Parametric Study on Geogrid-Reinforced Track Substructure

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Abstract

The purpose of this paper was to evaluate the effectiveness of geogrid for conventional ballasted track and asphalt concrete underlayment track using PLAXIS finite element program. Geogrid element was modeled at various locations that include subballast/subgrade, subballast/ballast interfaces, middle of the ballast, and one-third depth of the ballast. The results revealed that the effectiveness of geogrid reinforcement appeared to be larger for ballasted track structure compared to asphalt concrete underlayment track. Particularly, in case of installing geogrid at one-third depth of ballast layer in a conventional ballasted track, the most effectiveness of geogrid reinforcement was achieved. The influence of geogrid axial stiffness on track substructure response was not clear to conclude. Further validations using a discrete element method along with experimental investigation are considered as a future study. The effect of asphalt concrete layer modulus was evaluated. The results exhibited that higher layer modulus seems to be effective in controlling displacement and strain of track substructure. However it also yields slightly higher stresses within track substructure. It infers that further validations are required to come up with optimum asphalt concrete mixture design to meet economical and functional criteria.

Keywords : Geogrid, Ballasted track, Asphalt concrete underlayment track

1. Introduction

Geosynthetics are available in a wide range of forms and materials and are used in many applications. Geosynthetics are often used by highway agencies in conjunction with unbound base layers as a means for enhancing the performance of pavements. Recently, several studies have been conducted to apply geogrid within ballast and subballast layers of track substructure in order to achieve better performance that results in minimizing maintenance cost and extending service life. Mittal *et al* (2008) found that the use of geosynthetic in ballast layer increased load bearing capacity and the coefficient of elastic uniform compression based on experimental study conducted. Indraratan *et al* (2010) conducted field test to examine the performance of a ballasted rail track reinforced with geosynthetics. From this study, the use of recycled ballast

along with a geocomposite has been verified by exhibiting reduced vertical and lateral strains of the ballast compared to the control condition. Mishra *et al* (2013) characterized railroad ballast behavior under repeated train loading via a new large triaxial test setup. They found that the use of geogrid generally reduced permanent deformation under repeated loading, but in case of installing two geogrids placed at one-third specimen heights from the top and bottom showed higher permanent deformation that might be attributed to inadequate interlock between the geogrid and ballast particles. In line with these observations, a parametric study was carried out to identify the effectiveness of geogrid reinforced track substructure by taking account for several factors that influence the performance of track substructure.

2. Parametric Study Setup

2.1 Structure and boundary condition

In this study, the author used a finite element program PLAXIS 2D (Brinkgreve *et al.* 2006) under plane strain condition of 15 node elements for the parametric study. Due to symmetry, only one half of the track section was
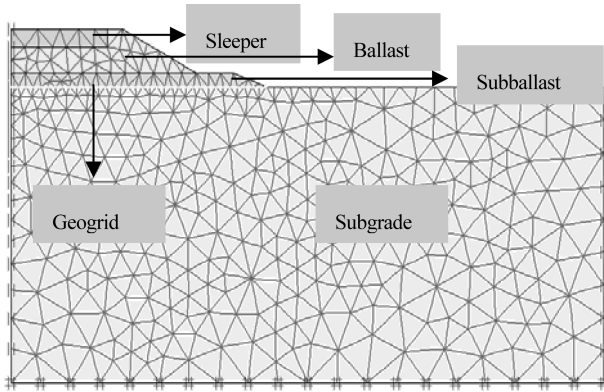
Fig. 1 Meshed track structure

considered in the numerical model. Two types of track substructure were meshed as shown in Fig. 1. Several studies have shown that the use of asphalt subballast might increase service life and minimize total life cycle costs (Teixeira *et al.*, 2010, Rose *et al.*, 2010).

With respect to the boundary condition, both sides were set to move vertically while the bottom was fixed to prevent any movement. Initial condition is to simulate the settlement of the model due to weight of the soil layers; Geogrid construction is to simulate the reinforcement of the geogrid within track substructure; traffic condition is to simulate the traffic load on the reinforced track substructure.

For the traffic loading, an equivalent dynamic wheel load (P_{dl}) for a given static wheel load (P_{sl}) was computed as per the American Railway Engineering Association (AREA 1996) approach and is given by:

$$P_{dl} = \left[1 + \frac{0.0052V}{D} \right] P_{sl} \tag{1}$$

Where V and D are train speed (in km/h) and wheel diameter (in meter), respectively. For the parametric study, a representative vertical load was applied to produce a maximum ballast surface stress of 448 kPa at the sleeper-ballast interface in a conventional ballasted track without geogrid. (US Army of Corps Engineers, 2000). Based on equation (1), an equivalent dynamic wheel load of 260 kN was applied with given vehicle speed equal to 200 km/hour, 1 meter of wheel diameter, and 125 kN of static wheel load.

With regard to geogrid modeling, a geogrid element provided by PLAXIS was employed along with interface elements that are connected with adjacent track substructure layers. The only property in a geogrid data set is the elastic axial stiffness, EA, in terms of force per unit width. For the parametric study, three levels of EA value were accounted to gauge the influence of its integrity on track substructure response. In addition, the location of geogrid

Table 1 Reference material properties used in the finite element analysis

Property	Sleeper	Ballast	Sub ballast	AC-Sub ballast	Sub grade	Geogrid
Model	Elastic	HS	MC	Elastic	MC	Elastic
Thickness (m)	0.2	0.3	0.15	0.1	3.5	-
γ (kN/m3)	24	15.3	19	23	17	-
E (MPa)	10340	-	100	2000	40	-
υ	0.3	-	0.35	0.38	0.4	-
E_{50}^{ref} (MPa)	-	70	-	-	-	-
E_{oed}^{ref} (MPa)	-	67	-	-	-	-
E_{ur}^{ref} (MPa)	-	210	-	-	-	-
u_{ur}	-	-	-	-	-	-
EA (kN/m)	-	-	-	-	-	500
C(kN/m^2)	-	0.1	0.1	-	5.0	-
φ (degree)	-	45	30	-	30.0	-
ψ (degree)	-	0.0	0.0	-	0.0	-
P_{ref} (kN/m^2)	-	100	-	-	-	-
m	-	0.5	-	-	-	-
K_0^{nc}	-	0.3	-	-	-	-
R_f	-	0.9	-	-	-	-

E_{oed}^{ref}: tangent stiffness for primary oedometer loading, E_{ur}^{ref}: triaxial unloading/reloading stiffness, υ_{ur}: Poisson's ratio for loading conditions, φ = effective friction angle, ψ = dilatancy angle, K_0^{nc} = coefficient of earth pressure at rest for normal consolidation, R_f = failure ratio.

was varied to identify an optimum location that yields best effectiveness in restraining deformations. The following locations were considered in this study:
- Interface between subgrade and subballast
- Interface between subballast and ballast
- Middle of ballast and one third from the bottom of ballast layer

It should be noted that the placement of geogrid between asphalt subballast and ballast layer was omitted since it is deemed unusual to install any geosynthetics over asphalt layer particularly in track roadbed construction.

2.2 Material characterization

It is well known that typical ballast and subballast materials exhibit stress dependency and resilient behavior. In order to stress dependent modulus of ballast layer, a hardening soil model was applied for ballast layer as given in equation (2).

$$E_{50} = E_{50}^{ref} \left(\frac{c\cot\phi + \sigma_3}{c\cot\phi + p^{ref}} \right)^m \tag{2}$$

Where E_{50} is a confining stress (σ_3) dependent secant modulus at 50% strength for primary loading, p^{ref} is a reference confining pressure, E_{50}^{ref} is a reference modulus for primary loading corresponding to the reference confining pressure p^{ref}, c is a cohesion, ϕ is a friction angle, and m is a factor ranging from 0.5 to 1.0. For the granular subballast and subgrade layer, the Mohr-Coulomb model was employed to capture the plastic points that indicate the stress states exceed the yield surface. Asphalt subballast layer was modeled as linear elastic material even though asphalt material is well known as viscoelastic material susceptible to the change of temperature and loading frequency. The author is of the opinion that the asphalt subballast layer in track substructure might be less sensitive to the change of temperature and loading frequency unlike a typical flexible pavement structure that is more directly associated with those conditions. Table 1 summarizes material properties used in parametric study.

3. Parametric Study Results

3.1 Effect of geogrid location

The influence of geogrid location on track substructure response was evaluated. The effectiveness of reinforcement was indicated by taking the percent difference given in the following equation to provide information on data bias. From this indicator, a negative percent difference indicates that the response of control case is larger than that of reinforced case.

$$\% in\ difference = 100 \times \left[\frac{R_R - R_C}{R_C} \right] \qquad (3)$$

Where R_R = response of reinforced case, and R_C = response of control case. The results of the investigations are shown in Fig. 2.

It was observed that the influence of geogrid reinforcement for conventional ballasted track was more significant than asphalt underlayment track. It might be attributed to the presence of asphalt subballast layer that improves load bearing capacity of track substructure leading to relatively low geogrid reinforcement effect.

With respect to the geogrid location, the most effectiveness appeared to be achieved when the geo-reinforcement was made one-third depth from the bottom of ballast layer. When the geogrid was installed at between subgrade and subballast, several percent differences exhibited positive values that indicate larger responses from geo-reinforcement. From this limited evaluation, it is deemed the placement of geogrid at interface of subgrade and subballast may not be ultimate option to improve track substructure performance unless the subgrade does exhibit a extremely poor load bearing capacity.
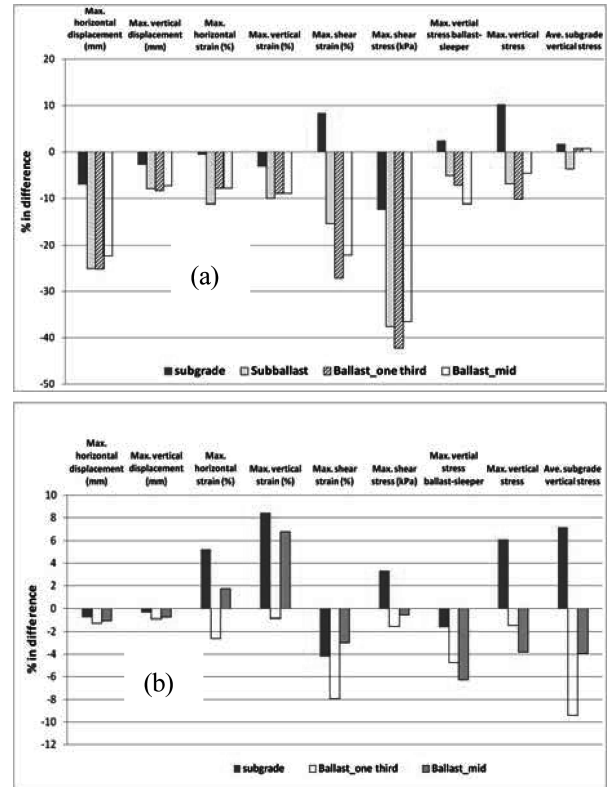

Fig. 2 The percent of difference of responses between control and reinforced cases: (a) conventional ballasted track and (b) asphalt underlayment track

3.2 Effect of geogrid property

There are key properties of geogrid that play a crucial role in enhancing load bearing capacity of geomaterials. The tensile strength is deemed one of key properties that produce lateral confinement for surrounding granular materials. The only property in a PLAXIS geogrid data set is the elastic axial stiffness, EA, in terms of force per unit width. Three levels of EA value were considered for this evaluation. Note that ballasted track reinforced with geogrid at one-third depth from the bottom of ballast layer was only considered for this evaluation. Fig. 3 shows the results of analysis. It was observed that the effect of EA of geogrid was not clear to conclude. Generally, while higher EA values seem to be effective in controlling stain and displacement, the same trend was not applicable to stress evaluation. It infers two things: One is that more accurate modeling technique needs to be applied to simulate the interaction between geogrid and materials such as using a discrete element method (DEM); the other is that further experimental investigations need to be conducted to identify an optimum combination between geogrid property and any materials tested.
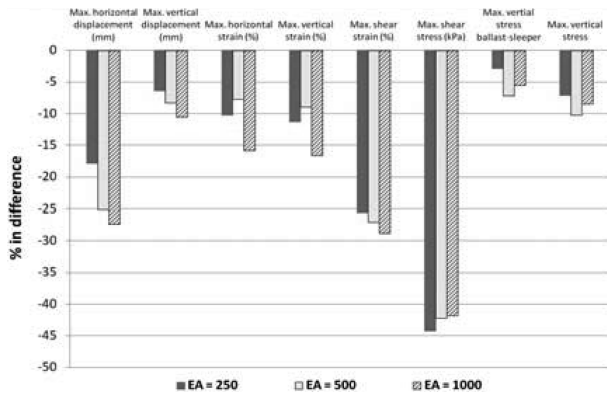
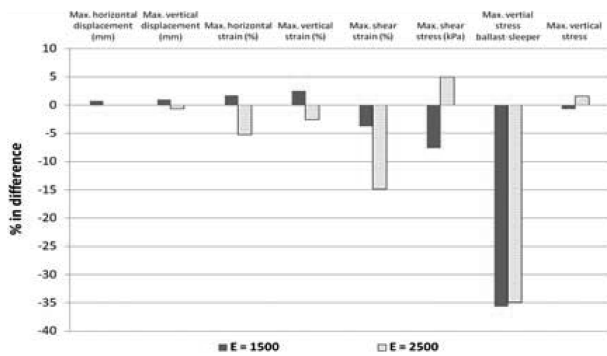**Fig. 3** The percent of difference of responses with different EA values

Fig. 4 The percent of difference of responses with different asphalt concrete layer modulus

3.3 Effect of asphalt concrete subballast modulus

Installing asphalt concrete subballast layer was found to be effective in distributing train loads that result in reducing substructure deformation. In this section, the effect of asphalt concrete layer moduli was investigated even though the asphalt concrete subballast layer is not directly subjected to train loading like a typical flexible pavement structure case.

For this evaluation, the control section was only used since the influence of geogrid reinforcement appeared to be alleviated in asphalt concrete underlayment track. The percent of difference was computed by taking the difference of responses with respect to the reference responses obtained when asphalt concrete layer moduli of 2000 MPa was assigned. It revealed that higher asphalt concrete layer modulus seems to reduce strain and displacements as shown in Fig. 4. With regard to stresses, lower asphalt concrete layer modulus seems to slightly alleviate the amount of intensive stresses indicated in red color coded zone as shown in Figs. 5 to 7.
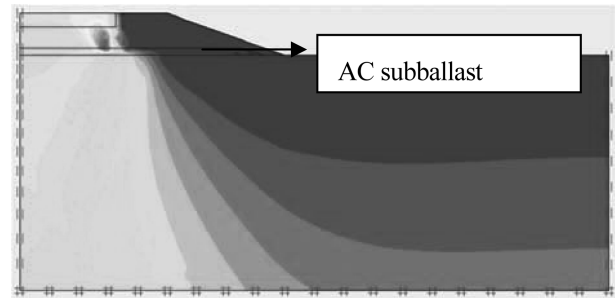

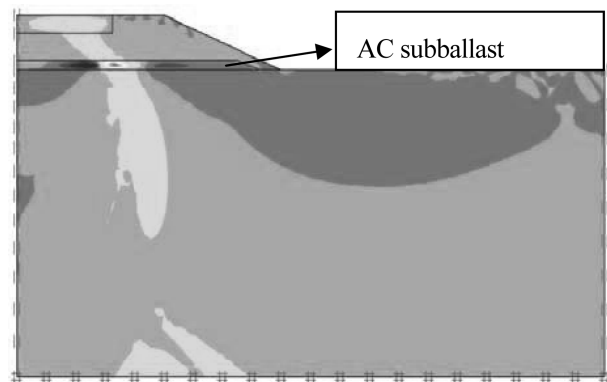**Fig. 5** Distribution of vertical stress asphalt concrete underlayment track

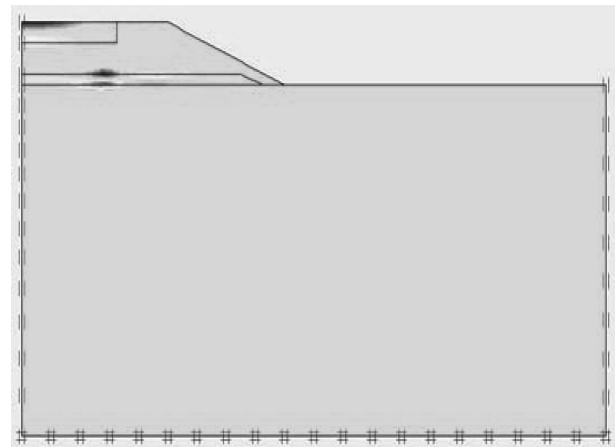**Fig. 6** Distribution of shear stress asphalt concrete underlayment track

Fig. 7 Distribution of horizontal stress asphalt concrete underlayment track

Based on the findings, the author is of the opinion that it is necessary to establish a performance prediction model to quantify asphalt concrete underlayment track performance to gauge the effect of differences in deformation on track performance during expected service life. In addition, further study needs to be carried out to determine optimum

asphalt concrete mixture design that meets both economical and functional perspectives since a high quality mixture design for flexible pavement structure (i.e. using high Performance-Grade (PG) grade) does not have to be the case for the track substructure.

4. Conclusions

The parametric study of the track substructure reinforced with geogrid has been conducted. The result of the study revealed that the location of geogrid plays a major role in controlling track substructure deformation. When the geogrid was placed at the one-third depth from the bottom of the ballast layer, the lateral confinement from geogrid installation seems to greatly mobilize particularly in conventional ballasted track structure. Asphalt underlayment track substructure showed a relatively less improvement due to geogrid installation. It might be attributed to the fact that asphalt subballast inherently improved the track substructure load bearing capacity that reduced the influence of geogrid reinforcement.

The influence of geogrid axial stiffness was not clear to conclude. The results suggest that advanced modeling technique such as a discrete element method be used to simulate interaction between geogrid and materials. In addition, further experimental investigations using pullout test are to be conducted to validate the mechanism of geogrid.

Finally, the analysis on asphalt concrete layer modulus found that higher modulus yields less deformation but leads to slightly higher stresses within track substructure. Since track substructure design practices depend on a threshold stress level, it is important to control those stresses in assessment of track performance. Further inves-

tigation will be conducted to identify optimum mixture design that gives economical and functional advantages for the asphalt concrete underlayment track.

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