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Experimental investigation of vertical and horizontal reinforcement geotextiles in forest road pavement

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Abstract

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In this research, the results of an experimental survey on the measurement of vertical stresses are presented. Four treatments were used in this study such as combination of geotextile vertical and horizontal structure with dimensions of 5 × 5 and 10 × 10 cm, horizontal geotextile and the treatment without geotextile. Five sensors were installed in different hole locations and the lead of the truck traffic was transmitted by cables to data logging and recording devices to measure the pressure from vehicle traffic on the simulated pavement layer. Mean comparison of the treatments showed that the geotextile with vertical and horizontal structure and dimensions of 5 × 5 cm exerted the lowest pressure on the lower layers compared with the other treatments and there was a significant difference between the value of this treatment and the other treatments and that this treatment could significantly reduce the pressure of truck traffic on the forest road.

Keywords: vertical stresses; treatments; sensors; measure of pressure; layer

There is a close connection between human society and roads, and our ancestors were aware of the importance of roads for transporting goods and for military purposes (Nevečerel et al. 2007). The role of forests as producers of wood in human society makes the importance of access to these natural resources more obvious. Nowadays, forest roads are built for various purposes such as forestry, access to rural areas, hunting, travel and tourism, agriculture, summer resorts, mountain and hunting lodges and even for military purposes (Potocnik 1996). The construction of forest roads is one of the most expensive levels of forestry operations and stabilizing them is an important step. The most important reasons for stabilizing forest roads include strengthening to prevent soil subsidence and changes in the permeability of the soil, which is done by employing different materials. In general, the main objective of the stabilization of forest roads is to provide the required resistance of the substructure and superstructure with thinner layers. Musavi et al. (2014) studied the stabilization of forest roads in the north of Iran (Kheyrud forest) by employing polymeric materials and concluded that the polymeric material reduces the plasticity index and the level of fluidity. Mousavi and Abdi (2015) studied the effect of polymer stabilizers on bumps on the surface and the California bearing ratio (CBR) of the constituents of forest roads and concluded that soils with high clay content are more effective on forest roads. In the above- mentioned study, the effects of Road Packer Plus (RPP) as a polymer stabilizer were studied on the soil inflation control and also CBR was done. The results indicated that improving the soil with RPP led to the improvement of the CBR and the maximum density and reduced the Atterberg limits. Lime is another substance whose role researchers have referred to in stabilizing roads. Stabilizing sandy materials with lime resulted in increased durability and road freight. Generally, sandy materials stabilized with lime are used in the lower layers of forest roads (Eskioglou, Efthymiou 1996; Légère, Tremblay 2003; Madjnounian, Sadeghi 2005; Primusz et al. 2009). Ash is the other element that plays an important role in stabilizing forest roads and many researchers such as Turner (1997), Kaniraj and Havanagi (2001), Phani Kumar and Sharma (2004), and Eskioglou and Oikonomou (2008) mentioned the role of ash for use in construction materials of forest roads. Nowadays, with worldwide advances in science, using geotextiles in roads is conventional. The use of these polymer-textile products, as well as enhancing quality, provides appropriate solutions to the common problems of road construction. However, this stabilizer is less often considered for forest roads, so studies and research in the field of geotextiles in order to achieve technical knowledge for their production and use in forest roads are essential because they could bring some advantages such as greater ease of transporting building materials, making road for unskilled workers, reduced use of heavy machinery, minimum IP preparation, easy surface drainage and fast construction (Sessions 2007). Geotextiles are permeable plates of polyester or polypropylene that are made into a kind of non-woven and woven material (Toman, Skaugset 2011).

Reinforcing the pavement and reducing the stress on the pavement layers are some of the key roles of geosynthetic materials in road construction projects. What is now known as geosynthetics are in fact products that were first used in 1966 by Bart in the control of the land degradation process (Hausmann 1987). Among the geosynthetics that are suitable for soil reinforcement are geotextile and geogrid (Giroud, Han 2004).

The tires of machines that are moving on forest roads exert two kinds of vertical force on the road. The first can cause surface deformation and the second is the weight of the vehicle that is transmitted by the tires to the body of the road, which has a significant role in the calculation of road pavement. Vertical pressures are not the only forces that act on the road through the tires, but shear forces under the tires of vehicles also affect the road. When cars increase their speed or alternatively when they slow down and are braking, the horizontal force in the direction of movement or in the opposite direction impacts on the road. Even when cars are moving at a steady speed, shear forces under their tires arise. Calculating and measuring the shear forces under the tires is very complex, but in all cases, the pavement surface characteristics must be chosen so that they can resist the horizontal force (Nevečerel et al. 2007). Studies on the use of geotextiles in forest roads have shown that the type and distribution of these products play important roles in their function (Douglas, Kelly 1986; Hausmann 1987; Latha, Nair 2014).

Strength, permeability, high tensile strength, high resistance to perforation, mechanical and physical properties and weight are the most important factors in the widespread use of geotextiles in road construction. Geotextiles enable a separation of the layers of soil, drainage and filtration and thus increase the life expectancy and reduce the thickness of the main layers of roads. On the other hand, one of the main disadvantages of geotextiles is their deformation in the long term. In order to extend the life of the geotextile and also to increase the lifespan of the road and reduce the cost of repair and maintenance, using alternative designs for pavement structures is necessary. In this kind of project, horizontal and vertical layers of geotextile are used in the pavement at the same time. It seems that in these alternative approaches, vertical geotextile prevents the freedom of horizontal forces that come from the bottom of the road and increases the lifetime of the geotextiles in roads. This research attempts to evaluate the effect of the simultaneous use of geotextiles both horizontally and vertically and its impact on reducing the pressure of wheels on the lower layer of construction layers. The development of an alternative design for the pavement structure, strengthening it in order to extend the life of the road, and also the quality of the alternative approach in the past and comparison of the costs of alternative designs were investigated in this study.

MATERIAL AND METHODS

The research was done at the Research Laboratory of the Department of Forest Road and Timber Transportation of the Forestry and Wood Technology Faculty of the Belarusian State University. The Research Centre has extensive experience in designing layers of roads, especially regarding forest

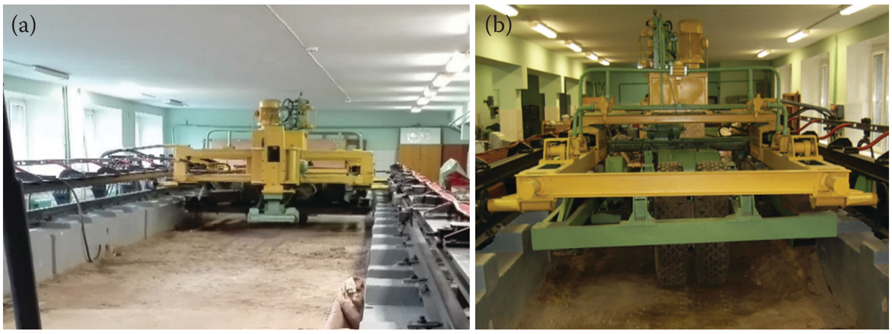

Fig. 1. Soil channels (a), MAZ truck model used in the study (b)

roads, and in order to do its experiments it uses soil channels (Fig. 1), 20 m long, 2.8 m wide and 1.5 m deep. The soil channel has trolley-like cargo trucks modelled on a MAZ-509 (Minsk Automobile Plant, Republic of Belarus).

In order to simulate the pavement soil layers within the soil channel, a hole 1 m wide and 28 cm in depth was dug. Simulation of a road pavement layer in two layers, 15 and 13 cm in depth and with different geotextile treatments was performed (Table 1). The pavement was placed between two layers of geotextile treatments (Fig. 2). The specifications of the geotextiles in this study are presented in Table 2. The soil gradation used in this study is shown in Fig. 3. The exact location of the truck traffic simulator was determined on a pit.

In order to measure the pressure from vehicle traffic on the simulated pavement layer, 5 sensors were installed in different hole locations and the load of the truck traffic was transmitted by cables to data logging and recording devices (Fig. 4).

Table 1. Geotextile treatments used in the study

No.	Treatment
1	without geotextile
2	with geotextile horizontally
3	geotextile structure vertical and horizontal with dimensions of 5 × 5 cm
4	geotextile structure vertical and horizontal with dimensions of 10 × 10 cm

Table 2. Characteristics of TYPAR SF40 geotextile (DuPont; Russia) used in the study

Characteristic	SF40
Specific gravity ($g \cdot m^{-2}$)	136
Tensile strength ($kN \cdot m^{-1}$)	8.5
Ultimate stretch ($kN \cdot m^{-1}$)	60
Tensile strength of 5% ($kN \cdot m^{-1}$)	4
Thickness at 200 $kN \cdot m^{-2}$ ($kN \cdot m^{-1}$)	0.39
California bearing ratio pressure (N)	1,340
Thickness at 2 $kN \cdot m^{-2}$ ($g \cdot m^{-2}$)	0.45
Folding strength (N)	745
Tear strength (N)	370
Speed indicator VI_{H50} ($mm \cdot s^{-1}$)	45
Water penetration up to 20 $kN \cdot m^{-2}$ (10^{-4} $m \cdot s^{-1}$)	2.2
Anti-permeability water up to 200 $kN \cdot m^{-2}$ (10^{-4} $m \cdot s^{-1}$)	1.5

VI_{H50} – velocity index for a head loss of 50 mm

After preparing each of the treatments, the MAZ truck trolley went 4 times forward and backward on the treatments and the maximum pressure in every move was recorded by the sensors that were installed in different parts of each treatment.

Maximum pressure readings at the sensors embedded at the experimental points were taken 8 times for each of the treatments. Evaluation of data normality was performed by the Kolmogorov-

Fig. 2. Different treatments related to the establishment of geotextiles: vertical and horizontal structure with dimensions of 10 × 10 cm (a), vertical and horizontal structure with dimensions of 5 × 5 cm (b), horizontally (c)

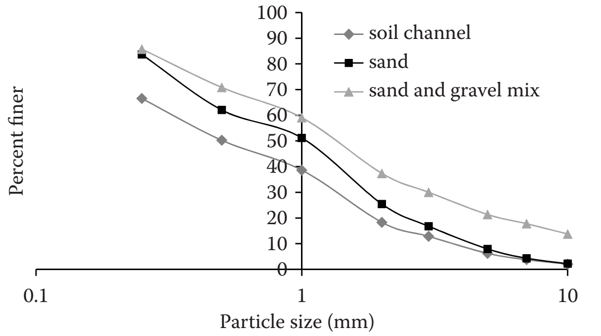

Fig. 3. Gradation curves used in the different layers of soil treatments

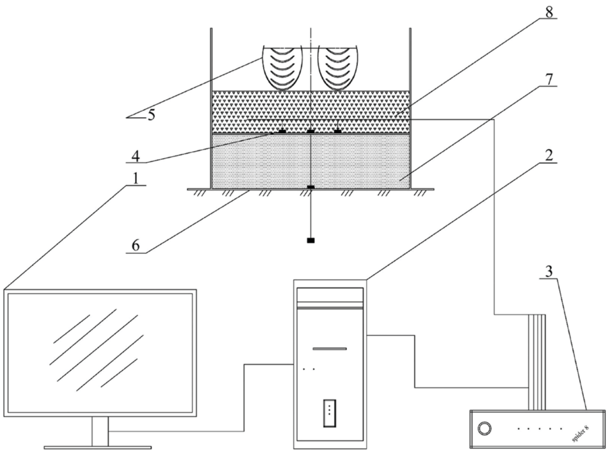

Fig. 4. The distribution of pavement layers of simulated truck traffic and barometric pressure sensors in the model

1 – monitor, 2 – computer case, 3 – spider 8, 4 – sensors for pressure measurement, 5 – wheel, 6 – base soil (soil channel), 7 – sand, 8 – sand and gravel mix

Smirnov test. Comparing the average pressure in MPa on each of the sensors for the different treatments was done by one-way analysis of variance. Comparisons between treatments using Duncan's test were conducted using the SPSS software (Version 16.0, 2008) and finally MS Excel (Version 2010) was used for diagramming.

RESULTS

Table 3 presents the results of the mean pressure in MPa on different parts in the treatments. In the non-geotextile treatment, the highest pressure was exerted by the left and right wheels and then the highest pressure was observed at a depth of 28 cm. The minimum pressure was between the wheels. The same trend was seen in the other treatments and only in the horizontal layers of the geotextile treatments the highest pressure was exerted by the left wheel.

Table 3. Descriptive statistics of pressure (MPa) on different parts of the treatments

Treatment	Depth sensors	Mean	SD	N
1.00	depth 43 cm	0.0656	0.00578	8
	depth 28 cm	0.2850	0.00822	8
	between wheels	0.0482	0.00601	8
	depth 13 cm L	0.3565	0.01459	8
	depth 13 cm R	0.4946	0.04552	8
	total	0.2500	0.17496	40
2.00	depth 43 cm	0.0639	0.00617	8
	depth 28 cm	0.2825	0.06475	8
	between wheels	0.0556	0.01014	8
	depth 13 cm L	0.4493	0.03104	8
	depth 13 cm R	0.3666	0.02816	8
	total	0.2436	0.16450	40
3.00	depth 43 cm	0.0505	0.00999	8
	depth 28 cm	0.2554	0.03281	8
	between wheels	0.0359	0.01402	8
	depth 13 cm L	0.3141	0.06083	8
	depth 13 cm R	0.4519	0.10218	8
	total	0.2215	0.16952	40
4.00	depth 43 cm	0.0572	0.01069	8
	depth 28 cm	0.2542	0.01960	8
	between wheels	0.0355	0.00746	8
	depth 13 cm L	0.4340	0.04526	8
	depth 13 cm R	0.4367	0.07729	8
	total	0.2435	0.18072	40
Total	depth 43 cm	0.0593	0.01006	32
	depth 28 cm	0.2693	0.03885	32
	between wheels	0.0438	0.01280	32
	depth 13cm L	0.3885	0.06887	32
	depth 13 cm R	0.4374	0.08092	32
	total	0.2397	0.17124	160

L – left wheel, R – right wheel, SD – standard deviation, N – number of drives

The two-way ANOVA results showed significant differences in the mean maximum pressure in the geotextile treatments and also between the different experimental points. In addition, a significant interaction was observed between treatments (Table 4).

Comparison of the average pressure of each of the treatments generally showed that there is a significant difference between the pressure of the treatment with dimensions of 5 × 5 cm and other treatments, and that this treatment was able to significantly reduce the pressure of the truck traffic on the road (Fig. 5).

Mean comparison of the treatments showed that the geotextile with vertical and horizontal structure and dimensions of 5 × 5 cm exerted the lowest pressure on the lower layers compared with the other treatments and there was a significant difference between the value of this treatment and the other

Table 4. Results of ANOVA and the effects of treatments and their interactions on soil pressure (MPa)

Source	Type III sum of squares	*df*	Mean square	*F*	Significance
Corrected model	4.434*	19	0.233	143.157	0.000
Intercept	9.189	1	9.189	5,637.240	0.000
Treatments	0.019	3	0.006	3.802	0.012
Depth sensors	4.257	4	1.064	652.875	0.000
Treatments × depth sensors	0.158	12	0.013	8.089	0.000
Error	0.228	140	0.002		
Total	13.852	160			
Corrected total	4.662	159			

*R^2 = 0.951 (adjusted R^2 = 0.944), *df* – degree of freedom

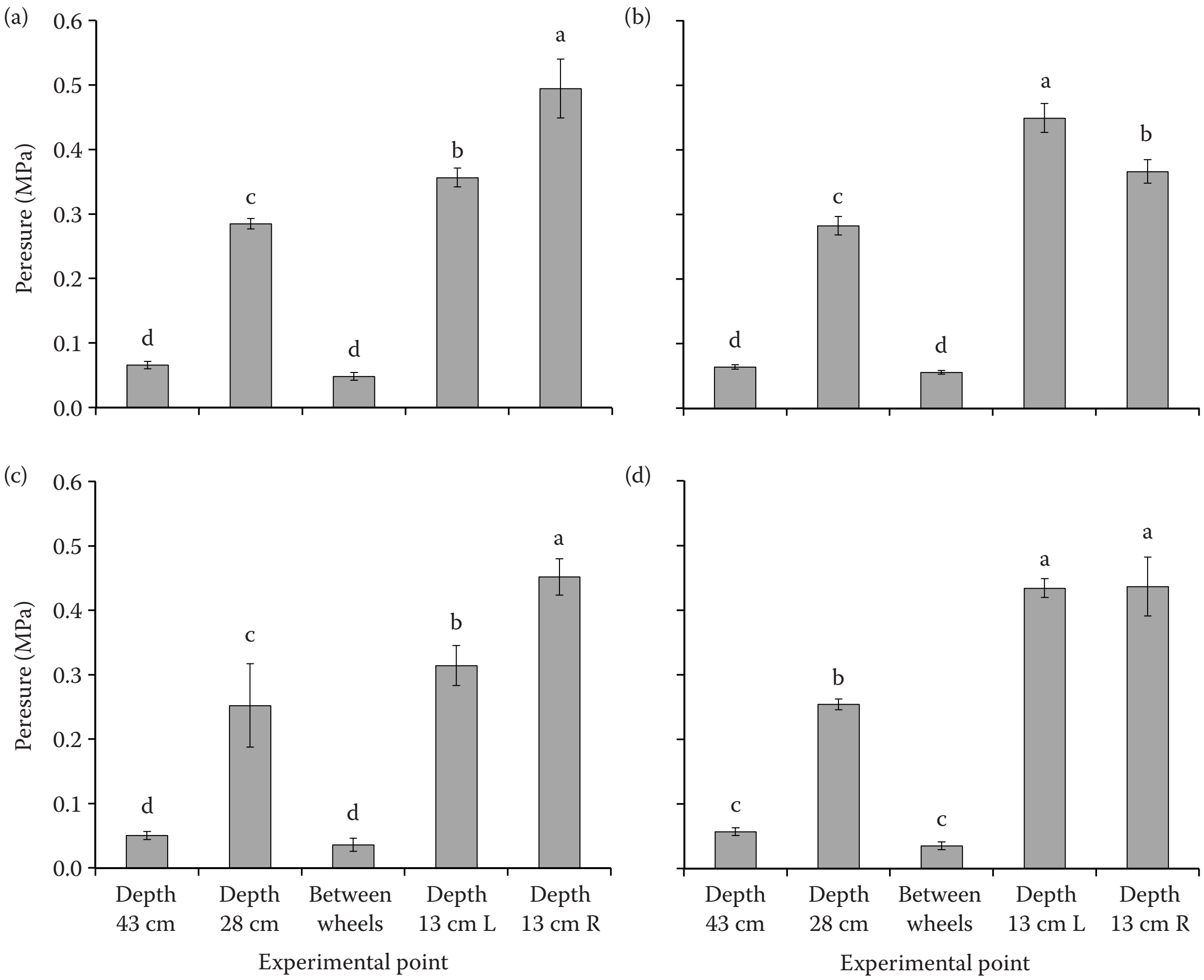

Fig. 5. Comparison of the mean pressure at various points in each of the studied treatments: without geotextile (a), with geotextile horizontally (b), with geotextile 5 × 5 cm (c), with geotextile 10 × 10 cm (d)

L – left wheel, R –right wheel

treatments, while no significant difference was observed in the amount of pressure from the other treatments. However, the pressure values in the treatment with the geotextile with vertical and horizontal structure and dimensions of 10 × 10 cm were lower than for the other two treatments (Fig. 6).

In examining the interaction between the treatments, the results showed that the maximum pressure was under the right-side wheels in the treatment without geotextile, and the lowest pressure was exerted in the treatment with horizontal geotextile, while between the two groups of combinations (5 × 5 and 10 × 10 cm geotextile) there was no significant difference. The greatest pressure was under the left wheel in the treatments with horizontal geotextile and 10 × 10 cm, and on the other hand,

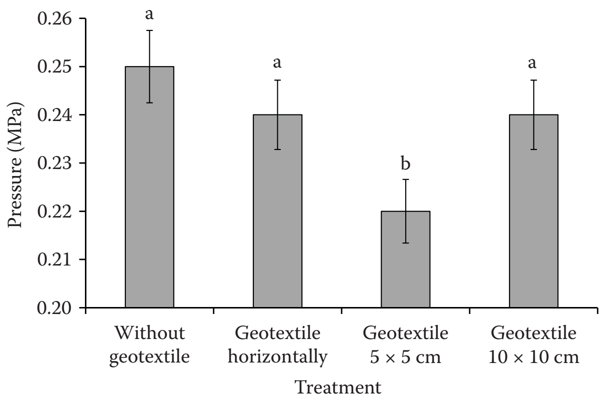

Fig. 6. Average pressure on all points in each of the studied treatments

the minimum pressure was recorded in the geotextile with 5 × 5 cm dimensions. No significant difference between the two wheels was observed in the treatments, although the pressure recorded for the treatments without geotextile and horizontal geotextile was greater than the rest. At a soil depth of 28 cm, the greatest pressure was in the treatments without geotextile and with horizontal geotextile. The exerted pressure of these two treatments was significantly higher than in the other treatments. At a depth of 43 cm, the horizontal geotextile treatment and the treatment without geotextile exerted a higher pressure on the soil, but in comparison with the 5 × 5 and 10 × 10 cm geotextile, the values were not significant (Fig. 7).

DISCUSSION

Machinery traffic on forest roads exerts pressure on the pavement layers and this transfer of pressure to the pavement materials will cause these layers to deteriorate early. Geotextile provides a protective layer and has a sustainable role in reducing the pressures on the forest road pavement. Geotextile layers as a preservative and with an environmentally friendly role are important in reducing the pressures on forest road pavements and their use in forest road construction has been suggested. Several studies have been carried out on the role of geotextiles in forest road construction (Douglas, Kelly 1986; Hausmann 1987; Latha, Nair 2014). But less attention has been paid to the composition of the structure of the layers. In this study, four different modes were studied, including without geotextile layers, with horizontal geotextile, and with horizontal and vertical geotextiles with dimensions of 10 × 10 and 5 × 5 cm. The use of geotextile layers showed a decreasing trend in pressure. The reduction in pressure in the 5 × 5 cm treatment was significantly greater than in the other treatments, although the 10 × 10 cm horizontal layers also had an impact in reducing the pressure on the pavement, although this was not significant. Comparison of the pressure exerted on the various points in all treatments showed the highest pressure at the left and right wheels and at a depth of 28 cm, while at the depth of 43 cm between the two wheels, the pressure was the lowest. The results showed that the pressure exerted by the wheels on the road was distributed to the lower layers. The highest pressure was exerted on the central axis of each wheel and the lowest pressure was between the two wheels. But in the lower layers for example at a layer of 28 cm, a lot of pressure was exerted. One of the major failures of forest road surfaces is deformation during the operation season. Where a part of the pavement is lowered from the rest of the pavement, generally, there are swelling and pressure on the underlying layers of the pavement outside this area, as well as inadequate compaction of the layers. That

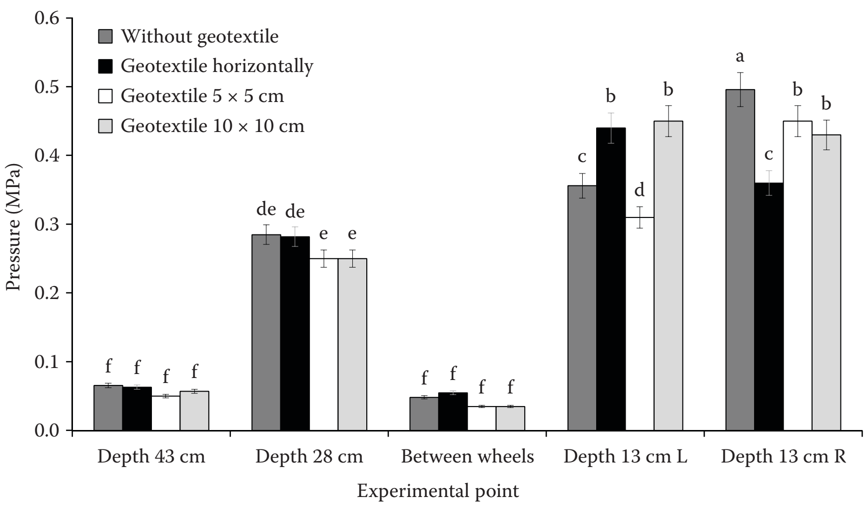

Fig. 7. Comparison of the mean pressure on different points in every studied treatment

L – left wheel, R –right wheel

is why the lower layers (28 and 43 cm) must have a better distribution of loads and pressures as well as they should create a flat surface. Therefore, the design should improve the soil structure and soil gradation and increase the strength of the soil. The results show that horizontal and vertical geotextile at a depth of 28 cm performs better than the other structures, while at a depth of 43 cm, the pressure difference becomes significant.

CONCLUSIONS

The findings of this study showed that:

(*i*) Geotextile with vertical and horizontal structure provides a reduction in stresses during the transmission of wheel loads along the structural layers, the stable operation of the surface, allows reducing the thickness of its layer and expenses for road construction materials;

(*ii*) Horizontal and vertical geotextile can be used as a structural layer that can play an important role in determining the thickness and capacity of the upper layers, reduce the deposition rate and the subsequent increase of the holding period, and also reduce costs;

(*iii*) Geotextiles with vertical and horizontal structure with dimensions of 5 × 5 and 10 × 10 cm are recommended for forest road surfaces, while the best strength parameters of the surface being provided by interlayers with 5 × 5 cm vertical strips.

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