geogrid Reinforced Section	50	480	565	217.5	386.1
Control Section	50	530	709	404.9	487.3
Geogrid Reinforced Section	50	530	709	283.9	415.2
Geogrid Reinforced Section	50	480	709	293.2	486.2

From the finite element study in PLAXIS 2D, it is observed for geogrid reinforced section with same granular thickness of 530 mm against 565 kPa tire pressure tensile strain is reduced down by 31.75 % and compressive strain by 16.95 %. Tensile and compressive strain for geogrid reinforced section with reduced granular thickness of 480 mm is reduced by 31.06 % and 0.2 % respectively, for 565 kPa tire pressure. For 709 kPa tire pressure tensile strain and compressive strain are reduced down by 29.88 % and 14.79 % respectively, for geogrid reinforced 530 mm granular layer section. Tensile and compressive strain for geogrid reinforced section with reduced granular thickness of 480 mm is reduced by 27.58 % and 0.2 % respectively, for 709 kPa tire pressure.

4 Service Life Ratio (SLR)

The SLR of pavement against rutting failure is given by the following equation (2),

$$SLR = \left(\frac{\epsilon_{v1}}{\epsilon_{v2}}\right)^{4.5337} \quad (2)$$

Where ϵ_{v1} and ϵ_{v2} are maximum vertical compressive strain at top of subgrdae with unreinforced granular layer and with geogrid reinforced granular layer respectively.
The SLR of pavement against fatigue failure is given by the following equation (3),

$$SLR = \left(\frac{\epsilon_{t1}}{\epsilon_{t2}}\right)^{3.89} \quad (3)$$

Where ϵ_{t1} and ϵ_{t2} are maximum horizontal tensile strain at bottom of bituminous layer with unreinforced granular layer and with geogrid reinforced granular layer respectively. SLR value for both rutting and fatigue failure are more than 1 for geogrid reinforced section which confirms the benefits of geogrid reinfocement in pavement.

Table 7 Service Life Ratio for Rutting and Fatigue Failure in Section

Section	DBM (mm)	Granular (mm)	Tire Pressure (kPa)	SLR	
				for Fatigue	for Rutting
Control Section	50	530	565	1	1
Geogrid Reinforced Section	50	530	565	4.42	2.034
Geogrid Reinforced Section	50	480	565	4.25	1.01
Control Section	50	530	709	1	1
Geogrid Reinforced Section	50	530	709	3.97	2.06
Geogrid Reinforced Section	50	480	709	3.51	1.00

CONCLUSION

1. A field study conducted by using FWD testing provides that the modulus value for 40 kN/m of the geogrid reinforced granular layer is increased by 1.40 times compared to unreinforced layer in the control section.
2. Finite element study in PLAXIS 2D, concludes that tensile strain in the geogrid reinforced section with same granular thickness of 530 mm is reduced down by 31.75 % and compressive strain by 16.95 %. Tensile and compressive strain for geogrid reinforced section with reduced granular thickness of 480 mm is reduced by 31.06 % and 0.2 % respectively.
3. The SLR value of geogrid reinforced section against rutting without reduction in granular thickness of 530 mm for 565 and 709 kPa tire preussure are 2.034 and 2.06 respectively. The SLR value with reduced granular thickness up to 480 mm for 565 and 709 kPa tire preussure are 1.01

and 1.00 respectively. SLR value higher than 1 confirmes the benefits of geogrid reinforcement against rutting failure.

4. The SLR value of geogrid reinforced section against fatigue failure without reduction in granular thickness of 530 mm for 565 and 709 kPa tire preussure are 4.42 and 3.97 respectively. The SLR value with reduction in granuar thickness up to 480 mm for 565 and 709 kPa tire preussure are 2.034 and 2.06 respectively. SLR value higher than 1 confirmes the benefits of geogrid reinforcement against fatigue failure.
5. A field study by FWD and finite element study in PLAXIS 2D confirmed the benefits of geosynthetic reinforcement in terms of improved performance of pavement against rutting and fatigue failures.

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