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APPLICATION OF A GEOTEXTILE AND GEOTEXTILE SEMI-MATTRESS TO REINFORCE A LOW-BEARING CAPACITY SUBGRADE OF A FOREST TECHNOLOGICAL ROUTE ON A SWAMPY TERRAIN

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Summary

Construction of forest roads on swampy terrains poses many problems and is expensive, therefore the Authors compared the method so far used to achieve road passability owing to the application of rubble with a modern method, where the main element is a geotextile with a track reinforcement of additional fibres. In the presented experiment the geotextile was embedded into the surface structure as a flat layer or as a semi mattress and covered with variously grained sand or crushed granite. Four variants of the surface construction obtained in this way with additionally established reference stretch of the rubble surface were tested using a light weight dynamic deflectometer (LWD) before and after rainfall. The obtained results demonstrated an approximate bearing capacity of the road surface in the tested technologies, clearly exceeding bearing capacity of the reference stretch of road. The rainfall caused a decrease in bearing capacity on all tested sections, however, the greatest decrease of bearing capacity was observed on the reference stretch. The tested technologies do not allow to achieve road surface bearing capacity suitable for the heavy vehicles carrying timber, but they may provide the base layer for this type of roads or form an independent surface on forest technological routes (so called permanent logging routes) used e.g. for logging and hauling of timber.

Keywords: forest technological routes, surface bearing capacity, geotextile, swampy areas, light weight dynamic deflectometer test

INTRODUCTION

Forest roads in the State Forests National Forest Holding (State Forests NFH), due to the functions they fulfil are divided into strategic, main, side roads, access roads and technological routes. Especially in recent years the administration of the state forests allocates considerable funds on construction, modernisation and repairs of forest roads. Still, the needs in this area are still great and concern all kinds of forest roads.

Road construction in swampy areas is difficult for at least two reasons. Firstly, because of a high cost of realization of this type of investment on the terrains with a low-bearing capacity subgrade, usually formed by hydrated organic soils of considerable thickness. Secondly, particularly in protected ecosystems, a very important aspect is disturbing their natural biological and hydrogeological continuity by road structures in result of soil replacement or drainage of the roadways.

It seems that in this situation it is possible to limit the costs and reduce human interference in the natural environment by the application of geosynthetics. Because of a large variety of materials with different or sometimes similar technical properties available on the market, their application must be well-considered. It is crucial to determine the functions which a geosynthetic material should fulfil in the earth structure. Usually these functions include filtering, separation of various ground layers and their reinforcement (Gradkowski 2007). They may also comprise drainage and surface anti-erosion protection.

Presented paper aimed at the comparison of so far frequently used method to achieve road passability through the application of rubble with a new technology, whose main element is a geotextile with track reinforcement of additional fibres.

METHODS

Description of experimental section

Experimental stretch of road on which a geotextile with track reinforcement was used (type GeoLas, MD 30 $kN \cdot m^{-1}$ in track and 15 $kN \cdot m^{-1}$ in background, Photo 1) was set up, in cooperation with ViaConPolska Ltd., in autumn 2014 on the existing technological route in the area of Forestry Experimental Enterprise of the University of Life Sciences in Poznań, located in Siemianice. The track reinforcement relied on adding stronger fibres to the geotextile on the width of two vehicle tracks of trucks, which for the forest roads seems the most practical solution. The fragment of a forest road selected for the experiment was characterized by a very high groundwater level, temporarily appearing also on the surface, whereas the road surface was strongly hydrated subsoil partly covered by swampy vegetation.

Photo 1. Construction of the experimental stretch of road (Photo A. Czerniak) and a view of the experimental stretch on the day of measurement (Photo S. M. Grajewski).

The 100-m long experimental stretch of road was divided into 4 research sections of equal lengths (A – D, Figure 1). A different surface reinforcement variant was used on previously levelled ground surface of each research section, elevated by the road embankment (Table 1). Additionally, eight prototype transverse 80-mm diameter drains were installed in the body of the experimental stretch of road. The established experimental stretch adjoins a previously repaired road fragment, with which it was joined by a rubble embankment. Since this type of material is often used to achieve road passability in swampy areas, it was also included in the investigations (fifth section E) and treated as a reference stretch (Figure 1).

Section E	Section A	Section B	Section C	Section D

Figure 1. Layout of research sections of the experimental and reference stretch.

The established stretches of road are characterized by 2% transverse surface gradient and by 2% longitudinal gradient. Shallow location of the stabilized ground water table, combined with the presence of organic and cohesive soils indicate very difficult geotechnical conditions of the realization of this road investment (Table 1).

Table 1. Characteristics of the experimental stretch divided into research sections and the reference stretch (classification by PN-B-02480:1986: P_s – medium sand, P_g – loamy sand, P_π – silty sand, G_p – sandy loam, $G_{z\pi}$ – compact silty loam, I_π – silty clay, Zwg – level of stabilized water table, b.s.l. – below surface level).

Characteristics	Research sections of the experimental stretch of road				Reference stretch **E**
	A	**B**	**C**	**D**	
Section length [m]	25	25	25	25	221
Roadway width [m]	3.0	3.0	3.0	3.0	3.0
Type of roadside ditch	On one side				On both sides
Surface	18 cm crushed granite 0-31.5 mm 10 cm Ps geotextile laid flat	15 cm crushed granite 0-31.5 mm 13 cm Ps geotextile semi – mattress	30 cm Ps geotextile semi-mattress	30 cm Ps geotextile laid flat	5 cm Ps 40 cm rubble
	25 cm drainage layer of medium, variously grained sand (Ps)				
Estimated cost 100 mb [PLN]	14 300	15 000	9 000	8 300	33 300
Subgrade	25 cm moorsh 40 cmP_g/G_p >65 cm b.s.l.P_π	20 cm moorsh 10 cm I_π 30 cm P_g >60 cm b.s.l.$G_{z\pi}$	35 cm moorsh 20 cm P_g/G_p 15 cm I_π >70 cm b.s.l.P_π	30 cm moorsh 25 cm P_g/G_p >55 cm b.s.l.P_g	30 cm moorsh 30 cm P_g 15 cm $G_{z\pi}$ >75 cm b.s.l.P_π
Zwg [cm b.s.l.]	121	113	112	108	79

Preliminary research

Preliminary research involved situational measurements, making geotechnical boreholes, conducting levelling measurements and making twelve pits on the surface to determine the real thickness of construction layers (Table 1).

Further research

Further research was conducted at the beginning of May 2015 and comprised measurements of bearing capacity and soil compaction conducted by means of ZFG 3000 GPS (Zorn Instruments)light weight deflectometer (LWD).

The tests using light weight deflectometer were made in compliance with the methodology recommended by the manufacturer (Instrukcja… 2014) and the

Road and Bridge Research Institute in Warsaw (Szpikowski*et al.* 2005). Between 25 and 35 measurements were conducted on each of the five sections (A to E).

The measurements using the deflectometer were repeated because of a two-day rainfall of a total amount of 8.7 mm, which occurred during testing, therefore two series of data were obtained: before (A1, B1, C1, D1 and E1) and after the rainfall (A2, B2, C2, D2 and E2).

The measurements allowed to compute the values of the following parameters:

- the size of average surface deformation during a thrice loading of the light weight deflectometer plate (s),
- the surface settling velocity after each plate loading (v),
- the value of a dynamic module of the surface deformation (E_{vd})
- value of s/v.

In order to compare the obtained results with the recommended surface bearing capacity values for the forest roads in Poland (Kamiński 2012, Czerniak and Grajewski 2014), the value of the dynamic deformation model E_{vd} was converted into the secondary module of deformation E_2 using the following formula (Gradkowski 2008):

$$E_2 \approx 600 \cdot \ln \frac{300}{300 - E_{vd}} \tag{1}$$

Statistical elaboration of the research results

The parameters characterising the bearing capacity of the technological route for the individual research sections was analysed using the tools of multivariate analysis of variance for a two-way classification (level of significance 0.05 or 0.01, Seber 1980, Lejeune and Caliński 2000, Kayzer et al. 2011). The H_0: $\mathbf{C\Xi} = \mathbf{0}$ hypothesis was considered, where $\mathbf{C} = \mathbf{I}_{10} - \frac{1}{10}\mathbf{1}_{10}\mathbf{1}_{10}'$matrix, while $\mathbf{\Xi}$ presents the estimates of bearing capacity for individual research sections (from A to E) maintained under different weather conditions (before and after rainfall). On the other hand, $\mathbf{C\Xi}$ matrix represents the object data (i.e. average values of bearing capacity parameters for individual research sections under established weather conditions, diminished by average value for all sections). The canonical variate analysis (Lejeune and Caliński 2000, Kayzer et al. 2009, Budka et al. 2011) was used for graphic presentation of the results of multivariate analyses of the object data. In result of conducted canonical variate analysis procedure the relative position of the research sections under established weather conditions in Euclidean space was obtained. Additionally, it was tested whether individual research sections differ concerning their values of bearing capacity parameters before and after rainfall (level of significance 0.05 or 0.01).

Table 2. Differences in the bearing capacity parameters between the research sections under determined meteorological conditions.

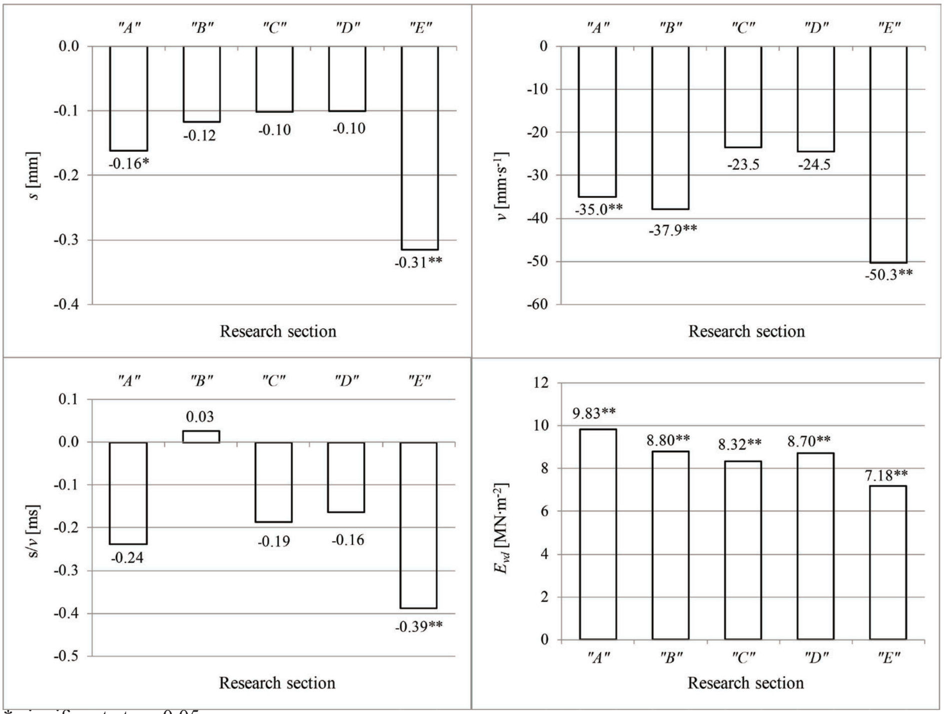
Difference	E_{vd} [MN·m^{-2}]	s/v [ms]	s [mm]	v [mm·s^{-1}]
A1-B1	-1.28	0.01	0.01	2.7
A1-C1	-3.12	0.36**	0.03	-8.7
A1-D1	-4.60*	0.32**	0.05	-1.1
A1-E1	13.35**	-0.34**	-0.28**	-62.3**
B1-C1	-1.85	0.35**	0.02	-11.4
B1-D1	-3.33	0.31**	0.04	-3.8
B1-E1	14.63**	-0.35**	-0.30**	-65.0**
C1-D1	-1.48	-0.04	0.01	7.6
C1-E1	16.48**	-0.70**	-0.32**	-53.6**
D1-E1	17.96**	-0.66**	-0.33**	-61.2**
A2-B2	-2.31	0.27*	0.06	-0.1
A2-C2	-4.64*	0.41**	0.10	2.9
A2-D2	-5.73**	0.39**	0.11	9.5
A2-E2	10.71**	-0.49**	-0.44**	-77.6**
B2-C2	-2.33	0.14	0.04	3.0
B2-D2	-3.42	0.12	0.05	9.6
B2-E2	13.02**	-0.76**	-0.50**	-77.4**
C2-D2	-1.09	-0.02	0.02	6.5
C2-E2	15.34**	-0.90**	-0.53**	-80.5**
D2-E2	16.44**	-0.88**	-0.55**	-87.0**

* significant at α =0.05
** significant at α = 0.01

RESULTS

Analysis of the comparisons between research sections from AtoD under specific meteorological conditions did not reveal highly significant differences between individual bearing capacity parameters (except *s/v* parameter) (Table 2). It may be noticed that the differences in the values of characteristics within different technologies using geotextile are nonsignificant.

On the other hand, an analysis of differences of characteristics between the sections of the established experimental stretch (sections from A to E) and the reference stretch, i.e. section E, revealed the significance of differences (Table 2). It should be emphasized that the research sections reveal more positive bearing capacity values than the reference stretch.



* significant at α =0.05
** significant at α = 0.01

Figure 2. Differences in values of analysed bearing capacity parameters determined before and after the rainfall for four research sections (A – D)and the reference stretch (section E).

While analysing the values of dynamic deformation model before and after the rainfall, it was found that they differ significantly on all research sections (Figure 2). Such unambiguity of differences was not noted for any of the remaining parameters.

A low *s/v* value noted before the rainfall denotes that only for the research sections A and B the compaction of the macadam road may be regarded as sufficient. A decrease in *s/v* value below the threshold of 3.0 ms observed on all sections after the rainfall qualifies them for the improvement of the compaction.

Analyses conducted to determine the values of bearing capacity parameters enabled a graphic presentation of relative positions of the individual experimental objects in the space of the two first canonical variables (Figure 3). It may be seen that the points representing research sections (A to D) before the rainfall are situated on one side of the ordinate, whereas the points describing the reference stretch (E) on the opposite. Location of the research sections is associated with relatively high values of the dynamic model of surface deformation (E_{vd}) and low velocities of surface settling (v) after each loading of the plate (Table 3). On the other hand, the changeability connected with the value of average surface deformation (s) during thrice dynamic plate loading and s/v value only to a lesser degree affects the research objects location (Figure 3).

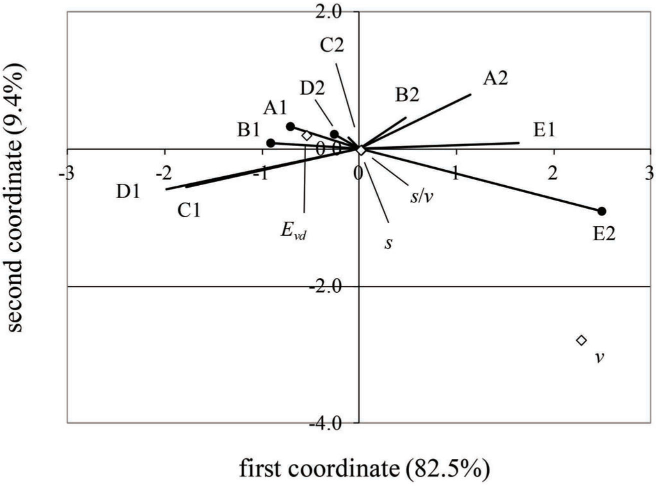


Figure 3. Distribution of the experimental objects in the space of two first canonical variables (e.g. A1 denotes the results obtained from research section "A" before the rainfall) and location of tested bearing capacity parameters in dual space (values of dual variables were multiplied by 0.1).

Table 3. Estimates of **CΞ** effects (differences between mean values of bearing capacity parameters from individual research sections under determined meteorological conditions and the object average value).

Experimental object	E_{vd} [MN·m^{-2}]	s/v [ms]	s [mm]	v [mm·s^{-1}]
A1	5.15**	-0.03	-0.12*	-31.0**
B1	6.43**	-0.03	-0.13**	-33.7**
C1	8.28**	-0.39**	-0.15**	-22.3**
D1	9.76**	-0.34**	-0.17**	-29.9**
E1	-8.20**	0.31**	0.17**	31.3**
A2	-4.68**	0.21*	0.05	4.1
B2	-2.37	-0.06	-0.01	4.2

Experimental object	E_{vd} [MN·m^{-2}]	s/v [ms]	s [mm]	v [mm·s^{-1}]
C2	-0.04	-0.20*	-0.05	1.2
D2	1.05	-0.18*	-0.07	-5.4
E2	-15.39**	0.70**	0.48**	81.6**

* significant at α =0.05
** significant at α = 0.01

DISCUSSION

The results obtained from the presented research demonstrated that applied technologies of road surface construction gave positive results, which indicates that they might be applied in forest conditions. It should be emphasized that obtained bearing capacity parameter values (including the secondary deformation model E_2 – Table 4) do not allow to provide the constructed road stretches for heavy vehicle traffic, e.g. to the timber hauling vehicles, they may only serve as technological routes – for logging and hauling of timber (Kamiński 2012, Czerniak and Grajewski 2014). The situation may be changed if the present surface layers were treated as the road base and reinforced by the subsequent layer or layers.

Table 4. Values of secondary deformation model E_2 [MPa] for research sections (A-D) and reference stretch (E) computed according to formula (1).

Measurementcondition	**Sections of the experimental road stretch**				**Reference stretch**
	A	**B**	**C**	**D**	**E**
Beforerainfall	107	103	99	96	65
Afterrainfall	86	84	78	73	49

Both the continuation of the research and observations on the established road stretches would be most advisable, because the expected difference of bearing capacity between the geotextile laid flat and rolled to the semi-mattress form was not reflected in the obtained results. It may be expected that only heavy road traffic would allow to see the differences.

CONCLUSIONS

1. The tested variants of road bases made with the use of geotextile revealed approximate bearing capacity values – no expected differences of surface bearing capacity were evidenced between the technologies using various variants of reinforcement with geotextile.

2. The technologies basing on geotextile revealed better parameters of surface bearing capacity of a forest technological route in comparison with the method of reinforcement with rubble.
3. Increase in moisture content after the rainfall resulted in a decrease in dynamic deformation module E_{vd} on all research sections by c.a. 20% (the greatest decrease was registered on the reference road stretch).
4. During the periods of increased soil moisture it is advisable to reduce the forest road exploitation.

REFERENCES

Budka, A., Borowiak, K., Zbierska J., Kayzer D., Krzesiński W. (2011). *Application of a multidimensional linear model to compare degrees of tobacco leaf injury caused by tropospheric ozone at rural and urban exposure sites*. Fresenius Environmental Bulletin 4, 969-975.

Czerniak A., Grajewski S. (2014). *Badanie nośności dróg – gwarancją solidności realizacji inwestycji*. Przegląd Leśniczy, 4, 10-12.

Gradkowski K. (2007). *Geosyntetyki w budowie dróg – zasady stosowania geosyntetyków o n-tym kierunku wzmocnień*. Inżynier Budownictwa, 7/8, 60-66.

Gradkowski K. (2008). *Efekt wzmocnień geotekstyliami gruntowego podłoża nawierzchni dróg – badania doświadczalne*. Drogi i Mosty, 4, 5-22.

Instrukcja obsługi lekkiego ugięciomierza dynamicznego ZFG 3000 (2014). Poznań:Merazet.

Kamiński B. (2012). *Badania techniczne dróg leśnych*. W: Jodłowski K., Czerniak A. (red.) *Nowoczesne technologie budowy dróg, mostów i przepustów leśnych*. Postępy Techniki w Leśnictwie, 119, SITLiD, Wyd. Świat, Warszawa, 47-51.

Kayzer D., Borowiak K., Budka A., Zbierska J. (2009). *Study of interaction in bioindication research on tobacco plant injuries caused by ground level ozone*. Environmetrics, 20, 666-675.

Kayzer D., Czerniak A., Poszyler-Adamska A. (2011). *Wpływ pierwiastków śladowych na parametry morfometryczne aparatu asymilacyjnego brzozy brodawkowatej*. InfrastrukturaiEkologiaTerenówWiejskich, 2, 261–273.

Lejeune M., Caliński T. (2000). *Canonical analysis applied to multivariate analysis of variance*. Journal of Multivariate Analysis, 72, 100-119.

Malkiewicz J. (2011). *Ocena geotekstyliów współdziałających z geogabionami w umocnieniach przeciwerozyjnych*. Nauka Przyr. Technol., 5, 4, #72.

PN-B-02480:1986 *Grunty budowlane. Określenia, symbole, podział i opis gruntów.*

Seber, G.A.F. (1980). *The Linear Hypothesis: A General Theory.* Charles Griffin, London.

Szpikowski M., Dreger M., Przygoda M., Dróżdż R., Dąbrowski M., Tokarczyk T., Har M., Mitrut M., Żuławnik P. (2005). *Badanie i ustalenie zależności korelacyjnych dla oceny stanu zagęszczenia i nośności gruntów niespoistych płytą dynamiczną*. Maszynopis, IBDiM, Laboratorium Geotechniki, Warszawa.

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