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Reinforcement and mud-pumping benefits of geosynthetics in railway tracks: Model tests

Sowmiya Chawla [a, *, 1], J.T. Shahu [b, 2]

[a] Department of Civil Engineering, Indian School of Mines, Dhanbad 826004, India
[b] Department of Civil Engineering, Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India

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ABSTRACT

The railroad track is one of the few geosynthetic applications in which a geosynthetic is used for multiple functions, namely, reinforcement, separation, filtration and drainage. In the present study, static and cyclic tests were performed on full-panel railway track models laid on compacted soil subgrades. Tests were performed on model tracks with two different thicknesses of subballast layers and laid on two different subgrade soils, namely, Dhanaury clay and Delhi silt. Model tracks were adequately instrumented to record induced stresses and displacements in the track. Model tracks were reinforced with a geogrid or a geotextile or both at suitable interfaces. Track conditions after heavy rainfall were simulated. The model tracks reinforced with a geogrid at the ballast–subballast interface were more effective in reducing the tie displacements, ballast and subballast strains and subgrade displacements compared to the model tracks reinforced with a geotextile at the subballast–subgrade interface when Dhanaury clay was used as the subgrade soil. Conversely, the model tracks reinforced with a geotextile performed better with respect to reduced tie displacement, subgrade displacement and subballast strain compared to the model tracks reinforced with a geogrid when Delhi silt was used as the subgrade soil.

1. Introduction

To increase transportation efficiency, Indian railways are now running heavier, faster and longer trains than they did in the 1990s. Since the 1990s, several subgrade shear failures and mud-pumping problems have been reported after heavy monsoon rains on heavily worked routes in central and western parts of India and the Indo-Gangetic plain on tracks laid on silty and clay soil subgrades.

When trains pass over a railway track, the subgrade soil is subjected to a certain cyclic stress. If this stress is greater than a particular stress level, subgrade shear failure occurs. Another mode of failure is mud-pumping. After heavy monsoon rains, the subgrade soil beneath a railway track becomes soft, and the overlying ballast causes attrition and erosion of the subgrade soil, thus resulting in the formation of slurry at the subgrade surface. Under the load of the passing train, the slurry climbs up through the voids inside the ballast layer and is pumped out on to the surface of the ballast. This mud-pumping displaces the clay and fines present in the subgrade soil and completely disrupts the drainage system, thereby causing progressive track deterioration (Indraratna and Tennakoon, 2014). However, very little information is available on mud-pumping in literature in spite of the wide extent of the problem (Hayashi and Shahu, 2000).

To safeguard against these failures, Indian Railways (RDSO, 2007) have recommended a minimum thickness of a subballast layer equal to 1 m for tracks laid on fine-grained soil subgrades. Because a subballast layer consists of free draining granular material, this provision becomes uneconomical where the track passes through a long stretch of clayey soil and requires the granular material to be hauled from over a long distance. Use of geosynthetics may provide an economical solution to reduce the subballast thickness under such conditions.

The railroad track is one of those few applications where geosynthetics serve multiple functions, namely, drainage, separation, filtration and reinforcement (Koerner, 2005). Geotextiles have the potential to mitigate the mud-pumping problem when used at the subballast–subgrade interface and to partially or fully replace the subballast layer. Geotextiles can help in draining away the water entering from above or below the geotextile within its plane out of the track structure. Geotextiles can act as separators and thus

* Corresponding author. Tel.: +91 9990907710; fax: +91 326 2296511.
E-mail addresses: sowmiya_iitd@hotmail.com, sowmiya_lazarus@yahoo.co.in (S. Chawla), shahu@civil.iitd.ac.in, bayleef10@rediffmail.com (J.T. Shahu).
[1] Former Research Scholar, Department of Civil Engineering, IIT Delhi.
[2] Tel.: +91 11 26591240/9968801590; fax: +91 11 26581117.

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prevent the intermixing of fine-grained subgrade soil with the overlying ballast or subballast material. Geotextiles can also act as filters by allowing the water to pass through it but retaining the soil within the subgrade. Geotextiles can also act as reinforcements and thereby reduce subgrade stresses by a membrane effect and a confinement effect.

Geogrids are used to reinforce the track and are generally used at the ballast–subballast interface. Geogrids reduce lateral spreading of the ballast particles, thereby resulting in an increase in lateral confinement and thus stiffness of the ballast layer, thereby giving rise to better stress distribution and a reduction in induced stresses. Geogrids also act as tension members to reduce induced stresses.

Model tests provide an alternative way to directly reflect the behavior of the prototype under simulated conditions. In the past, two types of tests, namely, single sleeper tests (ORE, 1982) and full panel tests (ORE, 1983) have been performed on unreinforced railway track models. Out of the two, full panel tests are considered a more accurate representation of the prototype owing to a more realistic load transfer mechanism. The few studies on reinforced track models available in literature are all based on single sleeper tests (Raymond, 2002; Shin et al., 2002; Indraratna et al., 2006; Indraratna and Nimbalkar, 2013; Brown et al., 2007). Except for Shin et al. (2002), all of these model studies were conducted to investigate the reduction in ballast degradation due to the provision of a geogrid. Thus, the main focus of these studies was the behavior of the ballast. Accordingly, a thin rubber mat was used in these studies to simulate the subgrade in place of the actual soil. In the case of Shin et al. (2002), the dimensions of the materials used in the construction of the models such as ballast particles, geogrid apertures, etc. were not scaled down.

The present study investigates the benefits of the use of geosynthetics on tracks laid on fine-grained soil subgrades after heavy monsoon rains with respect to track reinforcement and a reduction in mud-pumping. The study is presented in two parts. The first section discusses model testing and is presented in this paper. The second part addresses the evaluation of constitutive parameters of track materials and interfaces by conducting laboratory tests, comparisons of measured model test data with finite element analysis and a parametric study of prototype track stabilized with geosynthetics, all of which are presented in a companion paper. In this paper, monotonic and cyclic load tests are performed on full panel unreinforced and reinforced model tracks with a subballast layer laid on compacted silty and clayey soil subgrades. The influences of the subballast layer thickness and subgrade type on induced stresses and displacements are evaluated.

2. Materials

Tests were performed on model tracks prepared at a 1:3 scale to the prototype. The materials used in the model tracks are described below.

2.1. Ballast and subballast materials

Tests were carried out using a one-third scale ballast and subballast particles. The reduced size ballast was procured from Manesar quarry near Delhi, India, which also supplies full size ballast to Indian railways. As a subballast layer usually consists of a locally available free draining material (Shahu et al., 2000), a quarry dust from the same plant was used as the subballast material. The particles were mapped to a one-third scale parallel gradation to that specified by RDSO (Research Designs and Standards Organization, Indian Railways). The characteristics of the ballast and subballast materials used in the models are listed in Table 1, and the particle size distribution curves are given in Fig. 1(a). The range of prototype ballast and subballast materials as specified by the RDSO (Research Designs and Standards Organization, Indian Railways) after their one-third size reduction is presented in Fig. 1(a).

Le Pen et al. (2013) demonstrated that there are differences in the shape distributions associated with the different particle size bins of the same material, so that the particle shape distributions do not necessarily scale. However, for a scaling factor of 3, the differences attributable to size effects were less than those between full size ballasts from different sources meeting relevant industry specifications. In the present study, image analysis (Shahu and Yudhbir, 1998; Sowmiya, 2013) has shown the differences in particle shape distribution associated with size to be similarly small. Monotonic drained triaxial tests on scaled and full size ballast showed differences in strength and stiffness between the scaled and full size ballast to be negligible at the range of confining stresses relevant to track loading (Sowmiya, 2013). Thus from a mechanical point of view, the use of a scaled ballast was acceptable. This is consistent with the findings of Sevi (2008) and Le Pen et al. (2014).

2.2. Subgrade soil

Two natural fine-grained soils, namely, Dhanaury clay (DC) and Delhi silt (DS), were used as subgrade soils. The particle size distribution curves and typical characteristics of these materials are presented in Fig. 1(a) and Table 1, respectively.

2.3. Geogrid and geotextile

A biaxial geogrid (GG) (Fig. 1b) and a non-woven geotextile (GT) (Fig. 1c) were used in the model tracks. The geogrid was made up of

Table 1
Characteristics of track materials.

Item	Ballast	Subballast	Subgrade	
			Dhanaury clay	Delhi silt
Classification	GW	SW	CI	ML
γ_d (kN/m^3)	16.1	14.5	15.3	16.5
$\gamma_{d(max)}$ (kN/m^3)	16.4	16.0	17.9	17.6
$\gamma_{d(min)}$ (kN/m^3)	14.2	11.7	–	–
OMC (%)	–	–	16.7	15.4
w_L (%)	–	–	36	25.5
I_P	–	–	15	5
Minerals	Quartzite	Quartzite	–	–
Particle shape	Angular–Subangular	Angular	–	–
k (m/s)	–	–	3.28×10^{-10}	1.26×10^{-8}

Note: GW = Well graded Gravel; SW = Well graded Sand; CI = Inorganic Clays with medium plasticity; ML = Silts with Low plasticity; γ_d = Dry unit weight; $\gamma_{d(max)}$ = Maximum dry unit weight; $\gamma_{d(min)}$ = Minimum dry unit weight; OMC = Optimum Moisture Content; w_L = Liquid Limit; I_P = Plasticity Index; k = Permeability.