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INFLUENCE OF PAVEMENT MOISTURE CONTENT ON THE LOAD-BEARING CAPACITY OF FOREST ROAD

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Abstract

The aim of the study was to analyse the interaction between pavement moisture content and load-bearing capacity of an unpaved forest road. The selected experimental road sector was divided into three sections (A, B and C), which were flooded with three different amounts of water 10 mm (section A), 20 mm (section B) and 30 mm (section C), compared with the intense rainfall. Three series of tests were conducted at each section: prior to flooding (1^{st} day of measurements), during the first 24 hours after flooding (2^{nd} day) and during the next 24 hours after flooding (3^{rd} day of measurements). Moisture content of structural layers of the road (surface course, base course and subbase course) were determined and the measurements using a light weight deflectometer (E_{vd}, *s/v*) and a static plate (E_1, E_2, I_o) were conducted. Recorded averaged results clearly indicate a negative effect of an increase in pavement layers moisture content (e.g. resulting from heavy rainfall) on the forest road carrying capacity and on compaction parameters of its layers. On the third day of the measurements a decrease in the analysed modulus, on average between 16% (E_2) and 25% (E_{vd}) was observed, but a decrease in compaction by 16% (*s/v*) and 4% (I_o).

Keywords: light weight deflectometer, LWD, static load-bearing test, VSS, very low-volume roads

INTRODUCTION

Nowadays, roads play a key role in forest management. They make possible conducting the breeding, protection and fire-control activities, as well as the full utilization of the forest resources. Existence of an adequate road network determines a profitable timber extraction and its transport from the forest. Forest roads are usually characterized by low traffic intensity (Atończyk, 1989; Koczwański and Nowakowska-Moryl, 1992), which increases periodically, e.g. when heavy goods vehicles are used to transport timber. They have a considerable impact on the surface of the roads (Trzciński, 2011) and contribute to the degradation of road surfaces and the environment (Bień, 1987; Komorowski *et al*., 1990). The concept of road surface should be understood as a structure made of one layer or a group of layers used for receiving and load-balancing, providing suitable conditions for traffic (Czerniak *et al*., 2013).

In the State Forests National Forest Holding (State Forests NFH), managing 77.1% of almost 92 thousand km^2 of forest areas in Poland (Raport…, 2015), a vast majority of forest roads are unpaved or improved dirt roads (87%). Unpaved hard roads (such as gravel, crushed stone, slag) constitute about 14% of the total length of the forest roads. Paved roads (such as bituminous and concrete roads) constitute less than 2% of the total length (Trzciński, 2011). The surfaces made of subsoil reveal variable resistance to the impact of traffic, which is determined by the properties of the soil and the weather conditions. The dependence of the load-bearing capacity of roads on the moisture layers of the foundation and road surfaces is observed also for hard surfaces, especially when the designed elements of the surface and subsurface drainage of the road prove insufficient (Krarup, 1995).

It is known that the content of water in the unbound surface materials is an important factor affecting their mechanical properties (Erlingsson, 2010; Saevarsdottir and Erlingsson, 2013). The dependence of the state of the surface on the moisture of its structural layers and the road substrate was determined by laboratory tests (Thadkamalla and George, 1995), field experiments (Salour, 2015) and establishing experimental road sections (Roy *et al*., 1992; Wiman, 2001; Savard *et al*., 2005; Salour, 2015). It is worth noting, that in coarse-grained soil the elasticity moduli tends to reduce with the increase in moisture – up to about 20%, while in fine-grained soils the value can drop up to 50-75% (Thadkamalla and George, 1995). The coarse-grained soil is less dependent on moisture but also dries much faster and recovers the original capacity parameters (Stolle *et al*., 2009).

Recent studies conducted to improve the structure of the surfaces and methods of maintenance of roads with low traffic have shown, that in most cases the difficulties associated with designing and exploitation correlate with the excessive amount of water found in road substrate and substructure (Saarenketo and Aho, 2005; Aho and Saarenketo, 2006; Charlier *et al*., 2008; Laloui *et al*., 2008; Salour and Erlingsson, 2013b). This is a common problem in areas, where the surfaces are exposed to a larger amount of precipitation, significant fluctuation in the groundwater levels and the cycles of freezing and de-freezing (Salour *et al*., 2014).

Ground road surfaces, aggregate materials or the ground used to build the layers of the pavement structure have different physical properties, which can be extremely modified owing to the influence of temperature and humidity fluctuations. In this context, the information about the changes to the Earth climate is received with a growing concern, as the forecast is usually very negative for the road network (SOU, 2007; Bredefeldt, 2009; Li *et al*., 2011; Hudecz, 2012). The data for the territory of Poland have shown that the 12-year period (1991-2002) was distinguished by a clear increase in the amount of days with intense precipitation (e.g. for precipitation greater than 10 mm: an increase to 10 days/decade, for greater than 20 mm – 4 days/decade almost for the whole Poland) (Plakat, 2016). Hazards associated with this phenomenon will be the subject of thorough research in the future.

The aim of presented research was to determine the degree of reduction of the surface structure density parameters and load-bearing capacity of a forest road with hard unimproved surface, in the result of increasing the moisture content in the layers of the surface structure.

MATERIALS AND METHODS

The research was conducted in May 2014 on a main forest road with a hard unimproved surface, renovated 2 years previously. This road was a fire road no. 30 in the Świdwin Forest Division, Regional Directorate of State Forests (RDSF) in Szczecinek (Wisocki, 2014). A straight fragment of the road, characterized by a 0.5% decrease in vertical alignment of the surface and a bilateral decrease in transverse (Figure 1), was used as an experimental section. The section was divided into 3 subsections, 4.0-m long each, with a 1.5-m spacing between them (Figure 2a, 2b). The width of the section included the whole 4.0 m of the road. The research comprised:

- making 3 surface pits in the road axis to determine the thickness of the structural layers and the type of construction materials used,
- making 2 geotechnical boreholes to identify the types of soil lining the road substrate (PN-B-02480:1986) and to determine the depth of the groundwater table,
- collecting 80 samples of aggregate and ground to determine the moisture content of individual structural layers (surface course, base and

subbase course) and the road soil subgrade using the oven-dry method (PN-B-04481:1988; PN-EN 1097-5:2008),
- tests using a light weight deflectometer *LWD* (Zorn Instruments, ZFG 3000 GPS type with 10 kg falling weight) and one static plate sensor *VSS* (Prüfgerätebau GmbH, HMP PDG Pro type).

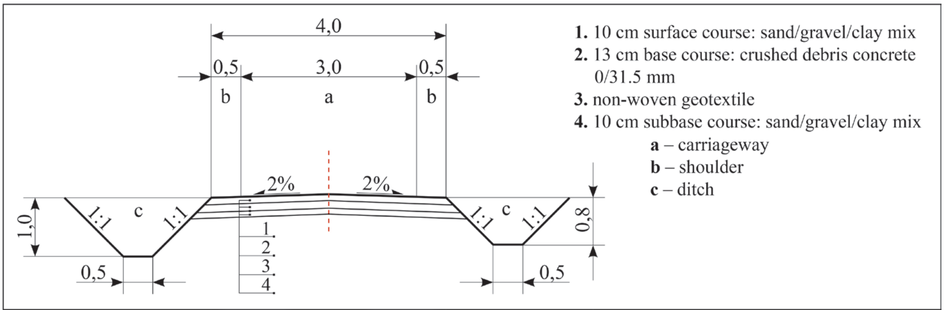

Figure 1. Cross section of the tested forest road

Samples of aggregate and ground (c.a. 0.2 kg each), used for moisture content assessment, were collected into sealed cylinders while making surface pits near the sites where measurement using the static plate were conducted.

Measurements and observations were carried out for 3 days (3 series of measurements were made). The results from the first day were used as a reference point for the subsequent second and third day of research, i.e. after morning flooding of all sections on the second day. The objective of the flooding was to increase the amount of moisture in the structural layers, therefore considerable amounts of water were used 10 mm (section A), 20 mm (section B), 30 mm (section C). In order to reduce the surface flow, the sections were divided into smaller parts with borders surrounded by the structure made of boards and sand dams. The method used to increase the level of moisture can be compared with the torrential rainfall. The used irrigation rates were used because a real threat of increasingly more frequent intense precipitations in this area (Lorenc *et al*., 2012).

Measurements of load-bearing capacity and degree of road surfaces compaction conducted by LWD plates were carried out following the methodology recommended by the manufacturer (Instrukcja…, 2014) and the Research Institute of Roads and Bridges in Warsaw (Szpikowski *et al*., 2005). The research comprised 8-9 measurements on each section, in each of the three measurement series. The value of a E_{vd} dynamic deformation modulus was determined and the *s/v* ratio, which is a degree of compaction measure, assuming that the tested layers' density is sufficient, if the value of *s/v* does not exceed 3 ms (Instrukcja…, 2014). The tests with a one sensor static plate were carried out in accordance with the provisions of BN-64/8391-02 and PN-S-02205:1998, i.e. two measurements on each analyzed section within each of the three measurement series. The primary (E_1) and the secondary value (E_2) were calculated the deformation modulus and the deformation ratio (I_o). The obtained research results were averaged and the results of the measurements made with the static plate referred to the indications from Kamiński (2012), Czerniak and Grajewski (2014) research.

Statistical data of the research results were elaborated using univariate analysis of variance for the value of E_{vd} deformation modulus and *s/v* compaction ratio (Dobek and Szwaczkowski, 2007).

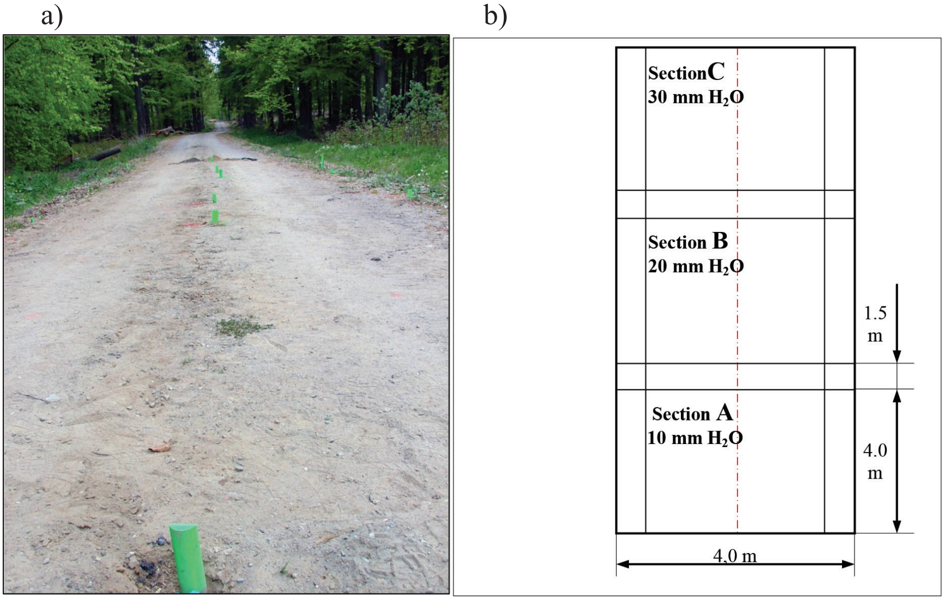

Figure 2. a) Experimental road section view (Photo S. M. Grajewski)
b) Diagram of research sections

RESULTS

The pavement structure consisted of a wearing course and a drainage layer for which a layer of soil has been used twice including – sand/gravel/clay mix with grain size: 20% of pebbles and gravel fraction, 77% of sand fraction, and 3% of clay fraction with the filtration coefficient $k = 2.5 \cdot 10^{-5}$ m/s (Figure 1). Loamy sand was found at the depth of 33-120 cm of the road surface (average moisture 9.0%), whereas below 120 cm sandy loam was spotted (average moisture 15.5%). A stabilization of the water table was recorded at 220 cm below the surface level (b.s.l.). Load-bearing capacity group of the road subgrade was established as G3 (Czerniak *et al*., 2013).

Variation in the moisture content in the surface layers was presented in Table 1. The values recorded during the first day (for the surface course and subbase course) and on the second day of measurements (for the subbase course) were significantly lower than the range quoted in the literature for optimum moisture w_{opt} for sand/gravel/clay mix (Wiłun, 2005). It is worth noting that on the second and third day the water content in the subbase course did not increase despite an earlier flooding, on the contrary – a decline in moisture content was observed in this layer (Table 1).

Table 1. Pavement layers moisture content [%] on the first, second (day after flooding) and the third studied day

Section	Surface course			Base course			Subbase course		
	1stday	2ndday	3rdday	1stday	2ndday	3rdday	1stday	2ndday	3rdday
A (10 mm H_2O)	3.3	8.1	7.6	4.1	4.2	6.2	5.1	4.9	4.2
B (20 mm H_2O)	3.6	10.2	8.3	4.6	6.4	6.8	4.0	3.9	3.2
C (30 mm H_2O)	3.9	11.1	9.3	5.2	6.6	7.2	6.8	6.6	5.0

The measurement results of the load-bearing capacity and density of the road surface on the first, second and third day were presented in Table 2. The measurements made with the dynamic plate showed an average 16% reduction in E_{vd} on the second day and a 11% reduction on the third. The amount of water used to flood the individual sections proved to be proportional to the final reduction of the dynamic modulus values. Analogously, the density of the layers described as *s/v* ratio was decreasing. The ratio value was increasing, respectively to 12% and 4% on the second and third day after flooding. However, considering the E_{vd} results obtained on the measurement days for respective sections, it may be seen that their reaction to the change of value after flooding varied, i.e. on the second day section A -2%, section B -23%, C -21%, while on the third day section B -3%, B and A -15%.

Flooding the section with 10 mm of water triggered a less drastic deterioration of the surface load bearing capacity in comparison to the two other water doses, where the surfaces responded with a significantly decreased E_{vd} and *s/v* density ratio already on the day of flooding (Table 3).

A decrease in the carrying capacity was confirmed by the VSS studies (Table 2). The expected decrease in the load-bearing capacity with the increase in delivered water was clearer for E_2 value. Changes in E_1 and I_o were not so obvious.

Similarly, the changes in the surface deformation – on average plastic deformations – were greater (Table 2).

Table 2. Measurement results of the load-bearing capacity and density of road pavement on the first, second (24 hours after flooding) and the third day(LWD – light weight deflectometer, VSS – static plate)

Measurement day	Research section	LWD*		VSS				
		E_{vd} [MPa]	s/v [ms]	E_1 [MPa]	E_2 [MPa]	I_o [-]	Strain [mm]	
							resilient	permanent
First	A	59.41a	2.69a	110	151	1.4	0.78	0.54
	B	55.64a	2.71a	113	174	1.5	0.76	0.41
	C	52.63a	2.67a	90	151	1.7	0.95	0.60
	Mean	**56.24**	**2.69**	**104**	**158**	**1.5**	**0.83**	**0.52**
Second	A (10 mm H_2O)	58.01a	2.90a	90	150	1.7	0.90	0.66
	B (20 mm H_2O)	42.95b	2.96ab	90	141	1.6	0.87	0.71
	C (30 mm H_2O)	41.38b	3.19b	90	145	1.6	0.87	0.62
	Mean	**47.45**	**3.02**	**90**	**145**	**1.6**	**0.88**	**0.66**
Third	A	49.20a	2.99a	82	141	1.7	0.85	0.75
	B	41.73b	3.05a	84	133	1.6	0.85	0.62
	C	35.24b	3.33b	87	126	1.5	0.89	0.55
	Mean	**42.06**	**3.12**	**84**	**133**	**1.6**	**0.86**	**0.64**

* sections marked with the same letters do not differ significantly ($\alpha = 0.05$)

Table 3. Differentiation of average E_{vd} and s/v for three consecutive days of studies

Feature	Measurement day	Research section		
		A*	B*	C*
E_{vd} [MPa]	First	59.41a	55.64a	52.63a
	Second	58.01a	42.95b	41.38b
	Third	49.20b	41.73b	35.24b
s/v [ms]	First	2.69a	2.71a	2.67a
	Second	2.90b	2.96b	3.19b
	Third	2.99b	2.99b	3.33b

* E_{vd} and s/v values marked with the same letters do not differ significantly ($\alpha = 0.05$)

DISCUSSION

The load-bearing capacity of the road surface varied and depended on the amount of moisture found in its structural layers, which is a derivative of the flooding. Despite this fact, registered absolute ranges of the primary E_1 values (from 70 to 113 MPa), the secondary E_2 values (from 112 to 187 MPa) of the deformation modulus and I_o deformation ratio (from 1.2 to 2.0) meet the minimum requirements for the forest roads in Poland (Kamiński, 2012; Czerniak and Grajewski, 2014). However, the decrease in the load-bearing capacity parameters, confirmed by the reduction of the averaged E_1 (-19%), E_2 (-16%), E_{vd} (-25%) values, especially during high traffic may lead to a damage of a road surface and shorten its exploitation time. The applied research method increasing the amount of moisture and a short time of observation did not allow for a full control of the functioning of a filtering layer made of gravel/sand/clay mix with a relatively low filter coefficient.

The research period was too short to observe a clear trend in the surface parameters reconstruction after flooding, especially since this process may be very slow – during the spring snowmelt it can last up to 3 months (Savard *et al*., 2005; Steinert *et al*., 2006) and does not always end with regaining all of its original values (Brodersen, 2013).

Presented research results show the inconsistency of the surface density measured with a light weight deflectometer (*s/v*) and a static plate (I_o). Although, in both cases a tendency to decrease the degree of the measured density layers with increasing moisture content was confirmed (on average respectively -16% and -4%), yet the range of (I_o) always fell within the limits of the allowable density level (≤ 2.2), while *s/v* value exceeded the threshold (< 3.00 ms) (in section C on the second day of measuring whereas in sections B and C on the third day). A similar situation has not been noted in the literature so far.

Presented pilot research should be continued to find out if the road structures subjected to radical moisture changes tend to fully regenerate their load-bearing capacity parameters, or whether a permanent decrease in their carrying capacity may be a consequence of i.e. periodic heavy rainfall.

In order to minimize and eliminate road surface damage, it is recommended to limit the use of or even close down the road sections when their structures have high moisture content. In order to accelerate the process of returning to the original road carrying capacity parameters it is necessary to maintain the efficiency of the draining equipment and keep the roadside vegetation in good condition, including overexposing the forest stands and tending the roadside trees (Czerniak *et al*., 2013).

CONCLUSIONS

1. The obtained research results confirm the negative impact of increased moisture in the structural layers of the surface, which is caused e.g. by heavy rainfall effect on the parameters of carrying capacity and density layers of the forest road surface.
2. In the light of the results of measurements by the light weight deflectometer done on the second day after the surface flooding, the road carrying capacity described by a dynamic modulus was 33% lower in comparison to the period before the flooding, whereas the *s/v* density value of the construction layers declined by 25%.
3. The researched load-bearing capacity and density indicators were getting worse with the increased amount of water used to flood the surface.
4. The results of the light weight deflectometer and the static plate measurements, generally coherent, in some cases differed making impossible a uniform assessment of the observed changes described only as values of parameters obtained from the measurements using the VSS plate.

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