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E-mail: editura@unitbv.ro

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CONTENTS

Murat ALAN: *Multi-Trait Selection in Aegean Region Low Elevation Breeding Zone for Pinus Brutia Ten.* 1-12

Ana G. ANUȚOIU, Ovidiu IONESCU: *Hunting and Human – Bear Conflicts* 13-28

Mihnea CĂȚEANU: Using IceSat-2 Satellite Data for the Retrieval of Forest Canopy Heights in Latoriței Mountains, Romania 29-42

Vasileios K. DROSOS, Evripidis D. FARMAKIS, Ioannis SISMANIDIS, Ioannis KOUKOULOS, Georgios TASIONAS: *Detection of Land Cover / Land Use Changes in a Semi-Mountainous Forest Suburban Area* 43-54

Vasileios K. DROSOS, Ioannis KOUKOULOS, Ioannis SISMANIDIS, Georgios TASIONAS, Evripidis D. FARMAKIS: *Multi-Criteria Assessment of the Environmental Construction and Operation of a Forest Road from a Forest Technical Point of View* 55-66

Vasileios K. DROSOS, Ioannis SISMANIDIS, Ioannis KOUKOULOS, Georgios TASIONAS, Evripidis D. FARMAKIS: *Rational Forest Opening-Up as a Tool for Sustainable Development and Exploitation of the Semi Mountainous Areas in Greece* 67-74

Călin V. HODOR, Dan T. IONESCU, Emanuel Ș. BALTAG, Sylvia M. HODOR, Nicoleta E. MĂRȚOIU, Daniel IORDACHE: *Distribution and Population of Tawny Owl (Strix aluco) and Ural Owl (Strix uralensis) in Deciduous Forests from Central Romania* 75-84

Dan T. IONESCU, Călin V. HODOR, Codrin L. CODREAN, Emanuel Ș. BALTAG, Dănuț N. MAZILU, Ștefan A. BARBU, Sylvia M. HODOR: *Density and Distribution of Seven Woodpecker Species in A Deciduous Forest from Central Romania* 85-98

Dimitrios LAZARIS, Vasileios K. DROSOS, Ioannis SISMANIDIS, Evripidis D. FARMAKIS: *Population Sustainability Analysis of Przewalski's Gazelle (Procapra przewalskii) Using the Vortex Software* 99-112

Oleg MACHUGA, Andriy SHCHUPAK, Oleg STYRANIVSKY: *Rut Depth Determining to Assess the Negative Impact of Forest Machines on the Ground Surface of Movement* 113-124

Ion MIREA, Mihai FEDORCA, Iulia BACIU, Roxana CAZACU, Daniel IORDACHE, Ovidiu IONESCU: *An Overview of the Photo Trap Camera as a Survey Tool for Wildlife* 125-134

Elena C. MUȘAT, Rudolf A. DERCZENI, Emilia A. SALCĂ, Constantin A. BRATU, Valentina D. CIOBANU: *Evaluation of Deformations of the Forest Road Pavements by Using the Finite Element Method* 135-148

Nikolay NEYKOV, Aureliu-Florin HALALISAN, Petar ANTOV: *Efficiency of Gross Fixed Capital Formation in Forestry – Data Envelopment Analysis and Malmquist Index for Cross-Country Comparison in EU* 149-156

Teijo PALANDER: *Impacts of Support Measures on the Operating Environment of the LHV in Finnish Timber Transportation* 157-172

Jasmina POPOVIC, Mladjan POPOVIC, Petar GAJIC, Marko PERUNICIC, Milanka DJIPOROVIC-MOMCILOVIC, Vladimir DODEVSKI*: The Changes in Chemical Composition of Narrow-Leaved Ash Wood in Regard to the Conditions of the Acetic Acid Pretreatment* 173-188

Cezar G. SPĂTARU, George E. SÎRBU, Codrin L. CODREAN, Ovidiu IONESCU: *Red Deer (Cervus elaphus L.) Trophies from Romania* 189-200

Cornel C. TEREŞNEU, Cristian S. TEREŞNEU, Maria M. VASILESCU: *The Use of Geographical Information Systems for Issues Regarding Land Receding of Forested Areas* 201-208

Authors Index 209

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EVALUATION OF DEFORMATIONS OF THE FOREST ROAD PAVEMENTS BY USING THE FINITE ELEMENT METHOD

Elena C. MUȘAT[1] **Rudolf A. DERCZENI**[1]
Emilia A. SALCĂ[2] **Constantin A. BRATU**[3]
Valentina D. CIOBANU[1]

Abstract: *The deformations produced by trucks and other vehicles on forest road pavements play a significant role in sustainable forestry. The Finite Element Method was used for the determination of deformations, for two types of forest trucks, namely Volvo FH 12.A60 and Mercedes – Actros 2646. Surface force was determined and calculated along curb displacement values on the road. The aim of the present study was to analyze the deformations of forest road pavement made of three layers as a function of traffic intensity and type of trucks that are running the forest roads. Based on the findings, it appears that the maximum displacement took place in the middle area of the contact surface between the road and wheel. The results indicate that the maximum residual deformations occurred after the passing of the rear wheel - axel 2. The residual deformations appeared to be higher after the passing of the last wheel and could increase significantly. Data found in this work can be used for a better maintenance of forest road networks and in sustainable forestry.*

Key words: *FEM, pavement, residual deformations, traffic intensity.*

1. Introduction

Forest roads are permanent transport routes of private property [27] which can be used only with the accord of the administrator of a road. Also, bridges anddefense and consolidation works for crossing rivers or streams, or for traffic safety, signaling signs, as well as other facilities are included in any forest road project design. Traffic is steadily increasing both in terms of the number of vehicles involved and tonnage loaded [5, 6, 9, 33]. Thus, the design calculation of a road pavement requires an accurate adaptation to the current situation. In this respect, the most used method to achieve accurate results is the Finite Element

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[1] Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Faculty of Silviculture and forest engineering, Transilvania University of Brasov, Romania;
[2] Faculty of Furniture Design and Wood Engineering, Transilvania University of Brașov, Romania;
[3] Regional Administration of Road and Bridges Brasov, Romania;
Correspondence: Rudolf A. Derczeni; email: derczeni@unitbv.ro.

Method (FEM) [12, 18, 28, 35, 36, 38]. The Finite Element Method is used successfully both for the determination of asphalt mixture cracking and for the evaluation of rutting pavement paths [4, 8, 16, 21, 22, 30-32]. Researchers in the field succeeded in predicting the life cycle of a road by using such an FEM methodological approach [2, 18]. Moreover, the FEM 3D method may be applied to simulate the vertical strain developed as a result of traffic loads for a road pavement which presents linear viscoelastic behavior [29, 32, 37]. It is worth mentioning that by using the 2D FEM method with the help of the Plaxis 2D software, the elastic modulus of the Californian Bearing Ratio (CBR) for the foundation soil can be determined [25]. Some of the most used software for FEM calculation is ANSYS and ABAQUS [17, 18, 37]. The use of the ANSYS software has led to results considered compatible with the ones obtained through other well-established methods of pavement design [7]. The FEM calculation mainly refers to three-dimensional (3D FEM) and axis-symmetric (2D FEM) calculations [11, 12]. Both methods yield similar results, and the 2D variant offers low resource consumption [10, 12]. In general, the first step in validating the FEM 3D calculation of a road pavementis the validation of the 2D method applied on the same structure [14]. It isalso possible to model the dynamic tire-road interaction in a rigorous and realistic way by using FEM [15, 34, 36]. It appears that the FEM analysis with ABAQUS is preferred for rigid pavements made of concrete [20]. But research studies have been performed on block pavements as well [13, 19]. In the case of asphalt layers it is possible to predict their cracking by using the FEM analysis. In Romania, the forest roads are designed in accordance with the national standardized regulations of the forest roads, based on the region geography where they are located, and according to their importance and functionality [27]. This standard stipulates that the load resulting in the tire contact area is uniform. But by using FEM, its non-uniformity has been modeled and predicted [23, 26]. Road pavement consists of three layers in case of a carried-on quantity more than 50,000 tons/year [27]. Such pavement consists of a ballast base layer (protective layer), polygranular stone foundation 0/90 (bearing layer), and a clothing layer made of broken pore stone 0/70 (wear layer). When the ground conditions impose, a foundation substrate can be introduced as an insulating, anti-foaming, antifreeze, drainage, and homogenization layer [1].

The opportunity of the research derives from the technical evolution that led to the increase of the loading capacity in vehicles of transport, currently reaching up to 38 tons, as the maximum authorized mass on the forest road network in Romania [27]. In addition, the fact that the forest transport network in Romania was designed for a maximum total weight allowed of 25 tons, according to AND 582 [3], and currently the loads exceed this value, it is an important attribute for the necessity and opportunity of the research, it being known that degradations are greatly influenced by traffic, tonnage, and mass distribution on the vehicle's axles [5, 9, 23, 37, 38]. According to what was mentioned above, the aim of the presentstudy wasto apply the Finite Element Method to analyze the deformations (elastic and residual) of the forest road pavement made of three-layers as a function of trafficintensity and type of trucks which are running the forest road.

2. Material and methods

2.1. Geometric Modeling of the Representative Road Pavement and Materials Used

A flat portion of the road with dimensions of 5 x 2 x 2 m was taken in consideration for the geometric modeling of the road. Therefore,the overall deformation occurred due to the pressure forces without any influence on the geometric size used for the numerical simulation as illustrated in Figure 1.

The 3D modeling sample was employed for the finite element calculation. With this approach, satisfactory large road surface was considered resulting in no influence of the geometric dimension of the road. The geometric model of the two roads for Finite Element Calculations is shown in Figure 2. The dimensions of the layers of the forest road took into consideration the dimensions of each layerpresented in Figure 1.

The materials used in this studyfor the three-layer pavement design and their properties are presented in Table 1. For the comparative calculation when using the Finite Element Method, the materials are considered homogeneous and only the elastic deformation area is taken into account.

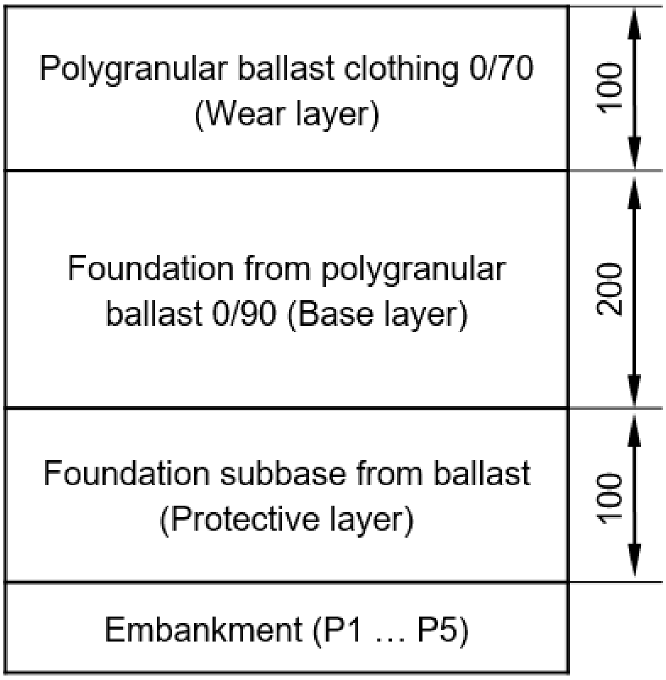

Fig. 1. *The geometric dimensions of the forest road*

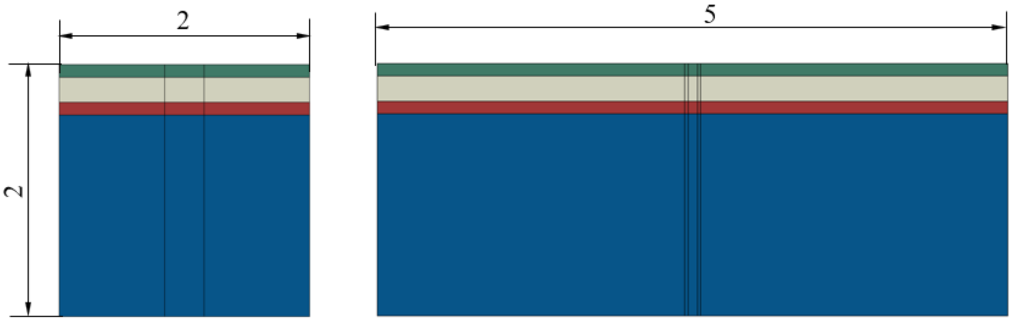

Fig. 2. *The three-layer pavement type*

Material properties used for the pavement Table 1

Type of material	Thickness layer [mm] type 1.x	The modulus of elasticity [MPa] type 1.x	Transverse contraction module ν
Polygranular ballast clothing 0/70 (Wear layer)	100	90	0.27
Foundation of polygranular ballast 0/90 (Base layer)	200	80	0.27
Foundation subbase of ballast (Protective layer)	100	70	0.27
Embankment (P1 … P5)	∞	12	0.27

2.2. Description of the Finite Element Model and application of the Boundary CONDITIONS

The discredited models compiled with the ABAQUS CAE design software (2019 version) of the road are presented in Figure 3. The finite 3D elements by hexadecimal type, which simulate the pavement layers, were attributed to the material properties of each layer. The connection between the layers is achieved by the common nodes between the finite elements.

For a comparative analysis in this study, the maximum load on two forest trucks that support different maximum loads was considered. The characteristics of the two forest trucks commonly used in Romaniaare displayed in Table 2. The total load supported by each axle is distributed on each wheel to obtain the deformation of the road pavement that comes into contact with each wheel at a given time [27, 38]. Thus, the residual deformation that occurs in the road pavement after the passing of a forest truck with a given load can be estimated.

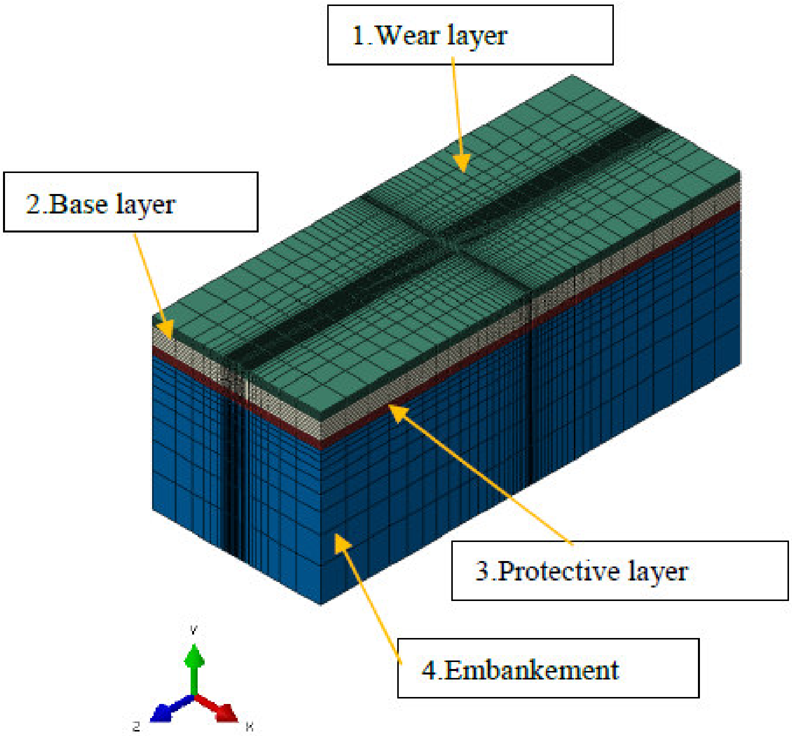

Fig. 3. *Finite element model of the pavement*

Characteristics of the main forest trucks used in Romania Table 2

Brand	Model	Loaded weight [tons]	Axle load [kN]		Load wheel [kN]	
			Front	Rear	Front	Rear
Mercedes	Actros 2646	22.84	60	2x85	30	42.5
Volvo	FH 12.460	47.18	75	2x197.5	37.5	98.75

The contact surface between the wheel and the road is calculated based on the tire size and the wheel pressure, and thus the contact surface is determined (Table 3).

The equivalent contact surfaces between the wheel and the road for each forest truck corresponding to one front andrear wheel are shown in Figure 4.

Figure 5 graphically illustrates the variation of the forces on each wheel pertruck type and the difference between the appliedloads.

The road pavementdesign was established in all directions, based on the embankment layer and the loading force, as presented in Figure 6.

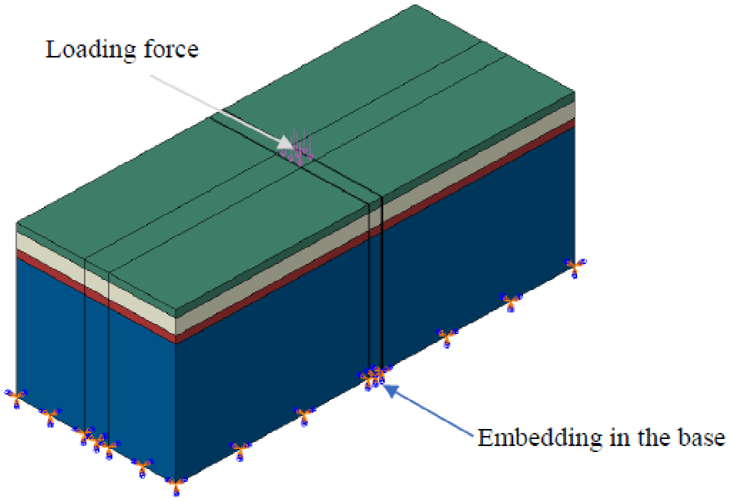

Fig. 6. Boundary conditions

Contact surface between wheel and road Table 3

Brand	Model	Tire size	Equivalent diameter of contact surface [mm]		Contact surface [mm^2]	
			Front wheel	Rear wheel	Front wheel	Rear wheel
Mercedes	Actros 2646	315/70R22.6	226	173	40115.00	23506.18
Volvo	FH 12.460	315/70R22.5	252	272	49875.92	58106.90

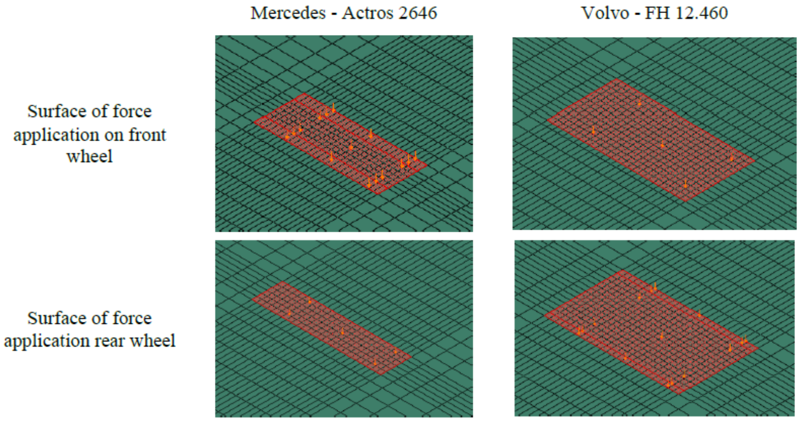

Fig. 4. *Surface of force application for two types of trucks*

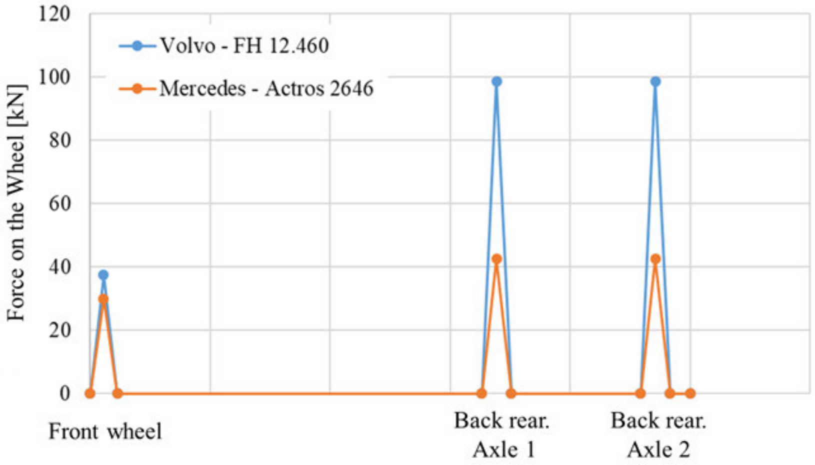

Fig. 5. *Distribution of forces on each wheel for each truck type*

3. Results

The main stresses inducedbythe front wheel – front axle, rear wheel - axle 1 and rear wheel - axle 2 were calculated. The obtained results per wheel and axle were analyzed.The structure displacements in all three cases are presented in Figure 7. It appeared that when running the forest road pavement with a Volvo truck, the structure displacements were higher as compared to the case of using a Mercedes truck on the same forest road; this aspect is a consequence of the technical characteristics of the two trucks (Table 2). Almost similar values for the structure displacement were noticed for the interaction of the rear wheels and their corresponding axles.

The displacement distribution and residual deformations per wheel and axle for each truck type were determined. They are represented in three different graphic ways, such as top view, plan and isometric views, respectively. Two examples of such an approach are presented in Figures 8 and 9.

In all cases, the maximum displacement andresidual deformation were observed in the middle zone of the contact surface between structure and wheel [24]. The maximum residual deformations are displayed in Table 4.

Table 4. *Maximum residual deformations as a function of interaction and truck type*

Type of interaction	Maximum residual deformations [mm]	
	Mercedes - Actros 2646	Volvo - FH 12.460
Front wheel-front axle	2.65e-4	3.35e-4
Rear wheel-axle 1	1.25e-3	2.79e-3
Rear wheel-axle 2	6.09e-3	1.51e-3

By applying the Finite Element Method, the main stresses and displacements for the front wheel – front axle, rear wheel - axle 1 and rear wheel - axle 2 were determined. In the case of front wheel – front axle, the maximum displacements were of approx. 2.87 mm for Mercedes -

Actros 2646 and 3.41 mm for Volvo - FH 12.460. The residual deformations represented approx. 9.23 and 9.82‰ of the elastic deformations for the first and second truck type, respectively.

In the case of rear wheel - axle 1, the maximum displacements were of approx. 4.54 mm for Mercedes - Actros 2646 and 8.64 mm for Volvo - FH 12.460. The residual deformations represented approx. 27.53 and 32.29‰ of the elastic deformations for the first and second truck type, respectively.

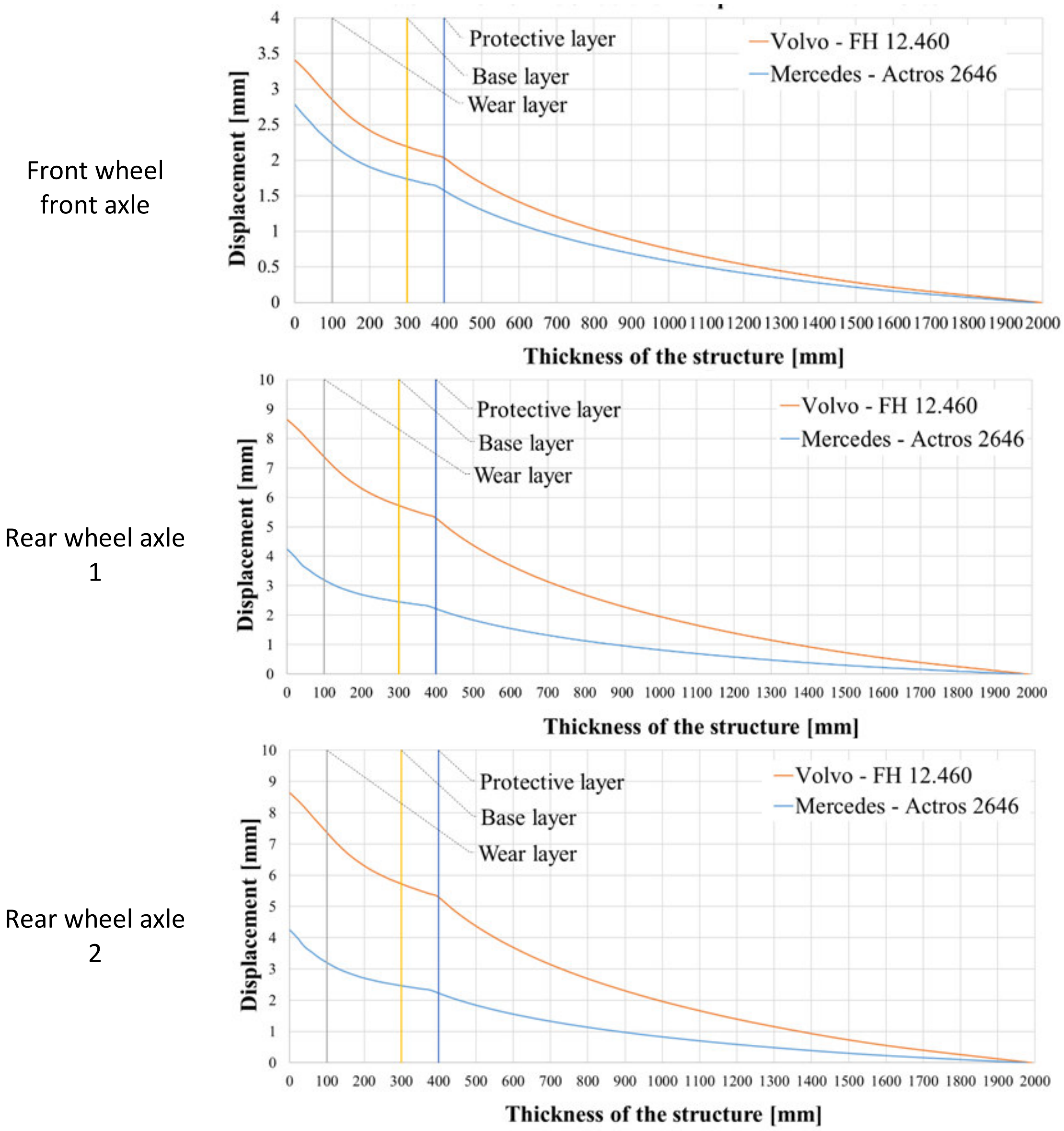

Fig. 7. *Structure displacements into the pavement depth per wheel and axle foreach truck type*

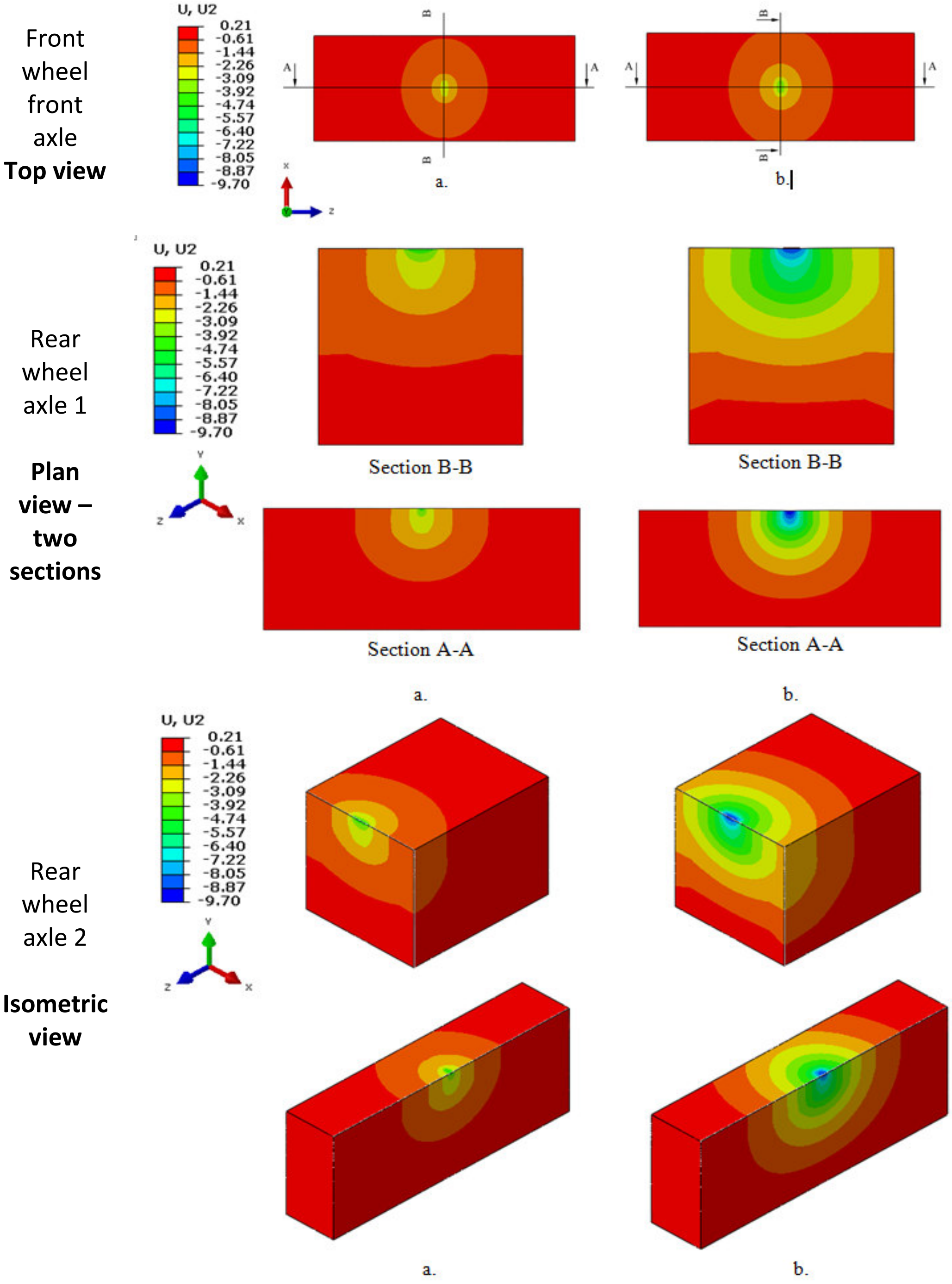

Fig. 8. *Displacement distribution under different graphic representations (top view, plan and isometric views) per wheel and axle for each truck type (a. Mercedes - Actros 2646; b. Volvo - FH 12.460)*

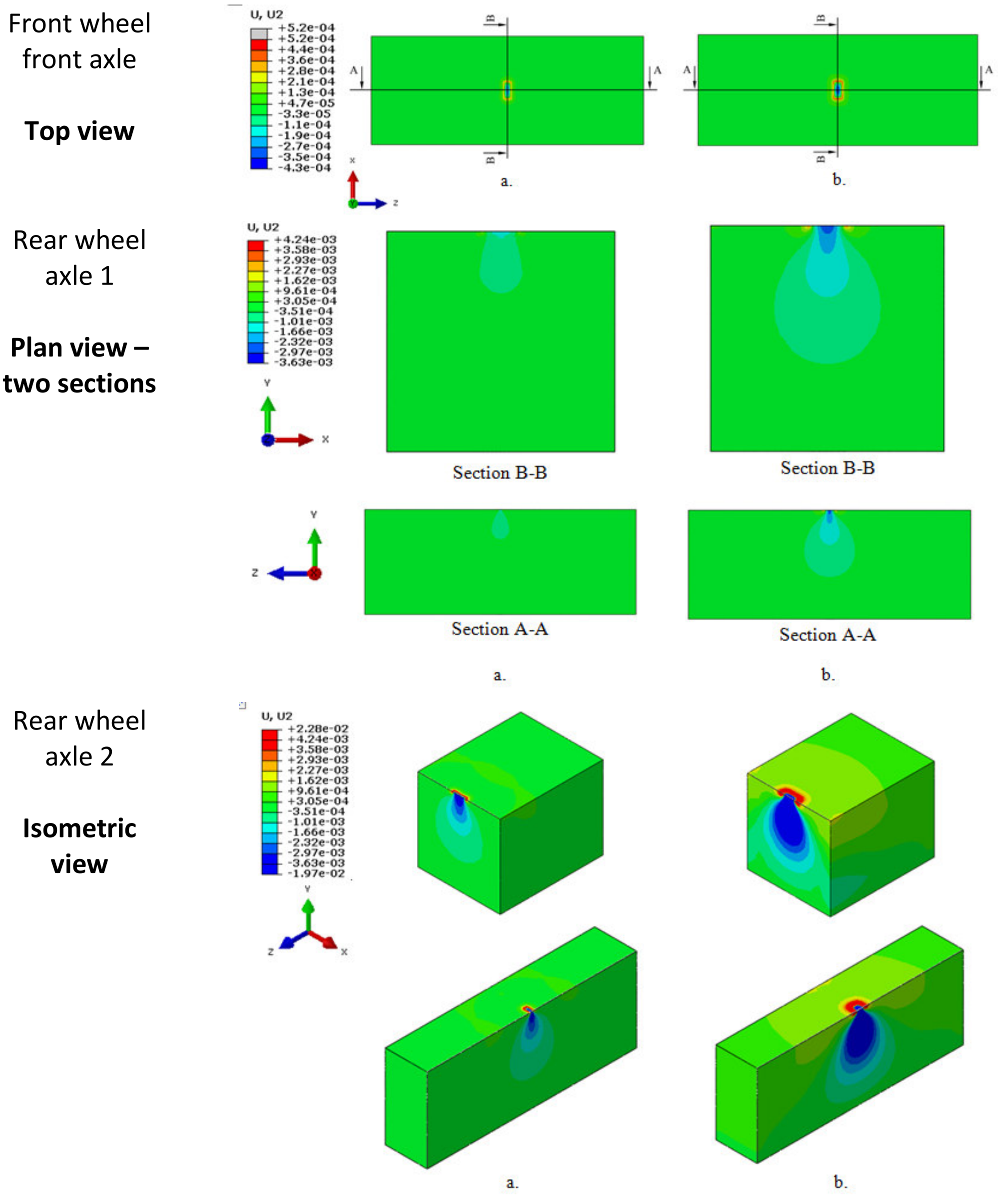

Fig. 9. *Residual deformations under different graphic representations (top view, plan and isometric views) per wheel and axle for each truck type (a. Mercedes - Actros 2646; b. Volvo - FH 12.460)*

In the case of rear wheel - axle 2, the maximum displacements were found to be aprox. 4.55 mm for Mercedes - Actros 2646 and 8.64 mm for Volvo - FH 12.460. The residual deformations represented approx. 13.38 and 17.48% of the elastic deformations for the first and second truck type, respectively.

The average residual deformations were found to be approx. 3.84% of the elastic deformations.

4. Discussion

For simplifying the calculations, the contact surface between structure and wheel, even if it is an ellipse, was considered a circle [24, 27]. The diameter of the equivalent circle varies between 20 and 30 cm in the case of the trucks with single axles and between 30 and 40 cm for those with double axles. The maximum admitted pressure on the contact surface is about 0.6 … 0.7 MPa [27].

Trzciński and Kaczmarzyk [33] state that on the forest roads with a single layer structure of gravel, the deformation modules are influenced in a small part by the thickness of the structure, because the deformations increase both with pressure and carrying capacity as well as with the road embankment or proper pavement construction. The influence of the pressure on the structure can also be easily observed in the present research, where Volvo – FH 12.460 trucks produce higherdisplacements and residual deformations than Actros 2646 trucks, regardless of the axle (front or rear).

Mulungye et al. [23] predicted strains from the Finite Element Model, and mentioned that the single wheel was 2.2 times more than those from the dual tandem pair per unit load in the longitudinal direction and 1.5 times in the transverse direction. Also, they showed that the single steering wheel generates 120% higher strains on average than the dual tandem axles for the same load.

Regarding the most affected point or zone of the structure under the pressure of loading, Leonardi et al. [18] and Musat and Bitir [24] reached the same result as the current study, where all the maximum displacement and residual deformation were observed in the middle zone of the contact surface between structure and wheel. Also, Leonardi et al. [18] mention that the maximum vertical deformations are greater with the increase of the number of carried loadings and the use of geogrid (glass fiber grid) can improve the behavior of the pavement, leading to a longer service period for the forest road.

5. Conclusions

The structure displacement produced into the pavement depth indicated that the maximum displacement was observed based on the values in the middle zone of the contact surface between ground and wheel.

Maximum residual deformations occurred after the passing of the rear wheel - axel 2. The residual deformations are higher after the passing of the last wheel. Therefore, after multiple passes, the residual deformation could increase significantly.

Data found in this work can be used for better maintenance of forest road networks and in sustainable forestry.

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References

1. Alexandru V., 2000. Construcţia şi întreţinerea drumurilor forestiere. Infomarke Publishing House, Brasov, Romania, 397 p.

2. Ambassa Z., Allou F., Petit C. et al., 2013. Fatigue life prediction of an asphalt pavement subjected to multiple axle loadings with viscoelastic FEM. In: Construction and Building Materials, vol. 43, pp. 443-452. DOI: 10.1016/j.conbuildmat.2013.02.017.
3. AND 582, 2002. Normativ privind proiectarea și execuția împietruirilor drumurilor de pământ. Condiții de calitate. Indicativ AND-582/2002.
4. Bakhshi B., Arabani M., 2018. Numerical evaluation of rutting in rubberized asphalt mixture using finite element modeling based on experimental viscoelastic properties. In: Journal of Materials in Civil Engineering, vol. 30(6): ID article 04018088. DOI: 10.1061/(ASCE)MT.1943-5533.0002116.
5. Bitir I., Musat E.C., Derczeni R.A. et al., 2019. The influence of the increased tonnage upon the superstructure of forest roads. In: Conference Proceedings of the 19th International Multidisciplinary Scientific Geoconference SGEM 2019, vol. 19 – Water Resources. Forest, Marine and Ocean Ecosystems, 3.2, pp. 853-860. DOI: 10.5593/sgem2019/3.2/S14.110.
6. Bitir I., Mușat E.C., Lunguleasa A. et al., 2021. Monitoring the transport on the Ciobănuș forest road within the Bacău Forestry Department. In: Recent Journal, vol. 1(63), pp. 10-16. DOI: 10.31926/RECENT.2021.63.010.
7. Bratu C.A., Ciobanu V.D., Derczeni R.A. et al., 2019. Study on the forest road pavements reinforced with geogrids by using the 2D FEM method. In: Road Materials and Pavement Design, vol. 20(6), pp. 1738-1752. DOI: 10.1080/14680629.2019.1566085.
8. Dai Q., You Z., 2007. Prediction of creep stiffness of asphalt mixture with micromechanical finite-element and discrete-element models. In: Journal of Engineering Mechanics, vol. 133(2), pp. 163-173. DOI: 10.1061/(ASCE)0733-9399(2007)133:2(163).
9. Derczeni R.A., Salcă E.A., Ciobanu D.V. et al., 2019. Establishing criteria for calculating the tax/road tolling for vehicles used for timber transport on forest roads. In: Proceedings of the Biennial International Symposium Forest and Sustainable Development, The 8th Edition, pp. 161-170.
10. Dosa A., Ungureanu V., Andrei B., 2010. SRM - Axisymmetric bidimensional discrete model for analysis of road structures. In: Proceedings of the International Scientific Conference CIBv. Brasov (Romania), pp. 187-194.
11. Elseifi M.A., Mohammad L.M., Ying H. et al., 2012. Modeling and evaluation of the cracking resistance of asphalt mixtures using the semi-circular bending test at intermediate temperatures. In: Road Materials and Pavement Design, vol. 13(1), pp. 124-139. DOI: 10.1080/14680629.2012.657035.
12. Erlingsson S., 2007. Numerical modelling of thin pavements behaviour in accelerated HVS tests. In: Road Materials and Pavement Design, vol. 8(4), pp. 719-744. DOI: 10.1080/14680629.2007.9690096.
13. Füssl J., Hengl H., Eberhardsteiner L. et al., 2018. Numerical simulation tool for paving block structures assessed by means of full-scale accelerated pavement tests. In: International Journal of Pavement Engineering, vol. 19(10), pp. 917-929. DOI: 10.1080/10298436.2016.1224410.

14. Ghadimi B., Nikraz H., 2017. A comparison of implementation of linear and nonlinear constitutive models in numerical analysis of layered flexible pavement. In: Road Materials and Pavement Design, vol. 18(3), pp 550-572. DOI: 10.1080/14680629.2016.1182055.
15. Jiang X., Zeng C., Gao X. et al., 2017. 3D FEM analysis of flexible base asphalt pavement structure under non-uniform tire contact pressure. In: International Journal of Pavement Engineering, vol. 20(9), pp. 999-1011. DOI: 10.1080/10298436.2017.1380803.
16. Kim S.M., Darabi M.K., Little D.N. et al., 2018. Effect of the realistic tire contact pressure on the rutting performance of asphaltic concrete pavements. In: KSCE Journal of Civil Engineering, vol. 22(6), pp. 2138-2146. DOI: 10.1007/s12205-018-4846-1.
17. Kim M., 2007. Three-dimensional finite element analysis of flexible pavements considering nonlinear pavement foundation behavior (Doctoral dissertation). Available at: http://ict.illinois.edu/files/2014/09/Minkwan_Kim_Dissertation.pdf. Accessed on: August 02, 2022.
18. Leonardi G., Lo Bosco D., Palamara R. et al., 2020. Finite element analysis of geogrid-stabilized unpaved roads. In: Sustainability, vol. 12, ID article 1929. DOI: 10.3390/su12051929.
19. Liao G., Wang S., Shi Q., 2016. Enhancing anti-rutting performance of asphalt pavement by dispersing shear stresses within asphalt layers. In: Road Materials and Pavement Design, vol. 19(2), pp. 453-469. DOI:10.1080/14680629.2016.1253494.
20. Lin W., Cho Y., Kim I.T., 2016. Development of deflection prediction model for concrete block pavement considering the block shapes and construction patterns. In: Advances in Materials Science and Engineering, ID article 5126436. DOI: 10.1155/2016/5126436.
21. Liu J., Asce M., Zhao S. et al., 2018. Evaluation of cracking resistance in Alaskan asphalt pavement with paving interlayers. In: Journal of Cold Regions Engineering, vol. 32(2), ID article 04018005. DOI: 10.1061/(ASCE)CR.1943-5495.0000162.
22. Mull M.A., Stuart K., Yehia A., 2002. Fracture resistance characterization of chemically modified crumb rubber asphalt pavement. In: Journal of Materials Science, vol. 37(3), pp. 557-566.
23. Mulungye R.M., Owende P.M.O., Mellon K., 2007. Finite element modelling of flexible pavements on soft soil subgrades. In: Materials and Design, vol. 28, pp. 739-756. DOI: 10.1016/j.matdes.2005.12.006.
24. Musat E.C., Bitir I., 2022. Evaluating the forest road systems subjected to different loadings by using the Finite Element Method. In: Forests, vol. 13, ID article 1872. DOI: 10.3390/f13111872.
25. Narzary B.K., Ahamad K.U., 2018. Estimating elastic modulus of California Bearing Ratio test sample using finite element model. In: Construction and Building Materials, vol.0 175, pp. 601-609. DOI: 10.1016/j.conbuildmat.2018.04.228.
26. Park D.W., Fernando E., Yoon H.C. et al., 2008. Effects of tire types on predicted pavement service life. In: Road Materials and Pavement Design, vol. 9(1), pp. 339-357. DOI: 10.1080/14680629.2008.9690173.

27. PD-003-11, 2011. Normativprivindproiectareadrumurilorforestiere (Regulations of forest roads design). Emitted by Order of the Minster of Environment and Forests no. 1374 on May 04, 2012, Romania, 272 p.
28. Rahmani M., Kim Y.R., Park Y.B. et al., 2020. Mechanistic analysis of pavement damage and performance prediction based on finite element modeling with viscoelasticity and fracture of mixtures. In: LHI Journal of Land, Housing and Urban Affairs, vol. 11(2), pp. 95-104. DOI: 10.5804/LHIJ.2020.11.2.95.
29. Ramos-García J.A., Castro M., 2017. Linear visco-elastic behavior of asphalt pavements: 3D-FE response models. In: Construction and Building Materials, vol. 136, pp. 414-425. DOI: 10.1016/j.conbuildmat.2017.01.015.
30. Roque R., Birgisson B., Drakos C. et al., 2004. Development and field evaluation of energy-based criteria for top-down cracking performance of hot mix asphalt (with discussion). In: Journal of the Association of Asphalt Paving Technologists, vol. 73, pp. 229-260.
31. Roque R., Birgisson B., Sangpetngam B. et al., 2002. Hot mix asphalt fracture mechanics: a fundamental crack growth law for asphalt mixtures. In: Journal of the Association of Asphalt Paving Technologists, vol. 71, pp. 816-827.
32. Shanbara H.K., Ruddock F., Atherton W., 2018. Predicting the rutting behaviour of natural fibre-reinforced cold mix asphalt using the finite element method. In: Construction and Building Materials, vol. 167, pp. 907-917. DOI: 10.1016/j.conbuildmat.2018.02.072.
33. Trzciński G., Kaczmarzyk S., 2006. Estimation of carrying capacity of slag and gravel fort road pavements. In: Croatian Journal of Forest Research, vol. 27(1), pp. 27-36.
34. Wollny I., Behnke R., Villaret K. et al., 2016. Numerical modelling of tire–pavement interaction phenomena: coupled structural investigations. In: Road Materials and Pavement Design, vol. 17(3), pp. 563-578. DOI: 10.1080/14680629.2015.1094399.
35. You Z., Liu Y., 2010. Three-dimensional discrete element simulation of asphalt concrete subjected to haversine loading. In: Road Materials and Pavement Design, vol. 11(2), pp. 273-290. DOI: 10.1080/14680629.2010.9690276.
36. Yu Q., Cai L., Wang J., 2018. Experimental and FEM research on airport cement concrete direct-thickening double-deck pavement slabs under aircraft single-wheel dynamic loads. In: Advances in Materials Science and Engineering, ID article 1952671. DOI: 10.1155/2018/1952671.
37. Zaghloul S., White T., 1993. Use of three-dimensional, dynamic finite element program for analysis of flexible pavements. In: Transportation Research Record, vol. 1388, pp. 60-69.
38. Zhu X., Law S.S., 2016. Recent developments in inverse problems of vehicle-bridge interaction dynamics. In: Journal of Civil Structural Health Monitoring, vol. 6, pp. 107-128. DOI: 10.1007/s13349-016-0155-x.