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## Performance of Geosynthetic Reinforced Ballasted Rail Track

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**ABSTRACT:** India, being the forth-largest railway network in the world by size, rely heavily on railways for the transportation of bulk commodities and passenger services. Large repetitive wheel loads from heavy haul and passenger trains can cause significant track deformation that leads to poor track geometry and safety issues. In this paper, the effect of inclusion of geosynthetics in the critical sections in the railway embankment for reducing these adverse effects is presented. Geosynthetics effectively controls the long term and transient strains in the ballast layer along with the reduction in the maintenance costs. The objective of this study was to determine the effect of geosynthetic reinforcement on the stability of ballasted rail tracks subjected to equivalent dynamic wheel load of moving trains. The finite element simulation geotechnical software PLAXIS-2D was used for the analysis. Geosynthetics such as geogrid and geocomposite were considered as reinforcing material, also various natural subgrade condition such as black cotton soil, alluvial soil and lateritic soil were considered for the analysis. The results show that there is reduction in settlement of railway track when the reinforcement is provided in railway embankment laying over black cotton soil and alluvial soil. Both the geosynthetics shows better results when placed at an interface of subballast and embankment fill, instead of ballast-subballast interface.

**KEYWORDS:** Ballasted rail tracks, Railway embankment, Geosynthetic reinforcements, Plaxis-2D.

### I. INTRODUCTION

Railways form one of the largest worldwide networks catering to passenger and freight transportation. Continuous up gradation in transportation needs have placed increased burden on railroad infrastructure. To meet the increased demand for efficient freight transport, the railroad industry has increased traffic volume and maximized axle loadings. i.e. the increased demand of such transportation has led to the use of heavier and faster trains, resulting in large traffic-induced stresses in rail tracks. This often causes significant cumulative deformation as well as the loss of stability and geometry of conventional tracks. Such degradation under repetitive wheel loads results mainly from a loss of stability in the ballast layer through particle breakage, fouling, cyclic densification and associated deformations, as well as settlement of the underlying layers of subballast and subgrade. The loss of stability and geometry has inevitably led to substantial increases in the cost of track maintenance, which mainly involves tamping the ballast. The performance of the ballast is also influenced by the type of subgrade; hence, subgrade stabilization is sometimes required for enhanced track performance and increased longevity. Geosynthetics are used as reinforcement in various applications in geotechnical engineering such as retaining walls, steep slopes, and embankments on soft soils. In addition to this, geosynthetics can also be used as reinforcement or separators in railway tracks. In comparison with other applications, in ballasted railway track the geosynthetic is subjected to very severe conditions, owing to the mechanically aggressive characteristics of the fill (ballast) and to the high load levels transmitted by the trains. The use of geosynthetic

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reinforcement in railways can reduce the development of permanent strains, increase track lifetime and reduce maintenance costs.

## II. RELATED WORK

Sanjay Nimbalkar<sup>1</sup>*et al.* (2016) studied the performance of geosynthetics and rubber mats (i.e. shockmats) in ballasted rail track by executing an extensive field trial in the town of Singleton, New South Wales (NSW), Australia. In their study, full-scale field monitoring on sections of instrumented track to study how effectively various types of geosynthetics and shockmats would improve the overall performance of ballasted rail tracks. It was concluded that, The geogrids and geocomposites decreased the settlement of the ballast by almost 35%, a result that would have significant implications on track maintenance. The geogrids reduced the transient track deformation by 40–65% at the soft alluvial deposit, and by 15% at the hard rock. The reduction in ballast breakage at the concrete bridge deck (stiff subgrade) to levels less than 5% could be attributed to the use of a shockmat.

G. Fernandes<sup>2</sup>*et al.* (2008) studied the use of geosynthetic reinforcement to reduce the consumption of good-quality sub-ballast material in a railway track in the state of Minas Gerais, Brazil. Six test sections on the railway were instrumented and monitored for a period of two years. Nonwoven geotextile and a geogrid were used as reinforcement in different positions in the subballast. The main objective of their research was to evaluate the use of a reinforced low-quality, heaper sub-ballast material as a substitution to the one traditionally used in a railway subjected to intense traffic and high loads transmitted by the trains. The results obtained showed that the presence of geosynthetic reinforcement reduced the strains mobilised in the sub-ballast, reduced the breakage of ballast element, and allowed the use of a cheaper alternative material in the sub-ballast construction. The results showed the potential of the use of alternative sub-ballast material reinforced with geosynthetic to reduce the costs of construction and maintenance of railway tracks.

Sanjay Nimbalkar<sup>3</sup>*et al.* (2013) investigated the relative performance and effectiveness of single-and dual-layer configurations of geosynthetics reinforcement using a large-scale prismatic triaxial chamber at the University of Wollongong, Australia. Also, laboratory tests on unreinforced and reinforced railway track were simulated in a numerical model and the results were then analyzed to better understand the distribution of displacements and stresses inside the railroad ballast layer. The primary objective of their study was to evaluate the deformation and degradation of railroad ballast under a large number of cycles and to study the influence of the type and tensile stiffness of the reinforcement on the overall performance of the railroad ballast. It was concluded that, the biaxial geogrid and nonwoven geotextile can be effectively used to reduce settlement and the movement of particles under cyclic loads, as well as to reduce grain breakage. The biaxial geogrid would be a suitable reinforcement to be placed below the ballast for overall railroad track stabilization. In view of strain and breakage control, both the type of reinforcement and its layout played a vital role in improving the capacity of the track.

Buddhima Indraratna<sup>4</sup>*et al.* (2011) studied the effectiveness of using geocomposite (combination of biaxial geogrid and nonwoven polypropylene geotextile) in railway track, that had been observed through field measurements and finite element analyses. Those were fully instrumented, comprehensive field trials, which was conducted on a section of instrumented railway track along the New South Coast in the town of Bulli, NSW Australia. The field results were then compared with FEM predictions which were found to be almost similar. The vertical deformations were monitored at the sleeper-ballast and ballast- subballast interfaces using settlement pegs. The values predicted by elastoplastic analysis showed slight deviation in comparison with the measured values of real track behavior. This was due to fact that the real cyclic nature of wheel loading was not considered and was approximately represented by equivalent dynamic plain strain analysis in FE studies. Nevertheless, considering the limitations of elasticity-based approaches, this prediction was acceptable for the design practice.

## III.METHODOLOGY

The objective of present research work was to analyse the performance of geosynthetic reinforcement in ballasted rail tracks subjected to cyclic loading by considering various parameters such as types of geosynthetics used as

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reinforcing materials, placement of reinforcing layer, number of reinforcing layers and various subgrade conditions. The analyses were carried out for three natural subgrade viz., black cotton soil, alluvial soil and lateritic soil. Fig. 1 shows the problem structure for the present study.

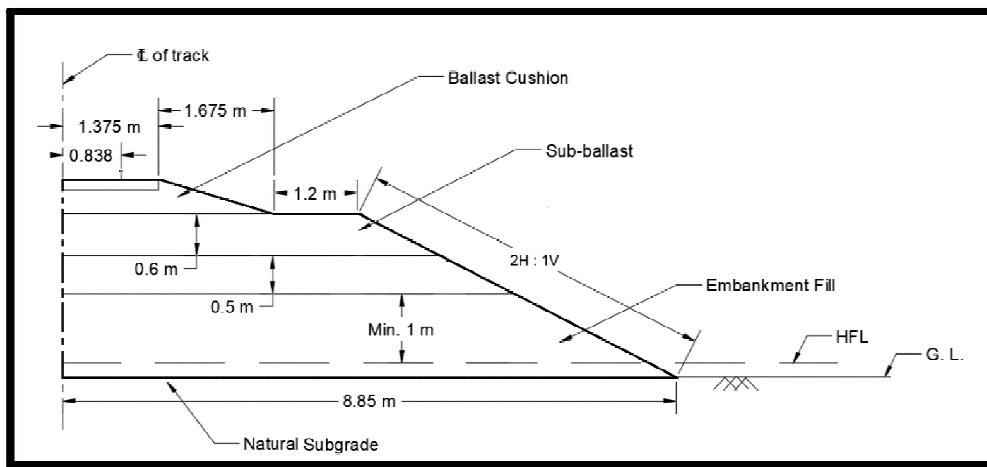


Fig.1: Problem structure for the present study

The material properties selected for the analysis are shown in Table 1 to 3.

Table1 : Properties assigned to geosynthetics

Sr. No.	Type of Geosynthetics	Model	Interface	EA value (kN/m)
1	Geogrid	Elastic	Ballast-subballast interface	1000
			Interface of subballast-embankment fill	2000
2	Geocomposite	Elastic	Ballast-subballast interface	1087
			Interface of subballast-embankment fill	2174

Table 2 : Properties assigned to railway embankment materials

Material	Rail	Sleeper	Ballast	Sub-ballast	Embankment fill
Model	Elastic	Elastic	HS	MC	MC
E (MPa)	$2.1 \times 10^5$	$3 \times 10^4$	-	140	67
$E_{50}^{ref}$ (MPa)	-	-	65	-	-
$E_{oed}^{ref}$ (MPa)	-	-	65	-	-
$E_{ur}^{ref}$ (MPa)	-	-	195	-	-
EA (kN/m)	-	-	-	-	-
$\gamma$ (kN/m <sup>3</sup> )	78	24	15.6	19	17
M	0.3	0.2	-	0.37	0.37
$\mu_{ur}$	-	-	0.2	-	-
C (kPa)	-	-	0	0	0
$\Phi$	-	-	58	45	40
$\Psi$	-	-	0	0	0

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Table 3 : Properties assigned to natural subgrade soil

Sr. No.	Parameter	Name	Type of Subgrade						
			Black Cotton Soil	Alluvial Soil					Lateritic Soil
				CL	ML	SM	CL	CH	
1	Depth (m)	-	23	0-6	6-7	7-8.4	8.4-16	16-23	23
2	Material Model	Model	MC	MC	MC	MC	MC	MC	MC
3	Type of Material Behaviour	Type	Drained	Drained	Drained	Drained	Drained	Drained	Drained
4	Dry Unit Weight	$\gamma_{\text{unsat}}$ (kN/m <sup>3</sup> )	18.35	14.69	13.29	15.85	14.07	14.28	20.5
5	Saturated Unit Weight	$\gamma_{\text{sat}}$ (kN/m <sup>3</sup> )	19.12	19.30	18.23	19.75	18.86	19.03	22.5
6	Young's Modulus	$E_{\text{ref}}$ (kN/m <sup>2</sup> )	6525	10400	8600	9800	13130	17950	19234
7	Poisson's Ratio	$\mu$	0.25	0.3	0.32	0.28	0.3	0.35	0.3
8	Cohesion	$C$ (kN/m <sup>2</sup> )	30	18	12	0	27	43	29
9	Friction Angle	$\phi$	17	0	0	26.4	0	0	44.79

Numerical model of railway embankment with geosynthetic inclusion was developed in PLAXIS 2D as shown in Fig. 2. The embankment was 17.70 m wide and 2.96 m high above the natural subgrade. The slopes had an inclination of 2H:1V. Due to symmetry, only half part of the embankment was modelled (in this case the right half was chosen), as shown in Fig. 3.17. There was an embankment fill above the natural subgrade. RDSO recommends that the embankment more than 1 m above the HFL. Above the embankment fill, there was a sub-ballast layer of 0.6 m. The upper most layer was of 0.3-0.35 m of ballast cushion. Above the ballast cushion, there were sleepers or tie provided perpendicular to the longitudinal direction to which the rail tracks were tied. The dimension of the natural subgrade considered for analysis were; depth = 23 m and width = 35 m. From the analysis carried out, vertical deformations along the depth of embankment for each of the case were determined. The effect of selected parameter on vertical deformation was studied. The details of parameters are shown in Table 4.

Table 4 : Details of parameter studied

Sr. No.	Parameters	Value
1	Reinforcement type	Geogrid, Geocomposite
2	Number of reinforcing layer (N)	1, 2
3	Depth of topmost layer of reinforcement from bottom of footing (u/B)	At ballast-subballast interface, at subballast-embankment fill interface
4	Type of natural subgrade strata	Black Cotton Soil, Alluvial Soil, Lateritic Soil

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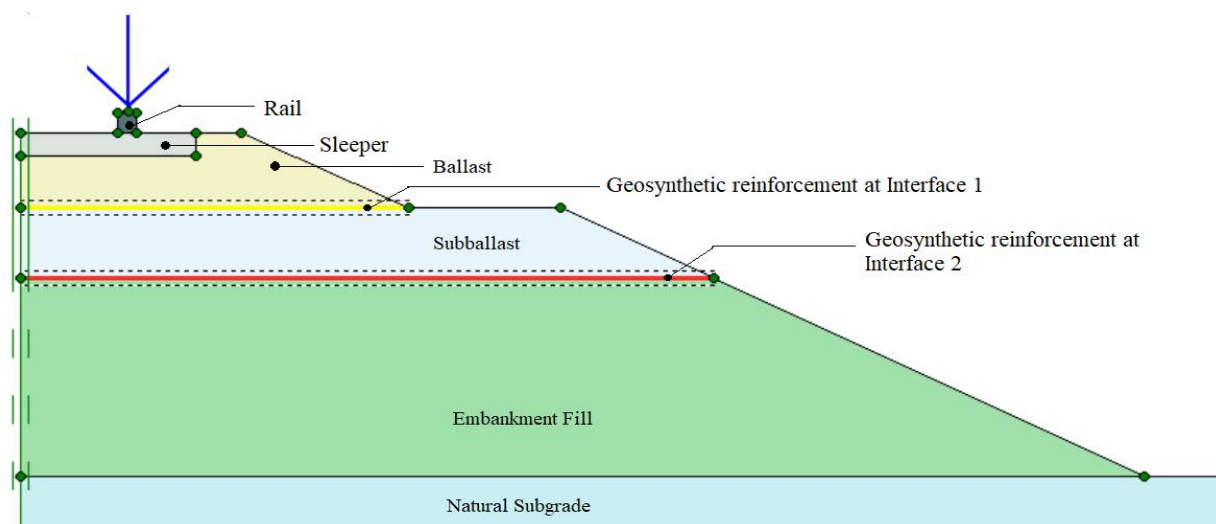


Fig.2: Numerical model developed in PLAXIS 2D

## IV.PERFORMANCE ANALYSIS

PLAXIS-2D software, which works on the finite element method approach, was used for analyzing the reduction of vertical deformation of railway embankment using geosynthetic inclusion. The present study of reduction of settlement of different layers of rail embankment has been carried out for three different subgrades and using two types of geosynthetics (i.e. Geogrid and geocomposite) at ballast-subballast interface and at the interface of subballast-embankment fill.

### 4.1 Performance of Railway Embankment without Geosynthetics

Initially the analysis was carried out for railway embankment without any reinforcement over natural subgrade strata of black cotton soil, alluvial soil and lateritic soil. The variation of settlement of embankment along its depth was presented in this section. Fig. 3 shows the variation in vertical deformation along the depth of embankment without any reinforcement for black cotton soil, alluvial soil and lateritic soil.

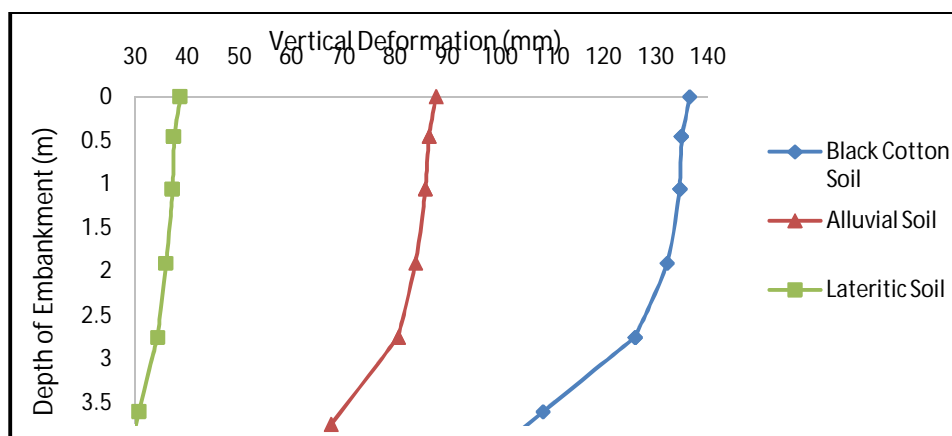


Fig. 3: Vertical deformation of embankment without reinforcements along its depth (without reinforcing material)

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The settlement at surface of the railway embankment is found to be 136.65 mm, 87.85 mm and 38.65 mm for black cotton soil, alluvial soil and lateritic soil respectively, when no reinforcing material is used.

## 4.2 Effect of Geosynthetics in Black Cotton Soil

The analyses were performed on railway embankment using geosynthetics as reinforcing material at different interfaces in black cotton soil. Fig. 4 shows the comparison between the optimum results of vertical deformation along the depth of embankment obtained for different cases.

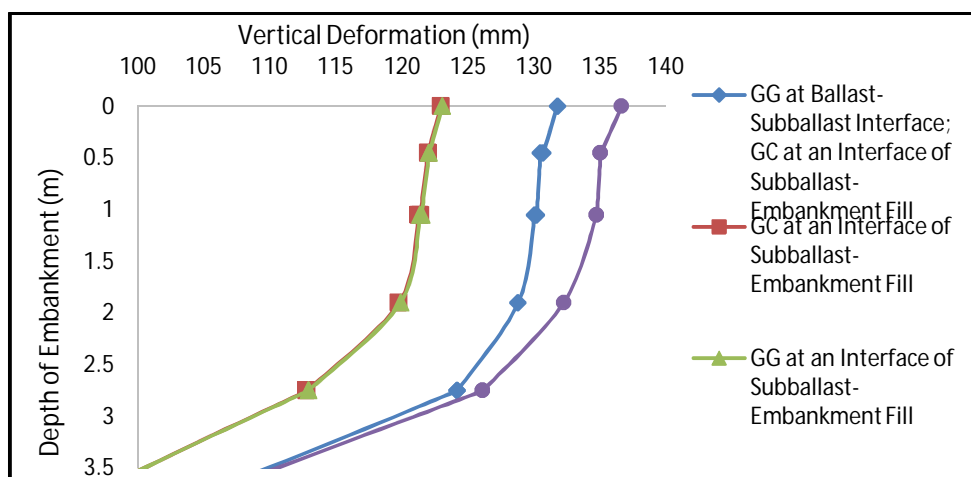


Fig. 4: Comparison between the optimum results of vertical deformation of embankment along its depth (geogrid and geocomposite as a reinforcing material at different interfaces)

The comparison is done between the optimum results of performance of different types of geosynthetics i.e. geogrid and geocomposite as a reinforcing material at different location of the railway embankment. The comparison between performance of different types of geosynthetics when included as reinforcing material in railway embankment is shown in Table 6.

Table 6 : Comparison between performance of different types of geosynthetics as reinforcing material in railway embankment

Sr. No.	Settlement of Soil without Geosynthetics (mm)	Settlement when Reinforced with Geosynthetics			% Reduction in Settlement
		Type of Geosynthetics	Location	Settlement (mm)	
1	136.65	Geogrid	Interface of subballast-embankment fill	123.08	9.93 %
2	136.65	Geocomposite	Interface of subballast-embankment fill	122.96	10.01 %
3	136.65	Geocomposite	Ballast-subballast interface	131.76	3.58 %
		Geogrid	Interface of subballast-embankment fill		

From the results obtained, it can be seen that the geocomposite when used as a reinforcing material at interface of subballast-embankment fill, gives maximum reduction in settlement to the extent of 10.01 % when the railway embankment is constructed over natural subgrade of black cotton soil. Geogrid also can be used at same interface in same situation which gives nearly same reduction in settlement of 9.93 %.

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## 4.3 Effect of Geosynthetics in Alluvial Soil

The analyses were performed on railway embankment using geosynthetics as reinforcing material at different interfaces in alluvial soil. Fig. 5 shows the comparison between the optimum results of vertical deformation along the depth of embankment obtained for different cases.

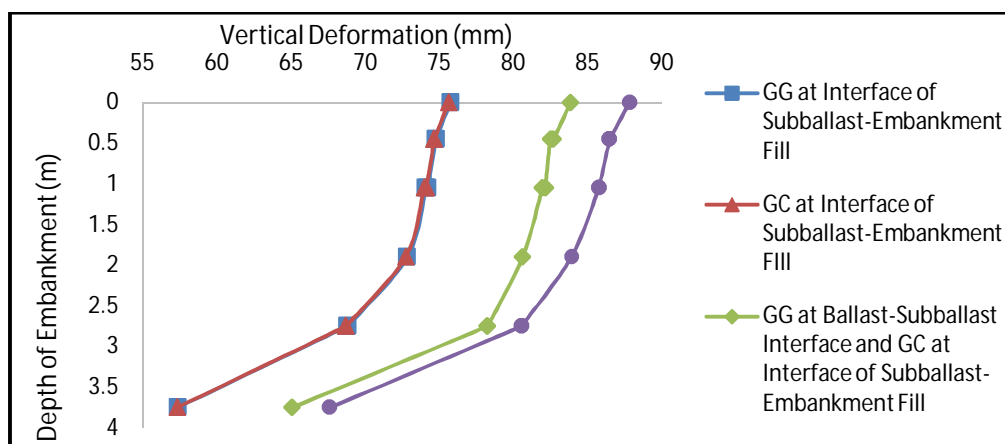


Fig. 5: Comparison between the optimum results of vertical deformation of embankment along its depth (geogrid and geocomposite as a reinforcing material at different interfaces)

The comparison is done between the optimum results of performance of different types of geosynthetics i.e. geogrid and geocomposite as a reinforcing material at different location of the railway embankment. The comparison between performance of different types of geosynthetics when included as reinforcing material in railway embankment is shown in Table 7.

Table 7 : Comparison between performance of different types of geosynthetics as reinforcing material in railway embankment

Sr. No.	Settlement of Soil without Geosynthetics (mm)	Settlement when Reinforced with Geosynthetics			% Reduction in Settlement
		Type of Geosynthetics	Location	Settlement (mm)	
1	87.85	Geogrid	Interface of subballast-embankment fill	75.75	13.77 %
2	87.85	Geocomposite	Interface of subballast-embankment fill	75.63	13.91 %
3	87.85	Geogrid	Ballast-subballast interface	83.84	4.56 %
		Geocomposite	Interface of subballast-embankment fill		

From the results obtained, it can be seen that the geocomposite when used as a reinforcing material at interface of subballast-embankment fill, gives maximum reduction in settlement to the extent of 13.91 % when the railway embankment is constructed over natural subgrade of alluvial soil. Geogrid also can be used at same interface in same situation which gives nearly same reduction in settlement of 13.77 %.

## 4.4 Effect of Geosynthetics in Lateritic Soil

The analyses were performed on railway embankment using geosynthetics as reinforcing material at different interfaces in lateritic soil. Fig. 6 shows the comparison between the optimum results of vertical deformation along the depth of embankment obtained for different cases.



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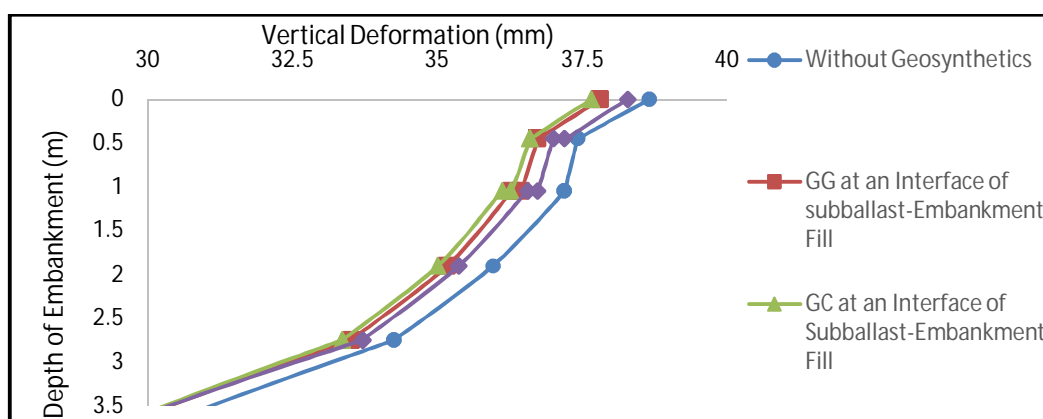


Fig. 6: Comparison between the optimum results of vertical deformation of embankment along its depth (geogrid and geocomposite as a reinforcing material at different interfaces)

The comparison is done between the optimum results of performance of different types of geosynthetics i.e. geogrid and geocomposite as a reinforcing material at different location of the railway embankment. The comparison between performance of different types of geosynthetics when included as reinforcing material in railway embankment is shown in Table 8.

Table 8 : Comparison between performance of different types of geosynthetics as reinforcing material in railway embankment

Sr. No.	Settlement of Soil without Geosynthetics (mm)	Settlement when Reinforced with Geosynthetics			% Reduction in Settlement
		Type of Geosynthetics	Location	Settlement (mm)	
1	38.65	Geogrid	Ballast-subballast interface	37.80	2.20 %
2	38.65	Geocomposite	Interface of subballast-embankment fill	37.65	2.59 %
3	38.65	Geogrid	Ballast-subballast interface	38.27	0.98 %
		Geocomposite	Interface of subballast-embankment fill		

From the results obtained, it can be seen that the geogrid when used as a reinforcing material at Ballast-subballast interface, gives maximum reduction in settlement to the extent of 2.59 % when the railway embankment is constructed over natural subgrade of lateritic soil. Geocomposite also can be used at an interface of subballast-embankment fill in same situation which gives slightly lesser reduction in settlement of 2.20 %.

## V. CONCLUSION

Based on the results of the present study, the following broad conclusions are drawn:

1. The geogrid and geocomposite can be used to decrease the vertical deformation of ballasted rail track, when placed at the interface of subballast-embankment fill, which may result in reduction of maintenance cost.
2. In case of railway embankment underlaid by black cotton soil, placement of geogrid at the interface of subballast and embankment fill, reduces the vertical track deformation by about 10 %, also the placement of geocomposite at the same interface reduces the vertical track deformation by almost same extent.



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3. In case of railway embankment underlaid by alluvial soil, placement of geogrid at the interface of subballast and embankment fill, reduces the vertical track deformation by about 13.8 %, whereas the placement of geocomposite at the same interface reduces the vertical track deformation by about 14 %.
4. In case of railway embankment underlaid by lateritic soil, placement of geogrid at ballast and subballast interface, reduces the vertical track deformation by about 2.2 %, also the placement of geocomposite at the interface of subballast and embankment fill reduces the vertical track deformation by about 2.6 %,.
5. There is significant reduction in settlement of railway track when the reinforcement is provided in railway embankment laying over black cotton soil and alluvial soil, but there is no significant reduction in settlement when the embankment is laying over lateritic soil.
6. Single layer configuration of geosynthetics are better in reducing the settlement than dual layer configuration.
7. Geocomposite, as a reinforcing material, shows slightly better performance in reducing the settlement than geogrid.
8. Both the geosynthetics shows better results when placed at an interface of subballast and embankment fill instead of ballast-subballast interface.

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