ANALYSIS OF RAILWAY TRACKS REINFORCED WITH GEOGRIDS

Giovanni Leonardi
Department of DICEAM, University of Reggio Calabria, Reggio Calabria, Italy
E-Mail: giovanni.leonardi@unirc.it

ABSTRACT

Use of geosynthetics in civil engineering has advanced rapidly in recent years and it has been popular in railways construction. Geosynthetics provide an important option to improve track support stabilization and to reduce the track maintenance costs. In the present paper, a reinforced railway track has been modelled using the finite element method (FEM). The principal aim of the study is to investigate the influence of geogrids reinforcement in the railway track behaviour. The results show that the reinforcement can provide a significant contribution to improve the performance of railways tracks.

Keywords: railway, geogrid, fem, ballast, reinforcement.

1. INTRODUCTION

Usually, geosynthetics are used to improve the mechanical characteristics of soils, combining the compression strength of the soil with the tensile strength of the geosynthetics. The interaction geosynthetics-soils and the geogrids behavior for the reinforcement of roads have been studied extensively [1-13].

The mechanisms associated with the interaction of geogrids and unbound aggregate can be summarized as (i) to restrain the lateral movement of the unbound materials (due to frictional interaction and interlocking between aggregates and the geosynthetic), (ii) to increase the stiffness and the shear strength of the unbound materials by providing additional confining stress, (iii) to improve the load distribution to the sub-grade layer, and (iv) to reduce the shear stress in the sub-grade (due to its stiffness, the geosynthetic exerts an upward force supporting the wheel load and thus improving the bearing capacity [14], this because it acts like a tensioned membrane [15]).

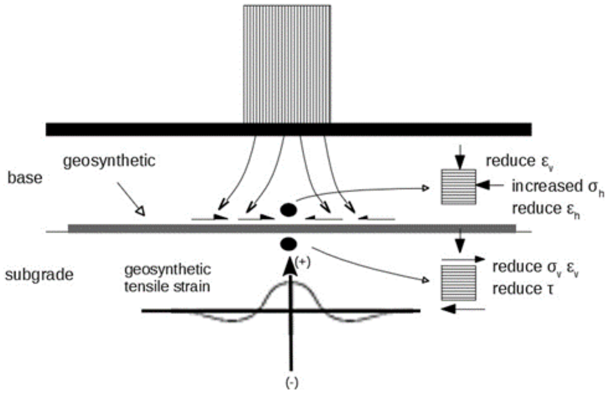

Figure-1. Reinforcement mechanism of geogrid in granular soil over a subgrade (based on Perkins [16, 17]).

However, there is limited comprehensively reported literature on the interaction between the geosynthetics and railway ballast. The understanding of the basic mechanism governing the reinforcing action of the geogrid or how geogrid reinforcement can be designed into rail track structures for different situation is still restricted.

Recently, different studies have been conducted to apply geogrid within ballast and sub-ballast layers of track substructure in order to achieve better performance that results in minimizing maintenance cost and extending service life [18-20]. The use of this reinforcement solution in the railway construction depends from the necessity to ensure railway embankments higher performances, also under the passage of the high speed and heavy axle loads.

Geogrids are used in one of two ways to reinforce track bed materials. When included at the bottom or within a ballast layer, the primary benefit is an extension of the maintenance cycle, i.e., the period between ballast cleaning and replacement operations. The second way geogrids are used beneath a rail line is to reinforce the sub-ballast. In this case, the primary purpose of the geogrids is to increase the effective bearing capacity of an underlying subgrade [18].

In particular, geogrids stabilize ballast and sub-ballast layers through the "interlocking effect", which can be imagined as the particles of the ballast material partially penetrate through the geogrid apertures and lock into position (Figure-2).

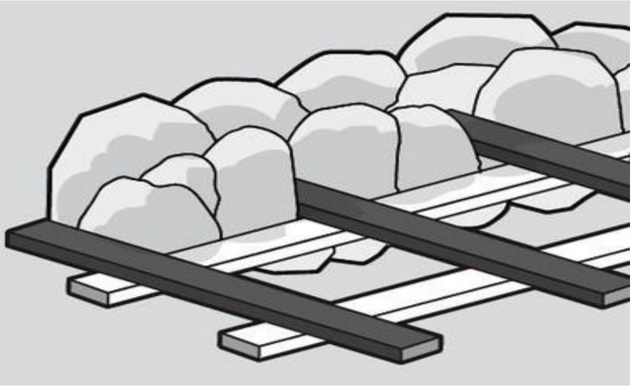

Figure-2. Interlocking effect between aggregates and geogrid.

In this manner, a quasi-strong and relatively skidproof layer would be guaranteed for other particles lying above and interlocked into these particles [13, 21].

Geogrid reinforced railway tracks can be simulated and analyzed with finite elements methods (FEM) or distinct element methods (DEM) in two and three dimensions.

Important results in DEM and FEM simulation were obtained by several authors [22-27]. These studies have shown that geogrid reinforcement in ballast can be effective in reducing the permanent deformations associated with lateral ballast spreading. The reinforcement effect of geogrid is generally attributed to the interlocking effect between the geogrids and surrounding aggregates. As a result, the geogrids provide lateral and vertical confinement to the ballast and, thereby reducing its settlement. In line with these observations, the current study is an attempt to apply FEM to numerically model the ballast and geogrid interaction with the main aims are to study the effect of geogrid reinforcement on stress-strain behavior of ballast.

The interaction mechanism and behavior of the geogrid and ballast at their interfaces, particularly when the ballast is severely fouled are not well understood.

Bathurst and Raymond [28] carried out a series of large-scale models comprising a single sleeper/ballast system reinforced with geogrids that were inserted at different depths and placed over artificial subgrade of varying compressibility, and then subjected to cyclic loading (Figure-3).

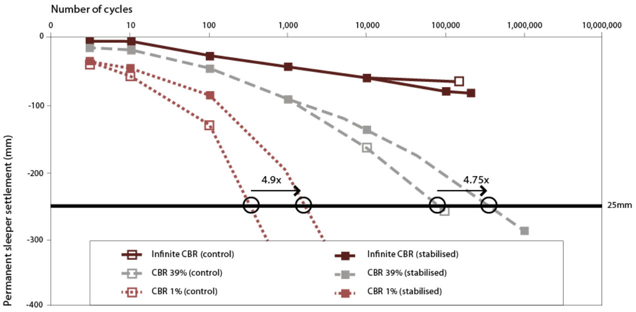

Figure-3. Geogrid over relatively weak and firm foundation soils maintenance life increased by a factor of 4.9 and 4.75 respectively.

According to these results, at 39% of CBR-value 4.75 times, and at 1% of CBR-value 4.9 times, more cycles generated 25 mm plastic settlements in the case of Tensar geogrid reinforcement than without it. Walls and Galbreath [29] carried out a case study on the use of polymer geogrid to reinforce ballast. They concluded that the inclusion of geogrids was an effective and economical method to minimize or prevent track stability issues. The inclusion of geogrid within the ballast layer reduced the lateral and vertical deformation of ballast, which was attributed to the ballast particles interlocking and being confined by the geogrid. Matharu [30] showed that geogrid-reinforced railway ballast has a positive effect on the retardation of the deterioration process. Fernandes *et al*. [31] conducted experiments in a segment of real track to evaluate the potential use of geosynthetics as reinforcement in ballasted rail tracks. The results indicated that the inclusion of geosynthetics decreases the strains mobilized in the sub-ballast and reduced ballast breakage. Most of the aforementioned studies for fresh ballast were conducted experimentally and only limited attempts were made to study the geogrid-ballast interaction numerically.

In this paper, the attention is focused on the use of geogrids as ballast reinforcement, which offer improved interface resistance due to interlocking. This one minimizes the lateral movement of aggregate particles and increases the modulus of the ballast, which leads to a wider vertical stress distribution over the subgrade and consequently a reduction of vertical and lateral deformations.

2. MATERIALS AND METHODS

2.1 Finite Element Analysis

The finite element simulations were developed using the ABAQUS software and considering a 2D simplified model perpendicular to the track. The finite element analyses in this study were performed in the time domain.

The proposed model of rail track is the conventional one and the principal elements of the model are reported in Figure-4.

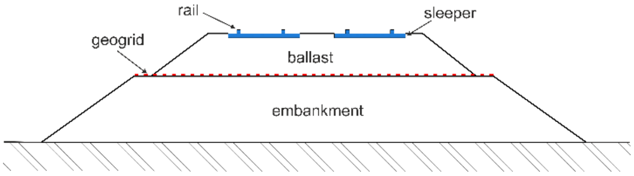

Figure-4. Schematic of main components of track structures.

The materials properties used in the model were derived from tests and available experimentations in literature [32-35]. Founded on elastic layered system hypothesis, railroad track materials are all linear elastic. The ballast and embankment materials are supposed to be elastoplastic by using the Mohr Coulomb model (MCM) [36]. The interaction between the materials is supposed to be completely continuous.

The equivalent parameters are recapitulated in Table-1.

Table-1. Simulation parameters of the track-subgrade structure.

Mechanical characteristics	Rail UIC60	Sleeper	Ballast	Embankment	Geogrid
Density ρ (kg/m^3)	7850	2400	210	1800	1800
Modulus E (MPa)	210000	30000	130	80	29000
Poisson's Ratio ν	0.30	0.15	0.30	0.40	0.20
Internalfriction angle (°)			28	25	
Cohesivestrength (kPa)			50	30	

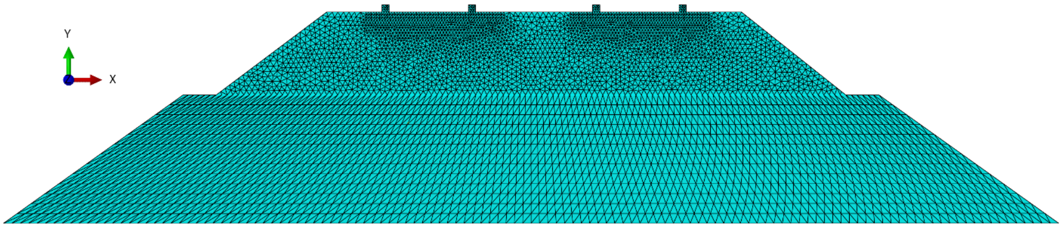

Figure-5. FE model of the double-line structure.

The train was simplified to a series of vertical loads [33, 37], which were placed according to the geometry and the composition of the train (locomotives, bogies, wheels, axles) and moving at a constant speed v on the track. In the following, a simplified composition (two locomotives and three bogies) of the Italian high-speed train ETR 500 was considered.

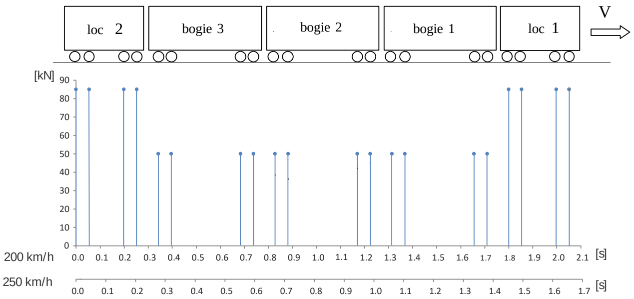

Figure-6. Time history of loading of ETR 500 train.

The forces are applied using a time function that represents the time history of the force in the considered node. Figure-4 shows the distribution of axle load in the time at 200 Km\h and 250 Km\h.

3. RESULT AND DISCUSSIONS

The behavior of the embankment was analyzed, at the exact time of passage of the train. The results show that the geogrid improves the behavior of the embankment.

It is evident that the geogrid reinforcement between ballast and subgrade reduces the vertical stress and displacements significantly (Figure-5 and Figure-6).

Figure-7 shows the vertical displacements at the interface between ballast and embankment caused by the locomotive passage.

3.1 Effect of Geogrid Property

There are key properties of geogrid that play a crucial role in enhancing load bearing capacity of geomaterials.

The elastic modulus E is deemed one of the key properties that produce lateral confinement for surrounding granular materials. Four levels of E value (29000 MPa, 10000 MPa, 5000 MPa and 1000 MPa) were considered for this evaluation.

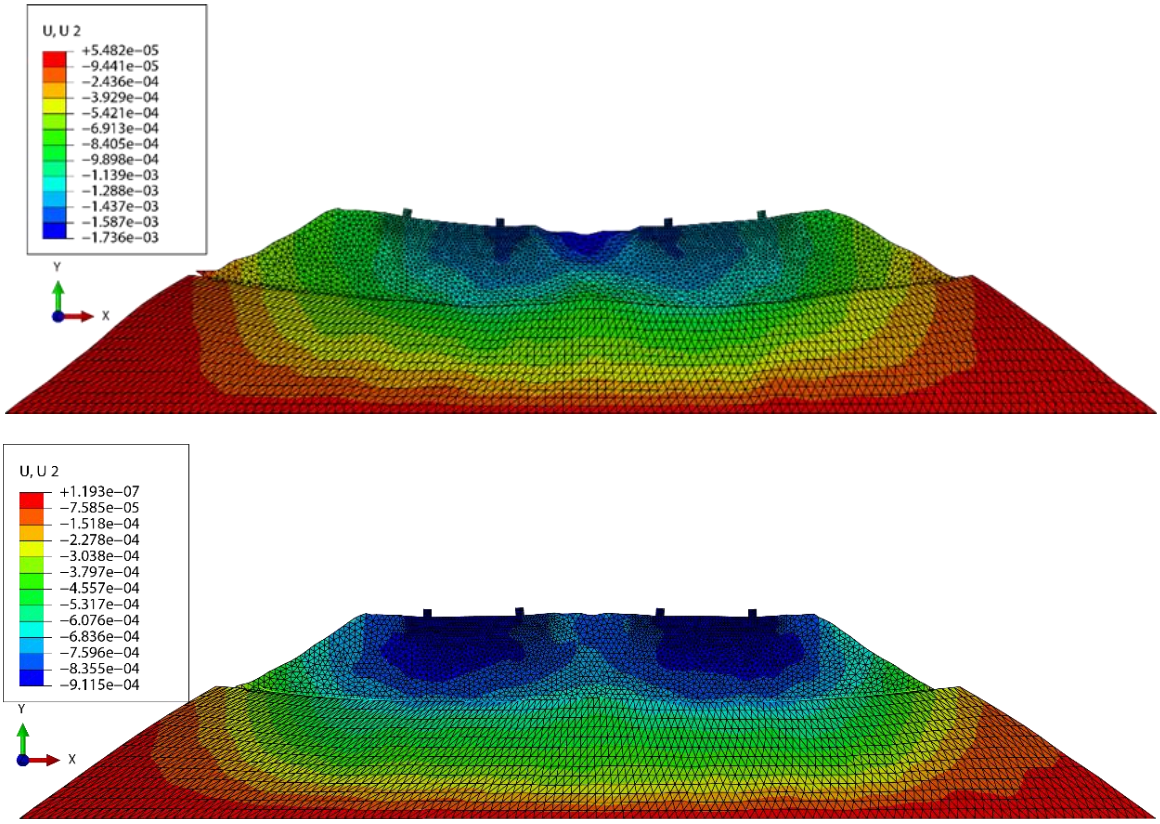

Figure-7. Vertical displacements (m) for the unreinforced and the reinforced model.

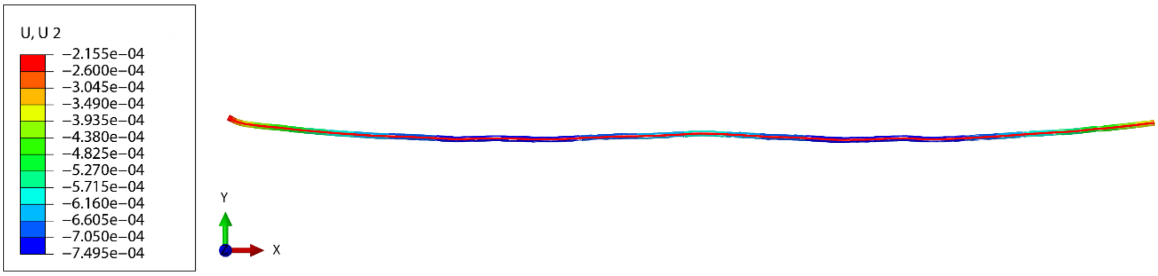

Figure-8. Geogrid vertical displacements (m).

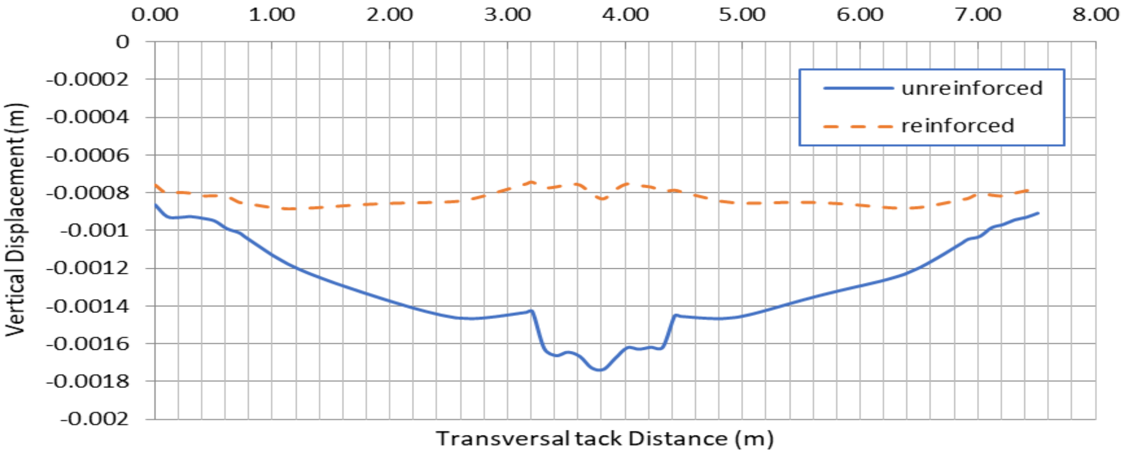

Figure-9. Vertical displacementsalong the transversal path.

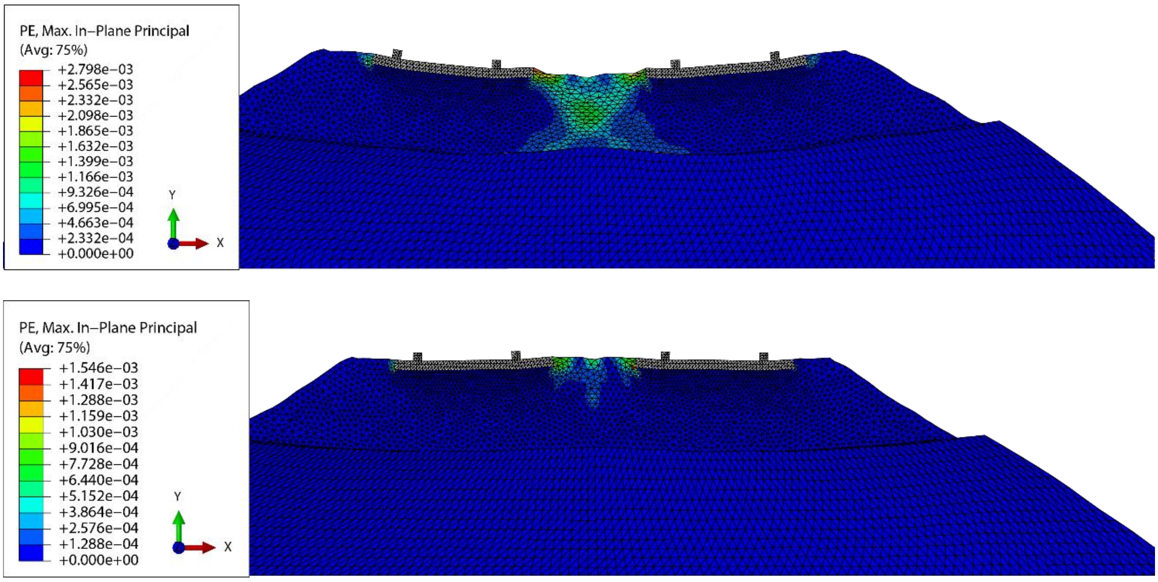

Figure-10. Maximum plastic strain for the unreinforced and the reinforced model.

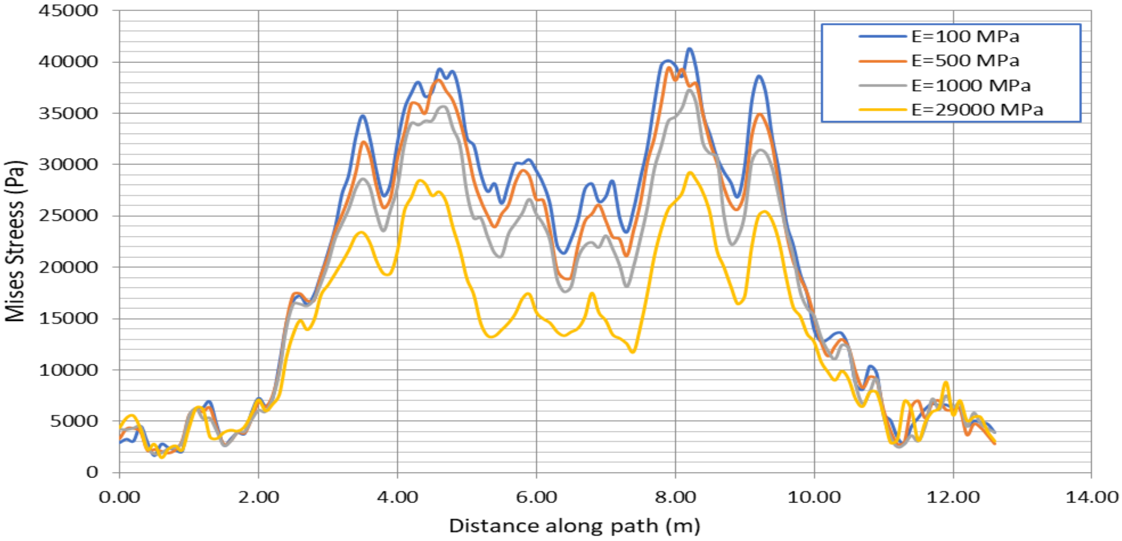

Figure-11. Misess stress distribution along the transversal path.

Figure-11 shows the results of analysiswhere the Von Mises stress distribution at the interface between ballast and subgrade caused by the locomotive passage is reported. It was observed that the effect of E of geogrid was clear to conclude. Generally, a higher E values seem to be effective in controlling the stress. To obtain more significate results advanced modelling technique needs to be applied to simulate the interaction between geogrid and materials such as using a discrete element method (DEM). In addition, further experimental investigations need to be conducted to identify an optimum combination between the geogrid properties and the properties of materials tested.

4. CONCLUSIONS

From this study, it is clear that the reinforcement between ballast and subgrade, reduces induced vertical stresses and displacements significantly. It is clear that this leads to a reduction in the maintenance costs, and in the shear failure. Geogrid offer an enhanced combination of interlock within stabilizing railway track infrastructure via confinement of both ballast and sub-ballast particles.

Using a finite element procedure, simulations and practical inferences were made by applying the geogrid to the actual geometry of a ballasted railroad substructure. Performing a parametric study on realistic geometry and applications could allow insight into its performance in actual railroads. Analyses were performed by varying geogrid stiffness to observe the effect of reinforcement material on overall performance.

It is possible to observe that the amount of settlement increased with increasing geogrid stiffness.

REFERENCES

[1] Wilson-Fahmy R. F., Koerner R. M. and Sansone L. J. 1994. Experimental behavior of polymeric geogrids in pullout. Journal of geotechnical engineering. 120(4): 661-677.

[2] Bergado D. T., Chai J. C. and Miura N. 1995. FE analysis of grid reinforced embankment system on soft Bangkok clay. Computers and Geotechnics. 17(4): 447-471.

[3] Ochiai H., Otani J., Hayashic S. and Hirai T. 1996. The pull-out resistance of geogrids in reinforced soil. Geotextiles and Geomembranes. 14(1): 19-42.

[4] Saad B., Mitri H. and Poorooshasb H. 2006. 3D FE analysis of flexible pavement with geosynthetic reinforcement. Journal of Transportation Engineering. 132: 402.

[5] Teixeira S. H., Bueno B. S. and Zornberg J.G. 2007. Pullout resistance of individual longitudinal and transverse geogrid ribs. Journal of geotechnical and geoenvironmental engineering. 133(1): 37-50.

[6] Siriwardane H., Gondle R., Kutuk B. and Ingram R. 2008. Experimental Investigation and Numerical Analysis of Reinforced Geologic Media, in the 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG). Goa, India.

[7] Tang X., Chehab G. R., and Palomino A. 2008. Evaluation of geogrids for stabilising weak pavement subgrade. International Journal of Pavement Engineering. 9(6): 413-429.

[8] Sieira A. C. C., Gerscovich D. and Sayão A.S. 2009. Displacement and load transfer mechanisms of geogrids under pullout condition. Geotextiles and Geomembranes. 27(4): 241-253.

[9] Liu C.-N., Ho Y.-H. and Huang J.-W. 2009. Large scale direct shear tests of soil/PET-yarn geogrid interfaces. Geotextiles and Geomembranes. 27(1): 19-30.

[10] Siriwardane H., Gondle R. and Kutuk B. 2008. Analysis of Flexible Pavements Reinforced with Geogrids. Geotechnical and Geological Engineering. 28: 287-297.

[11] Buonsanti M. and Leonardi G. 2012. FEM analysis of airport flexible pavements reinforced with geogrids. Advanced Science Letters. 13(1): 392-395.

[12] Buonsanti M., Leonardi G. and Scopelliti F. 2012. Theoretical and computational analysis of airport flexible pavements reinforced with geogrids. in 7th RILEM International Conference on Cracking in Pavements. Springer.

[13] Fischer S. and Horvát F. 2011. Investigation of the reinforcement and stabilisation effect of geogrid layers under railway ballast. Slovak Journal of Civil Engineering. 19(3): 22-30.

[14] Perkins S. W. 1999. Mechanical response of geosynthetic-reinforced flexible pavements. Geosynthetics International.

[15] Kawalec J., Grygierek M., Koda E. and Osiński P. 2019. Lessons Learned on Geosynthetics Applications in Road Structures in Silesia Mining Region in Poland. 9(6): 1122.

[16] Perkins S. and Ismeik M. 1997. A synthesis and evaluation of geosynthetic-reinforced base layers in flexible pavements: part I. Geosynthetics International. 4: 549-604.

[17] Perkins S. 1999. Geosynthetic reinforcement of flexible pavements laboratory based pavement test sections, Federal Highway Administration Report FHWA. MT-99-001/8138, Montana Department of Transportation.

[18] Das B., Penman J. and Anderson P. 2010. Use of geogrid in subgrade-ballast system of railroads subjected to cyclic loading for reducing maintenance. California State University, Sacramento, USA.

[19] Ibrahim S. F., Kadhim A. J. and Khalaf H. B. 2018. Reinforcement effect of geogrid in ballast and sub-ballast of the railway track. International Journal of Geomate. 15(48): 22-27.

[20] Keene A., Edil T., Fratta D. and Tinjum J. 2013. Modeling the effect of polyurethane stabilization on rail track response. in Geo-Congress 2013: Stability and Performance of Slopes and Embankments III.

[21] Sowmiya L., Shahu J. and Gupta K. 2011. Railway tracks on clayey subgrade reinforced with geosynthetics, in Indian Geotechnical Conference. Kochi.

[22] McDowell G. R., Harireche O., Konietzky H., Brown S. F. and Thom N. H. 2006. Discrete element modelling of geogrid-reinforced aggregates. Proceedings of the ICE-Geotechnical Engineering. 159(1): 35-48.

[23] Indraratna B., Ngo N. T. and Rujikiatkamjorn C. 2011. Behavior of geogrid-reinforced ballast under various levels of fouling. Geotextiles and Geomembranes. 29(3): 313-322.

[24] Indraratna B., Rujikiatkamjorn C. and Nimbalkar S. 2011. Use of geosynthetics in railways including geocomposites and vertical drains. GeoFrontiers 2011: Advances in Geotechnical Engienering. 4733-4742.

[25] Mittal S., Sharma A., Lokesh B. V. and Dwivedi A. 2009. Study of Behaviour of Ballast Using Geosynthetics, in Geosynthetics in Civil and Environmental Engineering, G. Li, Y. Chen, and X. Tang, Editors. Springer Berlin Heidelberg. pp. 656-661.

[26] Tutumluer E., Qian Y., Hashash Y. M. A., Ghaboussi J. and Davis D. D. 2013. Discrete element modelling of ballasted track deformation behaviour. International Journal of Rail Transportation. 1(1-2): 57-73.

[27] Ngo N. T., Indraratna B. and Rujikiatkamjorn C. 2014. DEM simulation of the behaviour of geogrid stabilised ballast fouled with coal. Computers and Geotechnics. 55(0): 224-231.

[28] Bathurst R. J. and Raymond G. P. 1987. Geogrid reinforcement of ballasted track. Transportation Research Record. 1153: 8-14.

[29] Walls J. and Galbreath L. 1987. Railroad ballast reinforcement using geogrids. in Proceedings of Geosynthetics.

[30] Matharu M. 1994. Geogrids cut ballast settlement rate on soft substructures. Railway Gazette International. pp. 165-166.

[31] Fernandes G., Palmeira E. M. and Gomes R. C. 2008. Performance of geosynthetic-reinforced alternative sub-ballast material in a railway track. Geosynthetics International. 15(5): 311-321.

[32] Cirianni F., Leonardi G., Scopelliti F. and Buonsanti M. 2009. Study of the barriers for the mitigation of railway vibrations. in The Sixteenth International Congress on Sound and Vibration, Kraków.

[33] Yang Y.-B. and Hung H.-h. 2009. Wave propagation for train-induced vibrations: a finite/infinite element approach. World Scientific.

[34] Chango I. V. L., Yan M., Ling X., Liang T., and Assogba O.C. 2019. Dynamic response analysis of geogrid reinforced embankment supported by CFG pile structure during a high-speed train operation. Latin American Journal of Solids and Structures. 16(7).

[35] Leonardi G. and Buonsanti M. 2014. Reduction of train-induced vibrations by using barriers. Research Journal of Applied Sciences, Engineering and Technology. 7(17): 3623-3632.

[36] Chen J. and Zhou Y. 2018. Dynamic responses of subgrade under double-line high-speed railway. Soil Dynamics and Earthquake Engineering. 110: 1-12.

[37] Younesian D. and Sadri M. 2012. Effects of the trench geometry on vibration mitigation level in high-speed railway tracks. Journal of mechanical science and technology. 26(8): 2469-2476.