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INVESTIGATION OF THE MOST POSITIONS AFFECTED IN RAIL TRACK WHEN THE MODULUS OF ELASTICITY OF THE BALLAST LAYER IS CHANGED

Zaman ALANI[1], Adnan Q. MOHAMMED[2,*], Maysloon ZAIDAN[3]

[1] Geotechnical branch, KYTC, Frankfort, USA.
[2] Reconstruction and projects department, University of Baghdad, Baghdad, Iraq.
[3] Division of Water, EEC, Frankfort, USA.
[*] corresponding author: adnanqahtan4@gmail.com

Abstract

The railway is one of the cheapest methods to transport people and heavy goods. It is safer than highways. In Iraq, many railways connect the south country with the middle and north, which are old, damaged, and need to continued maintenance. Iraq needs to construct new lines of the rail track with low-cost, less maintenance, and highly stable structure, which requires understanding the behavior of rail track under train loads and the pattern of distribution of deformations, stresses, and strains inside the body of rail track and know the layer which more effected by changing the strength of ballast layer by change modulus of elasticity of it. This paper investigates the influence of modulus of elasticity of the ballast layer on the behavior of railways and the positions of deformation, stresses, and strains in the rail track which is most affected by the change in the modulus of elasticity and the value of the effect. The finite element approach was considered in this study using Abaqus Ver. 6.14-4 program. The investigation outcomes displayed that when the ballast layer's modulus of elasticity E increase by 100 MPa, the value of deformation in the rail track is affected in all layers, and the value of decreased is 6.8 % for rail, 6.9 % for ballast, and 6.7 % for the sub-ballast layer. Therefore the strain of the sub-ballast layer is affected by the change modulus of elasticity of the ballast layer more than other ballast and subgrade. Also, the result shows that stresses in the rail are the only part of the rail track affected by the change in the ballast layer's modulus of elasticity *E*, while the other layers are unaffected. So the increase in *E* of the ballast layer affects the layer beneath it, which is the sub-ballast layer.

Keywords:

Track way;
Ballast;
Modulus of elasticity;
Deformation;
Stresses;
Strain.

1 Introduction

To develop a logical design approach for installing or enhancing a railroad track, it is essential that the quantity and distribution of stresses and displacements within the track support structure be estimated exactly and a parametric study of the impact of different track characteristics on total track responses be executed [1].

Recently, studies have focused on the ballast layer's modulus of elasticity *E* and the layers beneath it. A finite element model was used to study the impact of different track parameters on overall track responses. A parametric study is conducted by holding some track characteristics and changing other properties to study their effects, such as the sub-ballast depth and *E* of the ballast, sub-ballast, and subgrade. The track characteristic that had the greatest impact on the total track responses was found to be subgrade modulus [1]. The impact of *E* of ballast and sand subgrade layers in rail displacement were studied [2]. A finite elements were used to investigate the impact of the modulus of elasticity of sleepers, ballast, and sub-ballast on railway behavior [3]. A numerical model and full-scale structure was built to study the mechanical response of earth structures related to rail traffic. Full-scale tests and finite element models were performed in plane strain and three dimensions [4].

Finite Element Analysis (FEA) is a method of numerical analysis used to obtain approximations of solutions to complex engineering problems [5-8]. The demand for numerical methods arises because,

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for most practical engineering problems, analytical solutions cannot be obtained [9]. This study aims to analyze the effects of the railway ballast Modulus of elasticity on the position of deformation, stresses, and strain distribution in railways by using three values of ballast modulus of elasticity which are 100, 150, and 200 MPa, by measuring the deformation, stress, and strain in three positions which are on the rail, at the center thickness of ballast layer and sub-ballast layer. By simulating the rail track using the finite element program Abaqus. Since the Abaqus program user's fundamental purpose is to indicate a specific circumstance or identify a problem and its remedy, dealing with the software in its language becomes necessary, including creating and analyzing a model. Use these models to determine the geometry, material attributes, and other physical characteristics and then use the model for analysis [10]. Abaqus program approved its ability to solve problems in civil engineering [11-13]. This study aims to understand what is going on in the body of a rail track when the modulus of elasticity changes and most parts are affected by the rail track.

2 Materials and methods

2.1 Materials

2.1.1 Ballast and sub-ballast

The rail track was divided into sub-structure and super-structure. Railway track structure comprises rails, rail pads, sleepers, fastenings, ballast, sub-ballast, and subgrade. The railway ballast layer is composed of various aggregate particles subjected to repeated heavy loads of trains [14-17]. Its main role is resisting vertical, lateral, and longitudinal forces applied to the sleepers to maintain track in the required position, provide the track with resilience and energy absorption, give drainage and lower traffic-induced stresses in the subsurface layers, and make maintenance activities easier [18].

Between the ballast and subgrade is a granular layer known as the sub-ballast. This improves drainage and lessens the amount of stress carried from the ballast layer to the subgrade. Additionally, the sub-ballast layer inhibits the subgrade from penetrating the ballast, fine material coming from the subgrade from moving higher, and ballast attrition of the subgrade [19].

The primary requirements for sub-ballast material used in rail tracks are locally accessible and free draining. Material for sub-ballast should be coarse, granular, and well-graded. The maximum fine for plastic is 5 %, and the maximum fine for non-plastic is 12 % [20]. The increase in fine material will increase the plastic deformation of the sub-ballast layer in railway structures and let to deformation in the upper layers and rail.

2.1.2 Material properties

The input characteristics of the material are shown in Table 1.

Table 1: Input characteristics of the material.

Material	Modulus of elasticity [kPa]	Density [kg/m^3]
Subgrade/ Soil	12500	1632
Sub-ballast/Granular material	80000	1700
Ballast/ Gravel	100000	1590

2.2 Abaqus model geometry

Three models were built. Each model has a different ballast modulus of elasticity of 100, 150, and 200 MPa, depending on local material properties. The sub-ballast and ballast layer thickness is 0.2 m, and the thickness of the subgrade is 4 m. The width of the ballast, sub-ballast, and subgrade layers is 4 m. According to local railway structure thicknesses, as shown in Fig. 1. For high accuracy and time savings, it is advised to use a square (aspect ratio equal to unity) or rectangular mesh, where the mesh is configured to produce square or rectangular elements [21]. Dynamic load is used in this analysis.

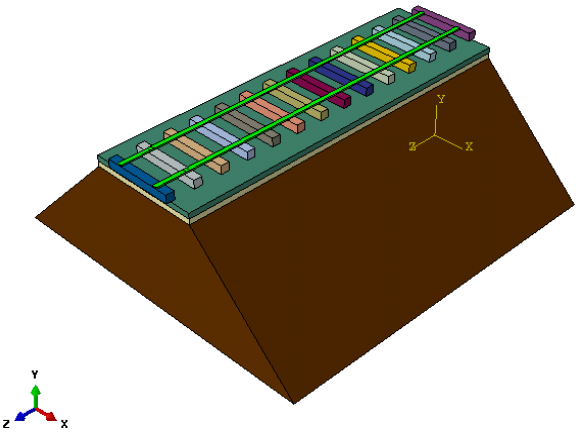


Fig. 1. General geometry of 3-D model of the railway.

2.3 Element types and mesh size finite

The 8-node continuum three-dimensional brick element (C3D8R), accessible in Abaqus, is used to model every component of the model to maintain the continuity of nodes between succeeding layers. All layers are simulated with the same geometry [6]. Fig. 2 demonstrates the meshing of the whole model and the cross-section in 2D.

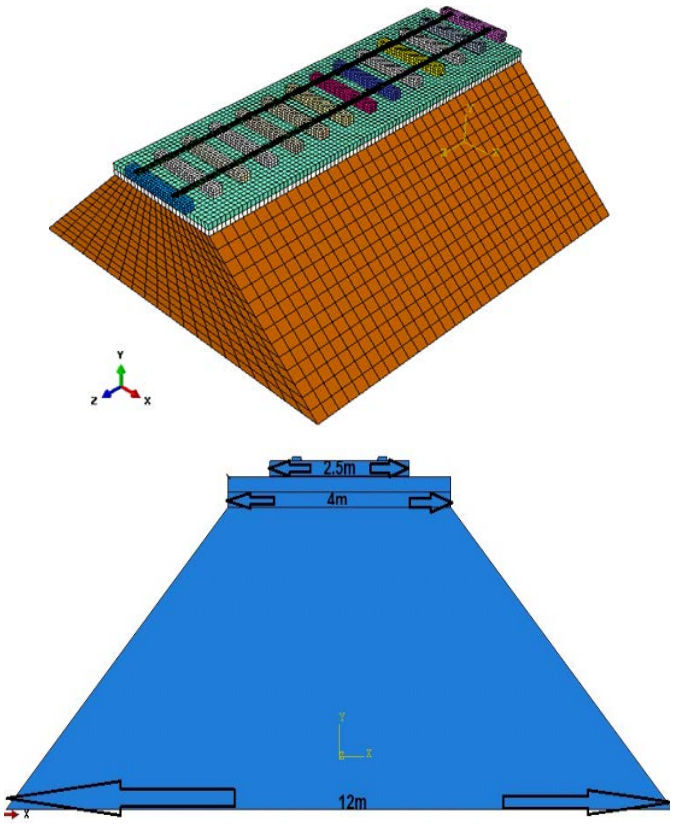


Fig. 2: Mesh of all layers.

3 Results and discussions

The investigation showed that when the ballast layer's elasticity modulus rises, the deformation decreases, as shown in Fig. 3 and Fig. 4 illustrating the rise in the *E* of the ballast layer to 100 MPa. The deformation is affected in all positions and decreases by 6.8 % for rail, 6.9 % for ballast, and 6.7 % for the sub-ballast layer, due to the increase in the strength of ballast material by increased elasticity modulus.

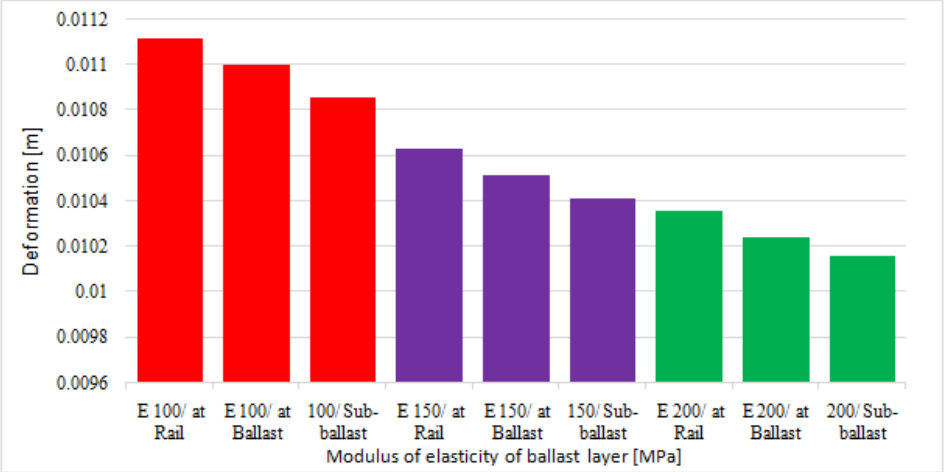


Fig. 3: Impact of changing ballast layer's *E* on the deformation.

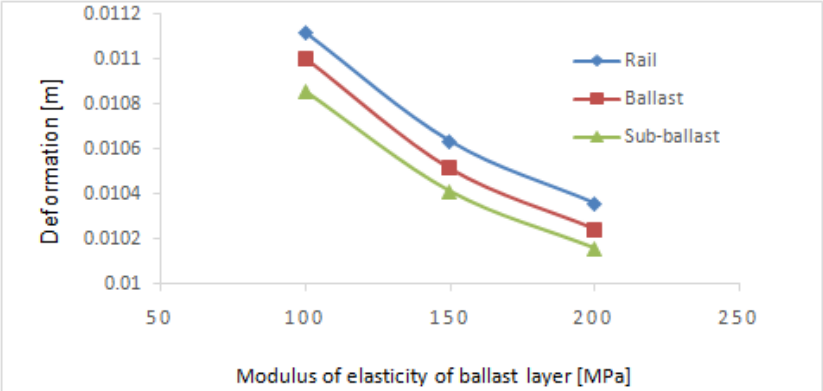


Fig. 4: Impact of changing ballast layer's *E* on the deformation.

Fig. 5 demonstrated that the increase of modulus of elasticity decreases strain at the rail, ballast, and sub-ballast. Also, the result shows the maximum strain value at the sub-ballast layer. Fig. 6 displayed that the increase of *E* of ballast layer affects the decreased strain at the sub-ballast layer while the strain in rail and ballast are unaffected.

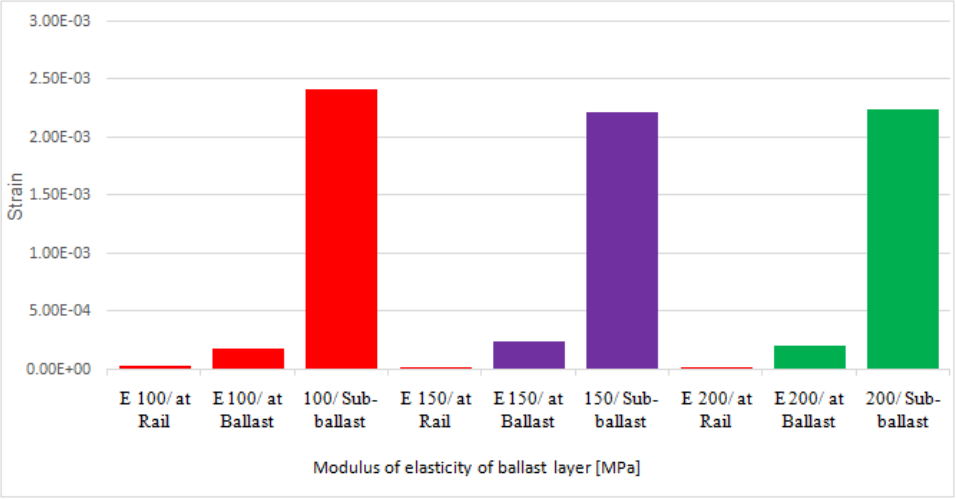


Fig. 5: Impact of changing ballast layer's *E* on the strain.

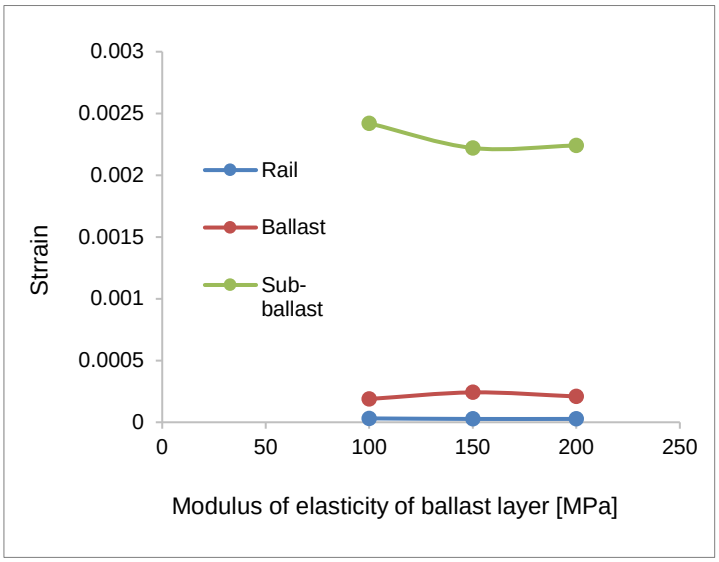


Fig. 6: Impact of changing ballast layer's *E* on the strain.

Fig. 7 illustrated that the rise in *E* of the ballast layer led to increasing stresses at the rail while the stresses at the ballast and sub-ballast were not affected; this is logical because the increased *E* of the ballast layer led to an increase in its ability to resist stresses from rail and increase its reaction, so the stresses in rail increased. Fig. 8 shows that the rail is affected when changing *E* of the ballast layer, while the ballast and sub-ballast layers are unaffected.

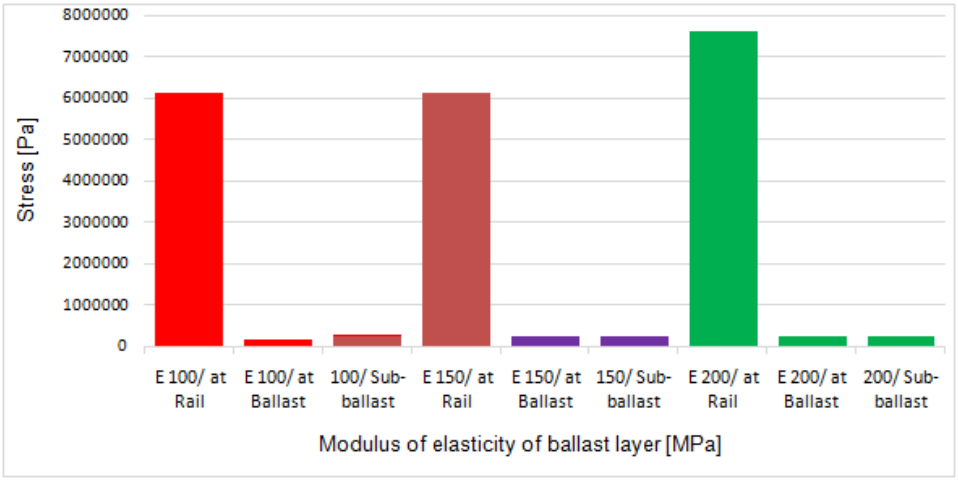


Fig. 7: Impact of changing ballast layer's *E* on the stress.

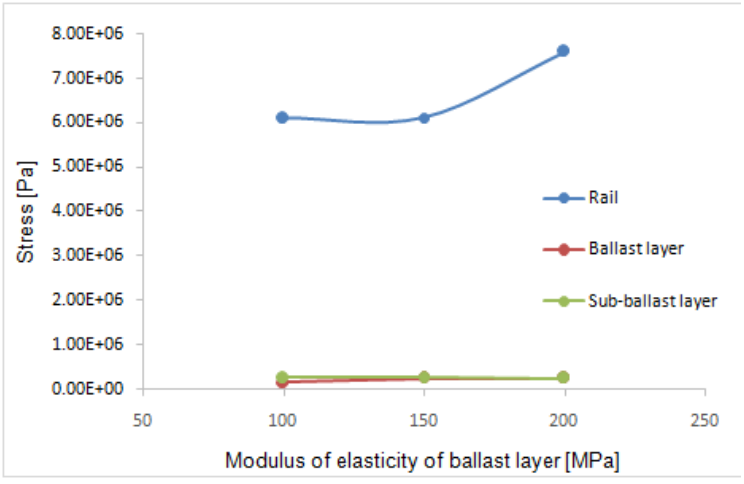


Fig. 8: Impact of changing ballast layer's *E* on the stress.

4 Conclusions

Studying the influence of increased *E* of the ballast layer in railway behavior is necessary to understand the side effect of increasing *E* of the ballast layer. Some conclusions are noted through investigation:

1) The increased *E* of the ballast layer decreases the deformation in the railway. The most deformation was in rail.

2) The increased *E* of the ballast layer increase by 100 MPa, and the deformation is significantly affected in all positions and decreases by 6.8 % for rail, 6.9 % for ballast, and 6.7 % for the sub-ballast layer.

3) The increased *E* of the ballast layer decreased the strain in the sub-ballast layer by a slight value, while the increased modulus of elasticity was not affecting in the strain of the rail and ballast layer because the increasing strength of the ballast layer by increasing its modulus of elasticity effect in decrease the load which transfers to layers beneath it, so the strain in the layer under ballast was affected. The significant value of strain was in the sub-ballast layer.

4) The increased *E* of the ballast layer led to increased stresses in the rail, while the stresses of the ballast and sub-ballast layer were unaffected. So, the conclusion is that the increased *E* of ballast let to increase its strength of it and, in consequence, increases its reaction to its upper layers of it and increases the stresses in the rail layer. Studying the effect of increased *E* of the ballast layer in railway behavior is necessary to understand the side effect of increasing *E* of the ballast layer.

5) For future work is recommended to build a prototype rail track, install sensors in all layers of the rail track and study the parts affected in the rail track when changing the thickness of the ballast layer**.**

References

[1] SHAHU, J. - RAO, N. K. - YUDHBIR: Parametric study of resilient response of tracks with a sub-ballast layer. Canadian Geotechnical Journal, Vol. 36, Iss. 6, 1999, pp.1137–1150.

[2] KALASIN, T.: Numerical and physical models for predicting responses of ballasted tracks with voided ballast layer effect on sand embankments. International Journal of Geotechnical Engineering. Vol. 16, Iss. 7, 2022, pp. 890-902.

[3] KUMARAN, G. - MENON, D. - NAIR, K. K.: Dynamic studies of rail track sleepers in a track structure system. Journal of Sound and Vibration, Vol. 268, Iss. 3, 2003, pp. 485–501.

[4] BOURGEOIS, E. - SOYEZ, L. - KOUBY, A. L.: Experimental and numerical study of the behavior of a reinforced-earth wall subjected to a local load. Elsevier Computers and Geotechn, Vol. 38, Iss. 4, 2011, pp. 515-525.

[5] DANIEL, L. - VALASKOVA, V. - KORTIS, J.: Numerical Simulation of Moving Vehicle across the Obstacle. Civil and Environmental Engineering, Vol. 10, Iss. 2, 2014, pp.88-92, doi: https://doi.org/10.2478/cee-2014-0016.

[6] THOMPSON, S.: A Practical Guide to Reliable Finite Element Modelling. The Aeronautical Journal, Vol. 113, Iss. 1141, 2009, pp. 203-4.

[7] MOHAMMED, A. Q.: Finite Element Application for Modified Cam Clay Model to Analyze Silty Clay Soil under Strip Footing Using MATLAB. Journal of Engineering and Sustainable Development, Vol. 16, Iss. 2, 2012, pp. 89-100.

[8] OBAID, A. Q. - ALI, F. H. - MOHAMMED, A. Q.: Finite Element Analysis of Strip Footing Resting on Gibson -Type Soil by Using Matlab. Journal of Engineering, Vol. 17, Iss.1, 2011, pp. 80-91.

[9] AYYUB, B. - MCCUEN, R. H.: Numerical analysis for engineers: methods and applications, 2nd edition. CRC Press, 2016.

[10] MASOOD, G. G.: Experimental and Numerical Investigation of stabilized unbound Granular Pavement Materials. MSc Thesis, College of Engineering, AL-Mustansiriyah University, 2013.

[11] AL-ABDULLAH, S. F. - SOFIA, G. G. - TEAMA, Z. T.: An approach in study behavior of sand dunes to use as a subgrade in pave road under moving loads. Proceeding In congress on technical advancement, 2017, pp. 53-64.

[12] AL-ABDULLAH, S. F. - SOFIA, G. G. - TEAMA, Z. T.: Evaluation of using geosynthetic material and the process of grouting to improve pavement performance over sand dunes subgrade. Proceeding in International conference on transportation and development, 2016, pp. 859-870.

[13] AL-ABDULLAH, S. F. - TEAMA, Z. T. - ALDAHWI, S. - ZAIDN, M.: Theoretical Evaluation of Sand Subgrade Behavior underneath the Asphalt Pavement with Rutting Deformation. Proceeding In Geotechnical Engineering and Sustainable Construction, 2022, pp. 597-609.

[14] ANDERSON, W. F. - FAIR, P.: Behavior of railroad ballast under monotonic and cyclic loading. Journal of geotechnical and geoenvironmental engineering, Vol. 134, Iss. 3, 2008, pp. 316-327.
[15] LACKENBY, J. - INDRARATNA, B. - MCDOWELL, G. - CHRISTIE, D.: Effect of confining pressure on ballast degradation and deformation under cyclic triaxial loading. Geotechnique, Vol. 57, Iss. 6, 2007, pp. 527-36.
[16] LU, M. - MCDOWELL, G. R.: Discrete element modelling of ballast abrasion. Geotechnique, Vol. 56, Iss. 9, 2006, pp. 651-5.
[17] INDRARATNA, B. - NIMBALKAR, S. - CHRISTIE. D. - RUJIKIATKAMJORN, C. - VINOD, J.: Field assessment of the performance of a ballasted rail track with and without geosynthetics. Journal of Geotechnical and Geoenvironmental Engineering, Vol. 136, Iss. 7, 2010, pp. 907-17.
[18] ZULKIFLI, M.A. - BASARUDDIN, K.S. - RAHIM, Y. A. - AFENDI, M. - GURUBARAN, P. - IBRAHIM, I.: Three dimensional finite element analysis on railway rail. In IOP Conference Series: Materials Science and Engineering, Vol. 429, Iss. 1, 2018, pp. 012010.
[19] BURROW, M. P. N. - BOWNESS, D. - GHATAORA, G. S.: A comparison of railway track foundation design methods. Proceedings of the Institution of Mechanical Engineers Part F, Journal of Rail and Rapid Transit, Vol. 221, Iss. 1, 2007, pp. 1-12.
[20] SHAHU, J. T. - SHARMA, A. - SHARMA, K. G.: Numerical modelling of railway tracks with ballast and sub-ballast layers using critical state parameters. Proceedings of the 12th International Conference on Computer Methods and Advances in Geomechanics, IACMAG'08, 2008.
[21] SHUBER, A. - HAMOOD, M. - JAWAD, W.: Performance of railway track system under harmonic loading by finite element method. In MATEC Web of Conferences, Vol. 162, 2018, pp. 01043, EDP Sciences.