Evaluation of Geosynthetic Reinforced Tracks on Clayey Subgrade

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ABSTRACT: In Railroad trackgeosynthetic is used for multiple functions, namely, reinforcement, separation, filtration and drainage. In the present study static and cyclic tests are performed on full panel railway track models laid on compacted soil subgrades. Tests are performed on model tracks with two different thicknesses of subballast layer and laid on subgrade soil, namely, Dhanaury clay. Model tracks are reinforced with geogrid or geotextile or both at suitable interfaces. Track condition after a heavy rainfall was simulated. The models reinforced with geogrid at ballast-subballast interface were found to be more effective in reducing the tie displacements, ballast and subballast strains, and subgrade displacements as compared to the models reinforced with geotextile at subballastsubgrade interface for tracks withDhanaury clay as subgrade. The present study is also carried out by using a commercially available finite element software code, MIDAS/GTS (Midas manual 2013).Laboratory tests (triaxial tests and interface tests) are being conducted to calculate the constitutive parameters of the different track materials and interfaces which are used in the analyses. Model test results were extended to the field and Subgrade modulus(Esg) and subballast thickness (dsb) as well as shear strength parameters ($c'sg$and $\phi'sg$) of the subgrade soil, stiffness of geogrid and coefficient of permeability of the subgrade soil were track parameters.

Keywords:*Railway tracks; clayey subgrade, mud pumping, geogrid, geotextile.*

1. Introduction

Railways form an important part of thetransportation infrastructure of a countryand play an important role in sustaining a healthy economy. Indian Railways have now geared up to overhaul and upgrade its infrastructure to meet the future demand of growing traffic. When trains pass over a railway track, the subgrade soil is subjected to a certaincyclic stress. If this stress is greater than a particular stress level, subgrade shear failureoccurs (Selig and Waters 1994). On the other hand, after heavy monsoon rains, thesubgrade soil beneath a railway track becomes soft, and the overlying ballast causesattrition and erosion of the subgrade soil resulting in the formation of slurry at thesubgrade surface. Since a subballast layer consists of free draining granular material (Shahu et al.2000), this provision becomes uneconomical where the track passes through a longstretch of clayey soil, thereby requiring that the granular material to be brought from longhaul distances. Geosynthetics could be an economical solution to bring about thereduction in the subballast depth under such conditions. Geosynthetics also provide animportant option to improve the overall track support structure and thereby reduce thetrack maintenance costs and operation costs due to train delays.Very little work has been done on gainful utilization of geosynthetics by Indian Railways.Therefore, the application of geosynthetics in Indian Railways needs a detailed studyunder various site specific conditions, such as type of subgrade soils, track structure, track geometry, material specifications, loading details and environmental factors. The present study will help in laying out properspecifications for various track materials and geosynthetics, and development of a rationalmethodology for design of reinforced tracks.

1.1 Application of geosynthetics in tracks

Figure 1 shows the main components of a typical geosynthetic reinforced track structure (Selig and Waters, 1994). The components may be grouped into two maincategories: superstructure and substructure. Railroad track is one of the few geosynthetic applications where a geosynthetic isused for multiple functions, namely, reinforcement, separation, filtration and drainage(Koerner 2005). Geogrids are used to reinforce the track and generally provided within orbelow the ballast layer. Geogrids reduce lateral spreading of the ballast particles increases lateral confinement to the ballast layer. This increases thestiffness of the ballast layer resulting in better stress distribution and reduction in inducedvertical and shear stresses on to the underlying subballast and subgrade (Koerner 2005).Geotextiles can act as aseparator preventing the intermixing of a fine-grained subgrade soil with the overlyingballast or subballast materials. They also act as a filter allowing the water to pass through it but retaining the soil within thesubgradent. When the subgrade soil is soft, the geotextile can also act as reinforcement and reduce subgrade stresses (Selig andWaters, 1994).

2. Model testing of railway tracks

The present study has investigated the benefits of the use of geosynthetics on tracks laid on fine grained soils after a heavy monsoon rain in terms of track reinforcement andreduction of mud-pumping. Monotonic and cyclic load tests are performed on modelreinforced tracks with a subballast layer laid on compacted clayey soilsubgrades. Track conditions after a heavy monsoon rain are simulated.

2.1 Materials

Tests are performed on model tracks laid at 1:3 scale to the prototype. Grain size distributions of different model track materials are given in Fig. 2 and typical characteristics are listed in Table 1.

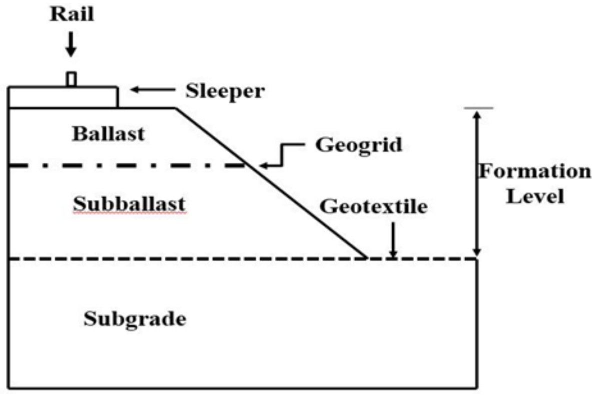

Fig. 1 Cross-section of a typical geosynthetic reinforced railway track

2.1.1 Subgrade Soil, Ballast and Subballast Materials

The ballast was procured from an aggregate crushing plant at Manesar in Haryana state which also supplies ballast to Indian Railways. The range ofprototype 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.2.Natural fine-grained soil, namely, Dhanaury clay used as subgrade soil.

2.1.2 Geogrid and geotextile

A non-woven geotextile (GT) and a biaxial geogrid (GG) are used in the model tracks. The geogrid was made up of high density polyethylene(HDPE) with an aperture size of 30 mm x 30 mm and an initial tensile stiffness of 240 kN/m. The tensile stiffnesses of the geogrid at 2.5% and 5% strain were 120kN/mand 88 kN/m, respectively.

2.2 Modeling considerations

2.2.1 Similitude Ratio Adopted for Model Testing

Similitude ratio refers to the ratio of any linear dimension of the model to thecorresponding dimension of the actual prototype track. Model dimensions were scaleddown based on the similitude ratio in such a way that induced stresses in the modelremain the same as those in the prototype. Since the ballast-subballast interface where the geogrid was used was subjected to high stresses similar to those in the field. Based on practical consideration, a full panel model track with a similitude ratio of one-third is used in this study. A comparison of the prototype track and the model track is given inTable 2.

2.2.2 Modeling Rail and Sleepers

It was assumed that the rail transfers stresses on to the sleepers by a beam action and the sleepers then transfer the stresses to the ballast layer mainly by a direct bearing. Therefore, a square rail section was used in the model such that the flexural rigidity (EI) of the model rail was reduced by 1/81th of that of the actual rail as per the similitude ratio and steel sleepers were used in the model with all the dimensions reduced except thickness as per the similitude ratio in place of prestressed concrete sleepers employed in the prototype

Table-1 Characteristics of different track materials

Item	Ballast	Subballast	Dhanaury Clay
Classification	GW	SW	CI
$\gamma_{d(max)}$ (kN/m^3)	16.4	16.0	17.9
$\gamma_{d(min)}$ (kN/m^3)	14.2	11.7	-
OMC (%)	-	-	16.7
w_L (%)	-	-	36.0
I_P	-	-	15
Fine Sand (%)	-	-	-
Silt (%)	-	-	75.0
Clay (%)	-	-	25.0
Minerals	Quartzite	Quartzite	-
Particle shape	Angular-Subangular	Angular	-
k (m/s)	-	-	$3.28\text{x}10^{-10}$

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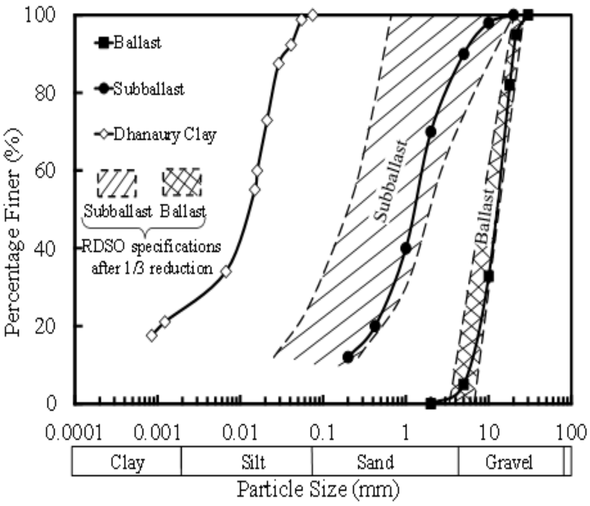


Fig. 2 Grain size distribution of various track layer materials.

2.2.3 Modeling Geogrid and Geotextile

A geogrid is used at the ballast-subballast interface and/or a geotextile is used at the subballast-subgrade interface. It acts as separator and helps in settlement reduction which influence load-deformation behaviour. Ageogrid with the aperture size of 30 mm was chosen. Usually, a relatively heavy geotextile of thickness greater than 4 mm is employedin tracks (Martinek 1986); accordingly, an available, heat-bonded, non-woven geotextileof reduced thickness of 2.2 mm was used in the model tests. A 2.2 mm thick geotextileis also considered adequate for the filtration and drainage functions. Based on symmetry, only one-half of the model track was constructed and a smooth boundary was provided along the center line. The load was applied on the top of the rail, and based on the similitude ratio used, this load was equivalent to nine times of that applied on the prototype track.

Table-2Comparison of model track with prototype track

Parameter	**Prototype track**	**Modeled track**	**Remark**
L_g	1.676 m	0.56 m	1/3
Rail Moment of Inertia, I_r	21580 cm^4	26.64 cm^4	Reduced by a factor of (1/81)
L_s	2.70 m	0.9 m	1/3
b_s	25 cm	8.3 cm	1/3
t_s	12 cm	3.4 cm	By equating $(EI)_S=(EI)_C$
S	65 cm	21.6 cm	1/3
Sleeper Material	Concrete	Steel	Practical testing considerations
d_{sg}	-	0.5 m	1/3
d_b	350 mm	116.7 mm	1/3
d_{sb}	600and 1000 mm	200and 330 mm	1/3

2.3 *Test set-up and instrumentation*

2.3.1 Instrumentation Used

All tests were conducted inside a specially fabricated steel tank with 1.48 m long, 1.3 m wide and 1 m high. The depth of subballast, ballast and subgrade being 200 and 330mm, 116.7mm and 0.5m respectively.Monotonic and cyclic loadings were applied at the top of the rail by a circular plunger attached to a flat plate, which was, in turn, bolted to the flange plates of the MTS machine. The lower end of the plunger was made to rest on a load cell pedestal through which the load was transmitted to the rail. The instrumentation consisted of displacement transducers, earth pressure cells and load cells connected to a digital data logger (Fig. 3).

Model tracks were adequately instrumented to record important responses during the tests. The vertical displacement was measured using dual type, strain gauge based displacement transducers that provide both an electronic signal as well as a digital readout for effective monitoring. Miniature earth pressure cells of 2.5 cm diameter and 0.5 cm thickness of 200, 500 and 1000 kPa capacity were used for measurement of stresses in the subgrade, sub-ballast layer and ballast layer, respectively,depending upon the expected magnitude of stressesin these layers (Shahu 1993). A load cell of 50 kN capacity was used to measure thevertical load**.**The whole instrumentation was connected to a 9-channel portable data logger having simultaneous display of measurement of 9 channels for effectivemonitoring and automatic recording. The actuator of the MTS machine was controlled via a computer operated servo-controlled system.

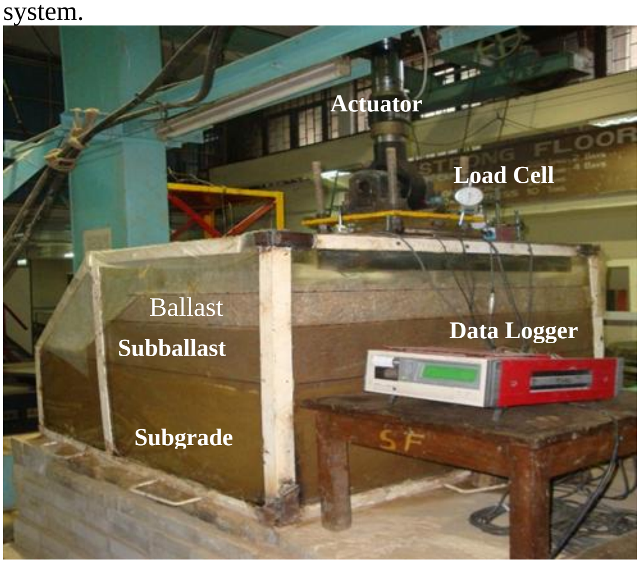


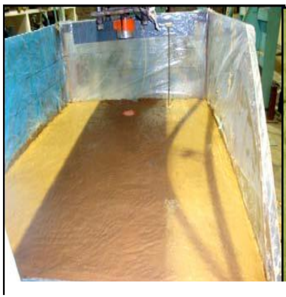
Fig. 3 A schematic view of model test setup

2.4 *Test procedure and observations*

The subgrade soil bed was prepared as follows: first, the dry soil was sieved toremove foreign particles; a required amount of water was then mixed with the soil namely, Dhanaury clay (DC).

(a) Through mixing with bare feet

(b) Kneading compaction using sheep foot roller



(c) Placing of earth pressure cells and settlement peg

(d) Close view of earth pressure cells arrangement

Fig. 4 Subgrade bed preparation and instrumentation.

To achieve approximately the same target undrained shear strength, Dhanaury clay was mixed with 30% water based on a trial and error procedure. The soil was mixed manually with bare feet in a 30 kg batch each in a large ceramic tub to break up any clods present (Fig. 4 a).

The soil was then filled up inseparate cylindrical drums and covered up with wet jute bags for 24 hours for moistureequalization. At the bottom of the test tank, circular holes were provided at constant intervalensuring a drainage boundary at thebottom of the tank. The test tank was filled up with a required amount of subgrade soiland compacted in three layers to achieve desired dry density. Kneading compaction was carried out using a small speciallymanufactured sheep foot roller of 22 kg weight asshown in Fig. 4 (b).

After kneading compaction, the subgrade surface was leveled with a smooth drum roller of 3.5 kg weight (Fig.4 c). After the compaction process, samples were collectedfrom three different locations in plan and from three different depths at each location tomonitor water content, dry density and undrained shear strength (by conducting alaboratory vane shear test). The entire surface area was then covered with wet jute sheetsand the soil bed was left in this condition for further 24 hours for moisture equalization.An earth pressure cell was then placed exactly below the position of the load cell and asettlement peg was placed beside it at the top of the subgrade soil (Fig. 4 c-d).A complete and continued test procedure is detailed inSowmiya(2013).

A total of 10 tests were conducted in two groups. Group 1 tests were termed as DC20 indicating that the models hadDhanaury clay (DC) as the subgrade soil and a subballast thickness (dsb) of 20 cm; group2 tests as DC33 indicating that the models had Dhanaury clay as the subgrade soil and asubballast thickness of 33 cm; In each group,one monotonic and four cyclic tests were conducted.

2.4.1 Monotonic Tests

For reinforced and unreinforced condition with geosynthetic material for a nearly saturated subgrade soil condition the cyclic loads which leads to non-terminating deformation in case of the unreinforced track condition was performed. The coupled analysis was carried out in a single stage wherein a total of 30 kN load was applied over a total time duration of 20 min spread over ten equalsteps.

2.4.2 Cyclic Tests

The details of the cyclic test of DC20 group on unreinforced model track (DC20UR-C) in terms of the number of load cycles with the tie displacement up to initial 100load cycles with 0.1 Hz frequency are shown in Fig. 5. A threshold stress is defined as a critical level of repeated stress (CLRS) such that when the cyclic stress level is above the CLRS, plastic deformation is non-terminating (Chawla and Shahu 2016).The tie displacement datameasured directly by the sensors in MTS machine and the displacement data for all thetrack layers recorded in the data logger are shown in Fig. 5.

Cyclic test results show thatthe presence of the geotextile at the subballast-subgrade interface (GT test) or the geogrid at the ballast-subballast interface (GG test) or both the geotextile and the geogridat their respective interfaces (GT-GG test) reduces the tie displacement δt as well as thesubgrade displacement as compared to those for the corresponding unreinforced track(UR test).

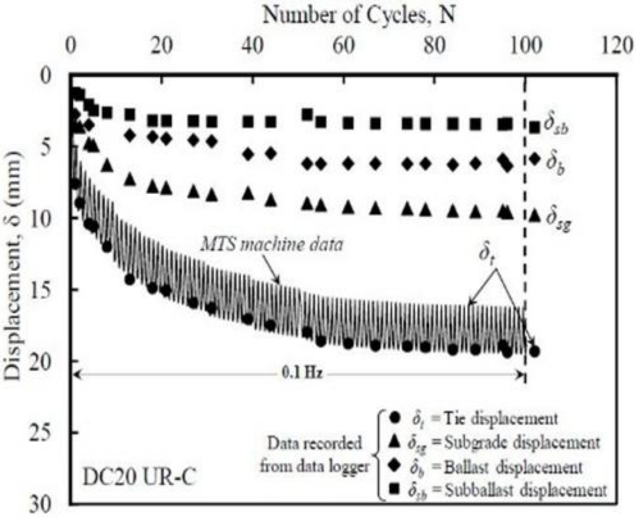


Fig. 5 Variations of tie displacement δt and displacement measured for the track layers beneath the rail seat for initial 100 load cycles N with 0.1 Hz frequency for DC20 UR-C test

For DC20 and DC33 tests the maximum reduction in thetie displacement at the end of 25000 load cycles is observed in case of GT-GG test (≅42%), followed by GG test (≅ 31%) and GT test (≅ 19%) as expected. The geogrid reinforcement is more effective owing to its nearness to the applied load and its higher stiffness as compared to the geotextile.

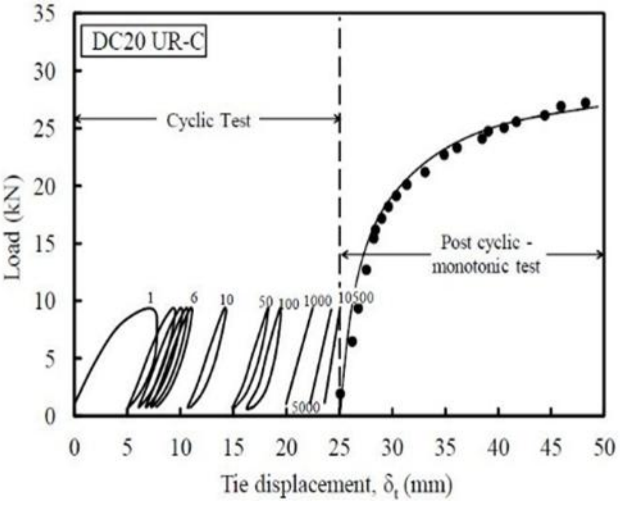


Fig. 6 Typical cyclic and post cyclic monotonic test responses of DC20 UR test.

2.4.3 Post Cyclic-Monotonic Load Behavior

After the cyclic loading, post cyclic-monotonic loading was applied to determine the stiffness and failure load of the model track. Typical cyclic and post cyclicmonotonicresponses for DC20 UR test are shown in Fig.6.In post cyclic tests A higher stiffness and approximately 33% higher failure load was observed for the unreinforced track (UR-C) during the post cyclic-monotonic test as compared to those observed during the monotonic test on a newly laid model track (UR-M) in case of DC20 group tests. Similarly, in case of GT, GG and GT-GG tests of DC20 group the failure load during the post cyclic-monotonic loading increased by 42.7%, 38.8% and 49%, respectively, as compared to that of the newly laid model track (UR-M).

3. FINITE ELEMENT ANALYSIS OF MODEL TEST TRACKS.

MIDAS/GTS (Midas manual 2013) a commercially available finite element software code, is used for the finite element analyses of model test tracks. The tests were carried out for three different analysis. First Non linear analysis second straight analysis and the third coupled analysis.

A series of 10 large-scale full panel railway track model tests divided into threetest groups (DC20 group: Dhanaury clay as subgrade with subballast thickness of 200mm; DC33 group: Dhanaury clay as subgrade with subballast thickness of 330 mm;was conducted. Within each test group, the following types of model testswere performed: a monotonic test (UR-M) and the first cyclic test (UR-C) wereconducted on unreinforced model tracks; the second cyclic test (GT) was conducted on amodel track stabilized with geotextile alone present at the subballast-subgrade interface;the third cyclic test (GG) was conducted on a model track reinforced with geogrid alonepresent at the ballast-subballast interface; and the fourth cyclic test (GT-GG) wasconducted on a model track reinforced with both geotextile and geogrid at their abovementioned respective interfaces.

3.1 Monotonic Tests

Figures 7 and 8 compare the results predicted by two sets of constitutive relationships with the measured results of monotonic tests for unreinforced tracks (URM)for DC20 and DC33 respectively, in terms of load versus tie displacement. Coupled analysis gives better prediction of the measured load-displacementbehavior of the model tracks as compared to the non-linear analysis and straight analysis.

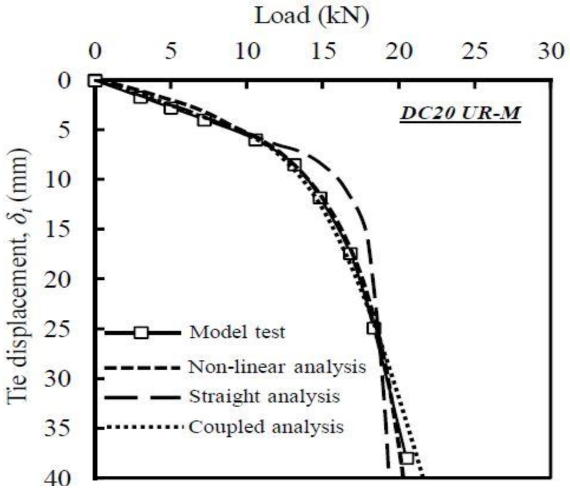


Fig. 7Model test results compared with the predicted FEM (DC20 UR-M).

The coupled analysis fairly predicts the measured load displacementbehavior of all the three model tracks under monotonic loading (Figs. 7 and 8).The non-linear analysis gives better results than the straight analysis.

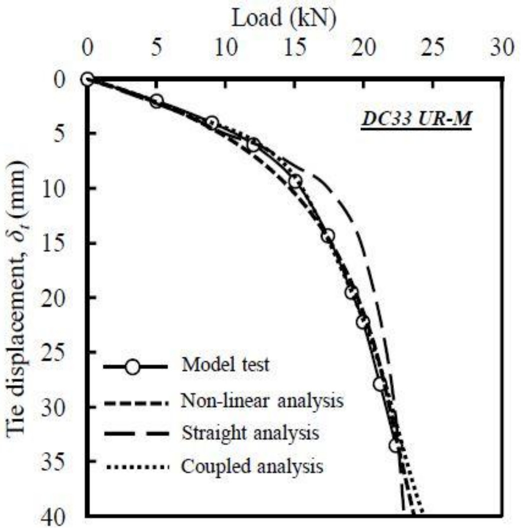


Fig. 8 Model test results compared with the predicted FEM (DC33 UR-M).

3.2 Cyclic Tests

3.2.1 Tie Displacement

Figure 9 shows typical vertical stress contours for DC20 GT-GG test. The deformed shapes of the track section after failure at wheel load = 13.75kNalong sleeper and rail directions observed through the visible perspex sheet for DC20 URMtest are compared with the deformed shapes observed in the coupled analysis. The surface profiles and deformed shapes of each layerobserved during the model test, match well with those obtained by the finite elementanalysis.

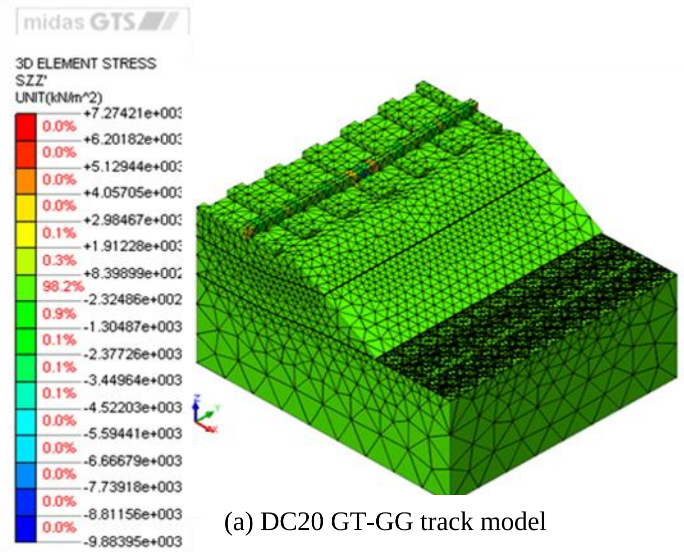
Model test analysis with finite element(coupled) analysis for DC20 and DC33test compare the measured load versus tie displacement resultsduring the first loading cycle up to 9 kN load for the cyclic tests of DC20 and

DC33 groups with the predicted results by the coupled analysis. The failure loads have been calculated using Vesic's criterion (refer Winterkorn and Fang 1986) as 12.5, 14.25, 15.6 and 16.8 kN, respectively, for UR, GT, GG and GT-GG tests of DC20 group. The corresponding failure loads are 14.5, 16.2, 17.5 and 19 kN for DC33 group. The geogrid reinforced track (GG) had a higherstiffness and a higher failure load than the geotextile stabilized track (GT) for both groups.

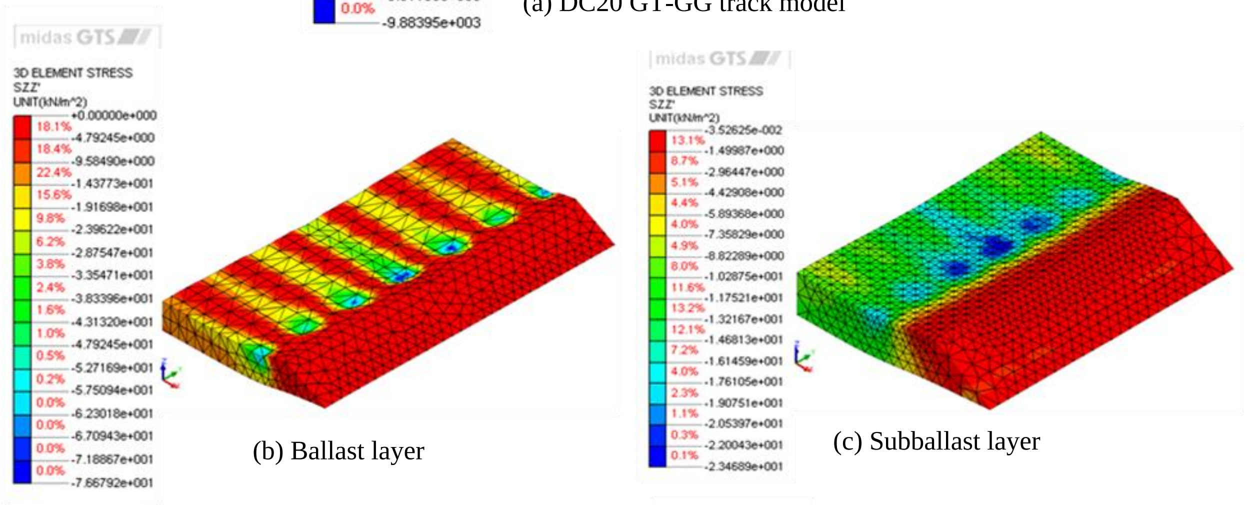
3.2.2 Vertical Stresses

In general, predicted vertical stresses lie within or at thebottom of the measured scatter values. While the measured stresses were measured duringcyclic loading and thus involved some inertial and impact effects, the predictions weremade for the static load.

The coupled analysis consistently predicts higher ballast and subballast topstresses as compared to the non-linear analysis; however, the reverse is the case for thesubgrade stresses. The reason for this is while the ballast and subballast stresses predictedby both coupled and non-

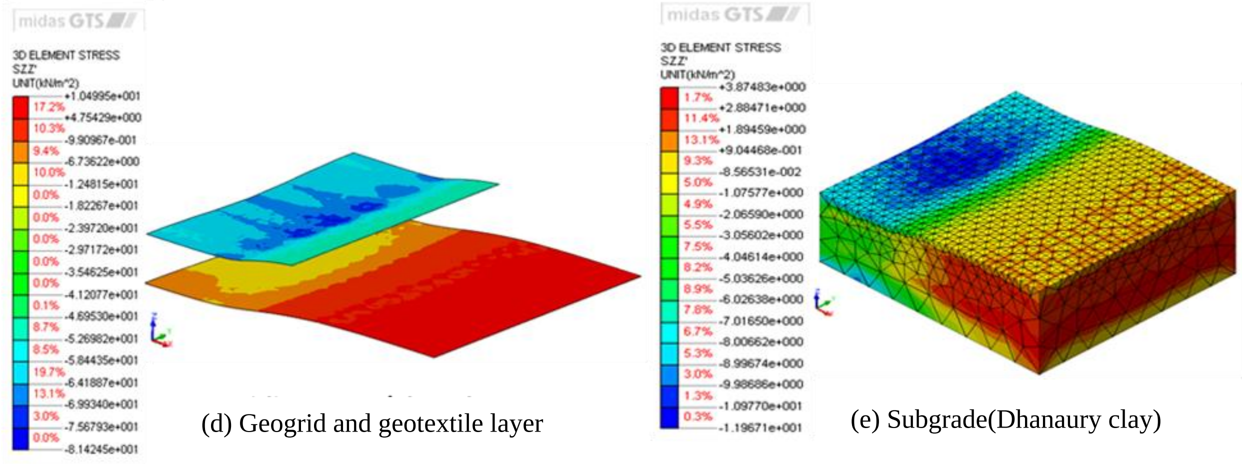


(a) DC20 GT-GG track model



(b) Ballast layer

(c) Subballast layer



(d) Geogrid and geotextile layer

(e) Subgrade(Dhanaury clay)

Fig 9 Vertical displacement contour for different components of DC20 GT-GG model (results of coupled analysis).

linear analyses are effective stresses, the subgrade top stressespredicted by the coupled analyses are effective stresses and those predicted by the nonlinearanalyses are total stresses. It may be noted that the pore water pressures at thesubgrade top predicted by the coupled analysis were approximately of the order of3-5 kPa.

4. CONCLUSIONS

1. Geogridwas found more effective at ballast-subballast interface (GG track) in reducing the vertical stresses at the top of ballast layer and moderately effective in at the top of subballast layer.
2. The geotextile (GT track) is almost equally effective in the reduction of subgrade vertical stresses owing to its closeness to the subgrade surface as the geogrid (GG track).
3. The coupled analysis predicts load versus displacement relationship for the first loading cycle for the cycle tests on both unreinforced and reinforced tracks (UR-C, GT, GG and GT-GG) for all test groups (DC20, DC33) accurately.
4. The non-linear analysis predicts lower vertical stresses at the top of ballast and subballast layers for the test groups (DC20, DC33) as compared to those predicted by the coupled analysis. However, the total vertical stresses predicted by the non-linear analyses at the top of subgrade were slightly higher than the effective stresses predicted by the coupled analysis.
5. The deformed shapes of the model track section in both sleeper and rail directions observed through the perspex sheets of the test tank compare well with the corresponding deformed shapes generated between the present coupled analysis.
6. Geogrid with higher stiffness decreases the tie displacement than the geogrid with lower stiffness. The consumption of subballast materials was reduced approximately by 55-70% with the inclusion of two geogrid layers at proper interfaces. For a long haul distances from which suballast material was procured, in such case it was found economical.
7. Compared to unreinforced section, the dissipation of the pore water pressure becomes faster with installation of geotextile layer between subballast and subgrade.

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