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A Structural Reinforcement Layer with Woodchips Used on Forest Roads

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Abstract – Nacrtak

Described biotechnical measures focus on the use of woodchips in the formation of a structural reinforcement layer on forest roads in the places with high levels of groundwater. These are often short sections of roads which can thus block off entire forests. In history, these sections were overcome using corduroy roads. Currently, there are tendencies to revive the biotechnical technology and replace logs used for corduroy roads with woodchips. This study investigates the possible reinforcement of a waterlogged section using woodchips in a forest road of multifunctional character, which serves for cycling as well as timber transport. In total, three different types of reinforcement were constructed using woodchips in combination with geotextile and crushed stone. The reinforcement was tested by common operations using a timber extraction tractor with tandem axle trailer. The modulus of deformation was measured on the surface and the deformation characteristics of the layer were determined. Subsequently, the shape of the reinforcement cross-section was surveyed. The results have shown that, even with very low modulus of deformation values, the shape of the reinforcement cross-section does not change statistically in two types of the reinforcement technology. These two types of reinforcement can be successfully used for forest roads that perform the recreational function or for timber transport by tractor. The main advantages are that renewable material is used and no extraction and moving of the ground occur during its production.

Keywords: Forest road, reinforcement, corduroy road, woodchips, waterlogging, trafficability

1. Introduction – *Uvod*

The reinforcement of forest roads is a broad issue that encompasses different solutions. An appropriate solution must take into account that forest roads need to meet the requirements of timber transport. The maximum pressures of the design vehicle (hauling machinery) axles on their surface are stipulated by valid regulations (axle – 10 t, driving axle – 12 t). Additionally, the economic aspect is important as forest roads are roads with a low intensity of transport and a variety of timber hauling vehicles. The suitable solution of the reinforcement of forest roads must incorporate both of these opposing requirements. Moreover, forest roads are used by the general public for recreational purposes. All in all, a forest road needs to be constructed so as to be economically acceptable in direct proportion with the revenues and costs of forest management, and at the same time, able to perform the recreational function. In this context, it is necessary to realize that forest stands are often located in terrains which are not suitable for road construction. The Czech Republic is characterized by broad valleys, basins, hills, highlands, and mountains. This fact is reflected in the process of landscape accessing, since 18.1% of the base soils are influenced by elevated amounts of water according to Buček and Lacina (1999) classification of hydric series. 15% of the Czech Republic territory falls into the 4th waterlogged hydric series, which is defined by an »additional« amount of water in periodically flooded areas in river alluvia. Excess of water can also be found in 3% of soils of the 5th wet hydric series. It is characterized by more or less permanently wet or muddy soils, the water table is high, in some periods may even reach the surface. Even in dry periods, only the top layers get dry. It is very difficult to build roads in such areas: avoid their caving in but also make sure the construction is economically viable with the technologies used.

Along with the development of means of transport and their increasing transport capacity, efforts have always been made to improve the load bearing capacity of forest roads and thus increase the amount of timber transported within a single route. The effort is understandable and well founded due to the fact that the timber harvest sites are often remote and difficult to access. The first attempts of road reinforcement appeared in about 4000 Before Christ in Great Britain (Lay 1992), when logs and poles were used to make corduroy roads. This type of reinforcement was especially used on sites with a low load bearing capacity affected by water, where putting the pole timber across the road created a wooden board which better spread the pressures of vehicle axles into an area. The presence of water prevents contact between air and wood and thus a faster decomposition of the pole timber. Even today, remains can be found of such roads from the 16th century, for example in Germany (Johnson 2014). Schmidt et al. (1997) investigated the physical and chemical properties of woodchips that were used 19 years ago to stabilize the road network in waterlogged areas in Minnesota. The samples for the research were collected from the road fill: the upper layer at a depth of 55 cm below the ground, and the lower layer at a depth of 150 cm. The woodchips had been closed with a layer of soil. The studied samples showed a low bacterial activity and the absence of mold. Though woodchips had different moisture holding capacities, their overall bulk density was essentially the same for locations within each site. The absence of fungal degradation was attributed to the lack of oxygen rather than limitations of pH, water, or nutrients. These data support the use of woodchips for lightweight fill of roadways in swamps. The authors concluded that woodchips preserved correctly are able to retain characteristics similar to new chips even after 19 years.

Currently, there are tendencies to revive the technology of wood use for the reinforcement of forest roads. Analogically, with the change from manual installation of stone pitching to machine installation of crushed stone, the manual installation of corduroy roads can be replaced with machine installation of shredded wood. The historical stone pitching technology was first replaced with a layer of coarse crushed stone by the Scottish builder John Loudon McAdam in 1816 (Makovník et al. 1973). He first crushed the stone mechanically, directly at the extraction spot, and then transported the crushed stone to the road subgrade as a reinforcement layer. In consequence, the technology of corduroy road construction was lost.

Most of the published studies dealing with the use of wood for the reinforcement of forest roads rather concentrate on the use of brushmats on forest routes during harvesting than on forest roads (Jakobsen and Moore 1981, Olsen and Wästerlund 1989, Owende et al. 2002, Labelle and Jaeger 2012). The effect of brushmats for the rutting depth reduction during timber transport has been proven, as well as the improvement of the load bearing capacity of soil with increased moisture content (Tufts and Brinker 1993). Sirén (2001) presented that many studies (McMahon and Evanson 1994, Cline et al. 1991, Brunberg and Nilsson 1988) had demonstrated that brushmats prevent great compaction of the stand soil, the soil damage, and related negative impacts on naturally rejuvenated stands. (Wronski et al. 1990, Bettinger and Kellogg 1993, Richardson and Makkonen 1994). McMullen and Shupe (2002) examined the issue of the temporary use of brushmats and corduroy roads on wetlands during the construction of pipelines and their subsequently required removal. They concluded that the removal of brushmats from wetlands and the disposal of the removed material, which is usually required by regulators, can create wetlands disturbance and are very expensive. Eliasson and Wästerlund (2007) stated that the weight of machinery used for harvest operations in the forest brings the risk of ruts and soil compaction and this risk increases especially in the event of adverse soil conditions. Labelle and Jaeger (2011, 2012) investigated the use of forest biomass from timber harvesting residues, which is often used during mechanized forest operations to improve trafficability of strip roads (machine operating trails). They mentioned that forest biomass is becoming increasingly important as a source of renewable energy. Using brush exclusively for biofuel will leave operating trails uncovered and can result in severe damage to forest soils. This may endanger the future use of this technology for road reinforcement, as the price of woodchips can climb up to the crushed stone price level. The use of woodchips to protect the road formation against erosion in the cut and fill slopes on rural roads has been described by e.g. Meyer et al. (1972). Other authors, George and Williams (1979), used woodchips for a coal hauling spur road where water sprinkling was the primary method of dust control. The duration of control was increased tenfold by covering the road surface with a layer of woodchips. Some of the newer publications mention the improvement of load bearing capacity in waterlogged sections of forest roads using logs and poles even in the present (Morris 1995, Wiest 1998, Sessions 2007).

The technology of using woodchips or wood mass for forest road reinforcement can be observed mainly in the USA, where it is often used for building forest trails and paths serving as reinforcement of waterlogged sites. Eberly (2004) presented a technology in which first the subgrade of a forest path is compacted, then 15 cm thick layer of brown chips is laid on, without a closing layer for air access restriction and easier passage. This layer is sloped as requested and compacted. At the sites with the highest waterlogging, anchored corduroy roads are built with a structural layer of brown chips. Trails and their parameters are primarily made for pedestrians, Automated Transfer Vehicles (ATVs), snowmobiles, cars, and small tractors, but not for heavy trucks. Dahlman et al. (2010) described alternative ways of wood use to make waterlogged sites in the forest accessible. Their work outlined many solutions. They described the use of logs, poles, boards, palisades, pallets, corduroy, brush, and woodchips. When woodchips are used for reinforcement, they recommend preventing the woodchip scattering by placing them on the geotextile. Blinn et al. (1998) applied only 15 cm layer of chips for forest road reinforcement. The authors stated that it is necessary to replenish the woodchips regularly. Chunk wood can have the same application as woodchips. Wiest (1998) devoted increased attention to the settling of the road formation and the appearance of ditches and culverts at bog sites. Woodchips are also mentioned, used as a coarse-grained filling material of a road base layer laid on the geotextile. The forest road is designed directly on the bog base without the peat being extracted. Instead of base concrete for the foundation of culverts, a combination of the geotextile, woodchips, and stakes is used. The main task of the woodchips is to make the construction of forest roads lighter. The US Federal Highway Administration (2016) provides information on making access to significant waterlogged and bog sites. They list access using geosynthetic materials, stone pitching, wood, and their combinations. In one of the solutions they use woodchips as a filler material for the pavement intended for barrier-free access to a waterlogged site. The road formation is always located above the groundwater level. The authors do not recommend constructing paths or roads with a surface made of smooth wooden boards for their slippery surface, shrinking, and the rise of knots. Russell (2015) stabilized forest roads on sandy soils using by-products of timber production. The stabilization presented was carried out using woodchips, shredded wood material, wood fibers, wood cuttings, sawdust, and raw wood waste. He also lists the possible use of waste from paper mills. However, the author stated that the shredded wood pushed out of the way did not lose its durability in the sandy environment even 27 years after its application. According to Bowman et al. (1987), woodchips were used as building material for forest roads in the fill of road formation to overcome a marshy section in the Chequamegon National Forest. Shook (1988) dealt with the use of shredded wood waste for the reinforcement of less load bearing forest soils. The technology was applied to sandy, wetland and waterlogged soils. Shredded wood was sized 1 to 15 cm, around 8 cm on average. The wood was prepared using a special machine called wood chunker on the site where it was then used. Especially after-harvest, remains were used so no material purchase or transport was needed.

Local waterlogging occurs in forest roads especially in the sections that are inappropriately routed, i.e. lead along the contour line, unreinforced, or have operational reinforcement only, and are at the same time affected by high levels of underground water. At times of high precipitation, the roads are heavily damaged by the passing vehicles or they are completely impassable. These sections can be short, but their condition can put the entire forest road system behind them out of operation. In the current practice, coarse crushed stone is usually used for waterlogged sections. This solution is cheap and simple. However, it is temporary and must be repeated. The aims of this study are to verify the possible replacement of the crushed stone by woodchips and to investigate their use as a natural and local material for the structural layers of reinforcement, in order to improve the trafficability and avoid material caving in the subgrade of forest roads in the places of their local waterlogging.

2. Material and methods – *Materijal i metode*

The construction took place in the territory of the Training Forest Enterprise Masaryk Forest Křtiny. The

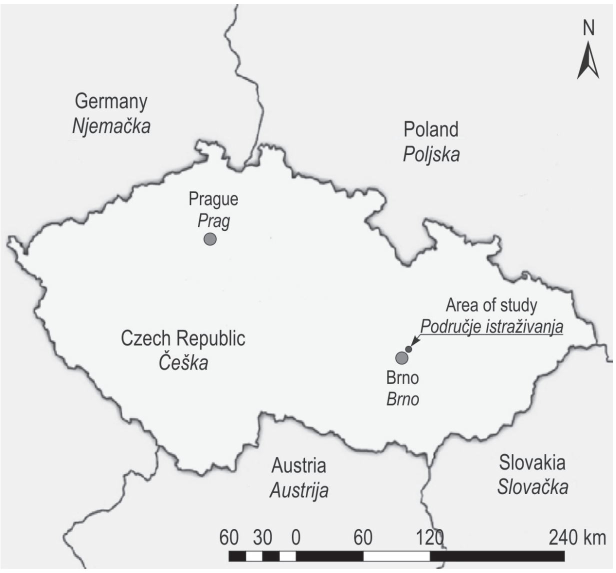


Fig. 1 Area of study (Forest district Nove Mesto na Morave)

Slika 1. *Područje istraživanja (šumski predio Nové Mesto na Morave)* forest road is located in cadastral area Jedovnice, southeast of the village Jedovnice behind the pond Olšovec (coordinates WGS-84 49.3270 N, 16.7853 E) (Fig. 1).

The forest road was in poor condition before the repair; the original reinforcement of the subgrade was completely missing and the very subgrade was damaged by ruts. The subgrade showed remnants of stone pitching reinforcement. No longitudinal drainage had been implemented (Fig. 2). A part of the road was waterlogged due to high levels of groundwater, as the forest road leads along a large marsh, which floods the road at the times of high precipitation. Due to the high water level in the marsh, water occasionally flows over the road formation at one point. The three test sections were constructed in this part of the forest road. Two samples of soil were taken from the forest road subgrade in the test section. Each sample was tested for the standard ratio of load bearing capacity (California Bearing Ratio – CBR) in compliance with EN 13286-47 – Unbound and hydraulically bound mixtures – Part 47. The resulting CBR was 8.0% and 8.5%, respectively. The optimum moisture content and consistency limits were set by the Proctor Compaction Test in compliance with EN 13286-47. The resulting values of CBR indicate that the subgrade given does not meet the required values for using the soil in the active zone of the road formation compliant to ČSN 73 6133; therefore, the soil would have to be modified or another solution should be proposed in order to increase the subgrade load bearing capacity, in the case of classical forest road reinforcement design. According to TP 170 Design of pavement structures (Ministry of Transport, Czech Republic 2004), the minimum value of CBR shall not drop below 15% for forest road surfaces in the VIth class of traffic load, which is the class of the present forest road.

Fig. 2 The original condition of the forest road

Slika 2. *Izgled dionice šumske ceste prije stabilizacije*

The presented technical solution uses a layer of brown chips together with the geotextile and a cover layer, which allows for better passage of cyclists, road vehicles and forestry machinery and mainly serves to close the layer of chips in order to reduce air access to the chips and prevent their disintegration. However, air access is also limited by the use of this technology in a waterlogged place – most of the year, chips are in contact with water preventing air access. Geotextile separates the layer of brown chips. As reported by, e.g., McDonald and Seixas (1997), Akay et al. (2007) or Han et al. (2009), the ability of a brushmat layer alone to resist vehicle passages decreases rapidly after 12 loaded forwarder passes. Then the brush gets broken, it is easily pushed into the ground and the layer mingles with the subgrade. In this case, the geotextile helps to keep a compact shape of the layer, as reported by Russell (2015).

In total, three types of reinforcement were installed in a length of 30 m each (Fig. 3). They differed by the way of subgrade leveling, the thickness of the brown chip layer, and the use of geotextile.

The first type was implemented as follows: the subgrade of the forest road was leveled and sloped into a roof-shaped transverse inclination of 3% with fine crushed stone of fraction 0/16 mm. Non-woven polypropylene geotextile with area mass of 300 g/m^2 was spread on the prepared subgrade in its entire width. A layer of brown chips, 200 mm thick, was spread (Fig. 4) and sloped into 3% transverse inclination by the grader and compacted by static pressure without vibration. It was covered with geotextile so that it totally enclosed the chips, i.e., including the edges of the woodchip layer (Fig. 5). Non-woven polypropylene geotextile with area mass of 300 g/m^2 was used again. This structure was covered with a cover layer of a total thickness of 150 mm. The cover layer must cover the chips and the geotextile even with the edges. The cover layer was formed in the following way: a layer of coarse crushed stone, fraction 32/63, was laid on the geotextile and two layers of crushed stone mixture of fraction 0/16 were gradually vibrated into it so that the thickness of the cover layer after compacting was 150 mm. The rule that fine crushed stone should not exceed 35% of the weight of coarse crushed stone was complied with; in this case it made up one third of the weight.

The second type of reinforcement using chips was installed similarly, except that the forest road with significantly damaged subgrade was leveled with a layer of chips, instead of fine crushed stone. The chips filled up the ruts and other bumps caused by vehicles. The

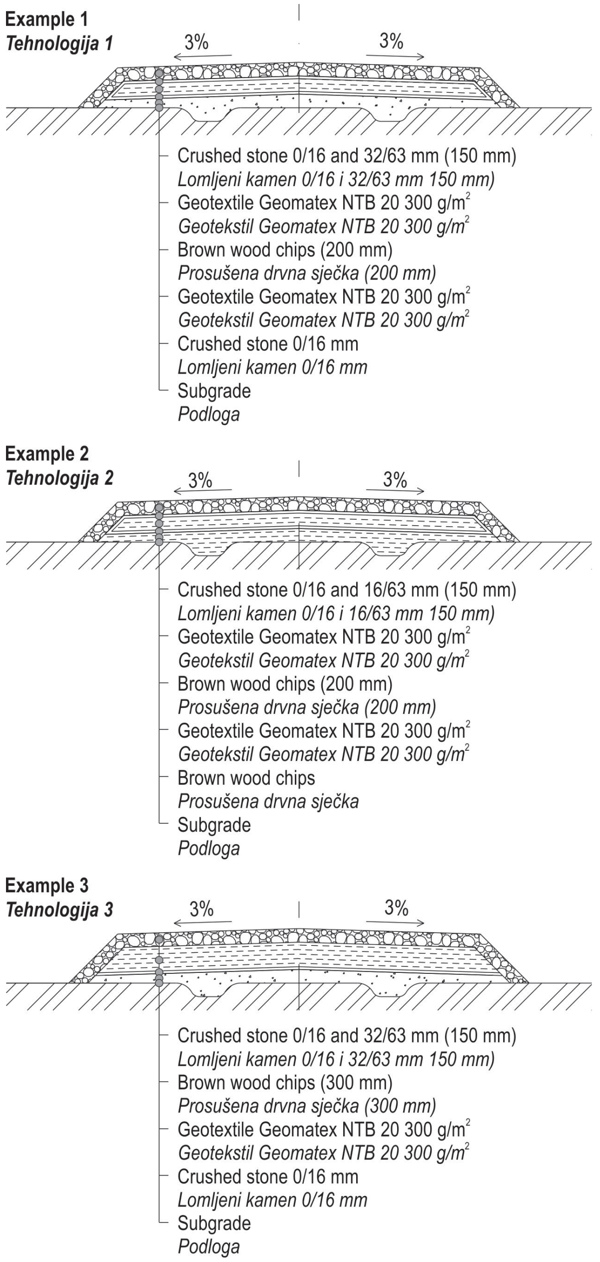


Fig. 3 A cross-section of reinforcement

Slika 3. *Izgled stabiliziranoga poprečnoga profila*

Fig. 4 Brown chips laid on geotextile and sloped and compacted subgrade

Slika 4. *Prosušena drvna sječka razasuta na geotekstil koji je položen na pripremljen donji ustroj*

Fig. 5 The layer of brown chips enclosed in geotextile

Slika 5. *Sloj prosušene drvne sječke prekriven geotekstilom*

leveling layer of brown chips was leveled and sloped into the roof-shaped transverse inclination of 3%. Non-woven geotextile with area mass of 300 g/m^2 was spread on it in the entire width of the subgrade and the desired length. The following stages of the technology are the same as in the first example.

The third type of reinforcement technology using chips was implemented at the beginning similarly to the first type, in which the subgrade was leveled and sloped into 3% roof-shaped transverse inclination with a leveling layer of fine crushed stone of fraction 0/16 mm. Geotextile was spread on the prepared subgrade in its entire width and then covered with a layer of brown chips, 100 mm thicker than in the previous cases, i.e. 300 mm thick. The layer was spread and sloped to the desired 3% transverse inclination by the grader and compacted by static pressure without vibration; as opposed to example 1, no geotextile was used to separate the woodchip layer from the cover layer. The cover layer was installed similarly to the previous cases (Fig. 6).

For the purpose of comparison and evaluation, each type of reinforcement was tested by static load test for its deformation characteristics using the mod-

Fig. 6 The implemented reinforcement using brown chips with a cover layer of vibrated gravel

Slika 6. *Dionica šumske ceste stabilizirana prosušenom drvnom sječkom sa nevezanim gornjim ustrojem izvedenim od lomljenoga kamena*

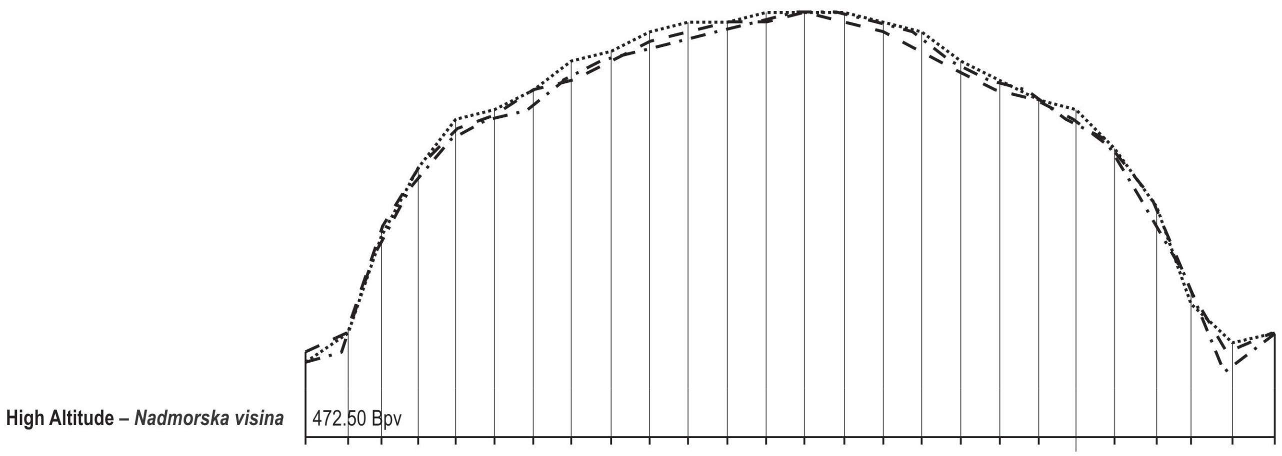
ulus of deformation from the second load cycle ($E_{def,2}$) and the ratio of the modulus of deformation between the second and the first load cycle ($E_{def,2}/E_{def,1}$), which serves to check the compaction. The static load test is performed according to ČSN 72 1006 Inspection of compaction of soils and fills, and is used for fills of coarse-grained materials and fine-grained soils with a rigid to solid consistency, i.e. unbound layers; the soil or crushed stone grains directly under the circular loading plate must not be larger than 25% of the plate diameter. Although a part of the crushed stone was replaced with woodchips in the technology presented, finally this structural layer performs the same role as the classical reinforcement layer consisting of crushed stone only. For this reason, static load test compliant to ČSN 72 1006, Annex A – Test for Transport Structures, was used to establish the modulus of deformation from the second load cycle ($E_{def,2}$) and the ratio between the second and the first load cycle ($E_{def,2}/E_{def,1}$) in the particular types of presented reinforcements. The measurement was conducted using ECM-Static, which serves for semi-automatic measurement of deformation parameters and check of static load bearing capacity of compacted fills. It consists of a circular load plate of 300 mm, a tensometric power sensor, an optoelectronic linear track sensor, which is located in the measuring beam, the hydraulic loading system, and the electronic part of the device (Fig. 7).

Fig. 7 Static load test for the detection of deformation characteristics

Slika 7. *Ispitivanje statičkoga opterećenja radi utvrđivanja deformacija*

In the context of evaluation and comparison of individual types of reinforcement, we monitored whether the cross profiles of each type of reinforcement changed in height. Two cross-sections were marked in each test section in regular distances for their tachymetric survey, in total six sample cross-sections. The cross profiles were marked by geoharpons so that the tachymetric measurements could be repeated and the height changes of the reinforcement cross-sections could be detected. The first measurement of the shape of cross-sections is considered the reference; then, repeated measurements were done twice in regular two-month intervals. At the same time, the number of passages and the machinery types that moved in the test sections were recorded. Each cross-section was surveyed with the total station Trimble M3 in regular distances, every 20 cm in each cross profile; i.e. 40 height control points were measured within a single measurement in each test section in two cross-sections. The geodetic survey of the control points for the connection of the tachymetric measuring in the S-JTSK coordinate system and the height system Baltic Vertical Datum – After Adjustment was carried out using the GPS receiver Topcon Hiper Pro. The cross profiles were subsequently created in AutoCAD Civil 3D, where the height of each measured point of the cross profile was recorded in absolute coordinates of the Baltic vertical system (Fig. 8).

The measured values were subsequently statistically processed in Statistica 12, where the statistical hypothesis that within measurements repeated over time there is no statistically significant change in the shape of the cross-section with the confidence level $\alpha = 0.05$ was verified using the analysis of variance (ANOVA). The differences in height of the particular measurement points were compared, the values from the second and third measurements being compared with the first reference measurement, and for each section separately. The results of the ANOVA and the static load test were used to compare the individual types of reinforcement and select the most suitable solution.



1. Measurement, m *1. mjerenje, m*	472.95	472.98	473.08	473.15	473.20	473.21	473.23	473.26	473.27	473.29	473.30	473.30	473.31	473.31	473.31	473.30	473.29	473.26	473.24	473.22	473.21	473.17	473.11	473.01	472.97	472.98
2. Measurement, m *2. mjerenje, m*	472.95	472.98	473.07	473.14	473.18	473.20	473.21	473.24	473.26	473.27	473.28	473.29	473.30	473.31	473.31	473.30	473.28	473.25	473.24	473.22	473.19	473.16	473.09	473.02	472.95	472.98
3. Measurement, m *3. mjerenje, m*	472.96	472.99	473.09	473.15	473.19	473.20	473.23	473.24	473.26	473.28	473.29	473.30	473.30	473.31	473.30	473.29	473.27	473.25	473.23	473.22	473.20	473.17	473.11	473.02	472.96	472.98
Horizontal distance, m **Horizontalna udaljenost, m**	00.00	00.22	00.39	00.58	00.77	00.97	01.17	01.37	01.57	01.77	01.97	02.17	02.37	02.57	02.77	02.97	03.17	03.37	03.57	03.77	03.96	04.16	04.38	04.55	04.77	04.99

Fig. 8 An example of a changed shape of the cross-section, including height changes in particular measurement points for the first type of reinforcement using woodchips

Slika 8. *Promjene u izgledu poprečnoga profila pri prvoj tehnologiji stabilizacije*

The forest road, where the test sections are located, is mainly used for recreational purposes and only occasionally timber transport. The changes over time were monitored during the improvement cutting of the surrounding stands for four months. The timber was transported by Zetor Proxima 8541 tractor with tandem axle trailer BSS 8. The total allowed trailer weight is 12 t with a loading capacity of 8 t. The number of tractor-trailer passages during the first two months of monitoring, in the period of May – June, amounted to 19 with the total quantity of 152 m^3 of transported timber; in the second monitoring period, in July – August, there were 14 passages with the total quantity of 112 m^3 of hauled timber.

3. Results and discussion – *Rezultati s raspravom*

Statistical processing of the results shows that with the mentioned timber extraction tractor technology there is no statistically significant change in the shape of the cross profile over time as regards the reinforcement technology types 1 and 3. Type 1 with a 20 cm layer of woodchips and both-sided enclosure in the geotextile achieves the best results. This solution proves to be more efficient than the solution with a higher layer of woodchips (30 cm) but without the geotextile separating the cover layer from the woodchips, although the difference is not large, as proven by the results of statistical processing, in which the p-values are 0.12458 for type 1 and 0.09103 for type 2. It turns out that the enclosure of chips including the edges and the formation of a sleeve-shaped body keeps the layer more compact. Russell (2015) reported similar findings. Comparing the deformation characteristics established by the static load test, the modulus of deformation values in both types are virtually the same, reaching $E_{def,2}$ = 14.3 MPa and $E_{def,2}$ = 13.4 MPa, respectively. These values are relatively low, but with respect to the results of the ANOVA, it is clear that the whole reinforcement system returns as much as possible back to the original position after the hauling machinery passes. The investigation of the shapes of the curves of individual measurements when printed over each other (Fig. 8) shows that this is not an overall decline in the layer height in each measurement, but a combination of the reinforcement surface decline and rippling. The compaction rate as a ratio of the moduli of deformation from the second and the first load cycle is $E_{\mathrm{def,2}}/E_{\mathrm{def,1}}$ 1.74 and $E_{\mathrm{def,2}}/E_{\mathrm{def,1}}$ 2.79, respectively, for the two types of reinforcement. Standard ČSN 73 6126-1 Road building – Unbound courses – Part 1: Construction and conformity assessment, stipulates the requirement for the modulus of deformation $E_{\mathrm{def,2}}/E_{\mathrm{def,1}}$ to be 2.5 at maximum, so only the first type of reinforcement fully meets the requirement. The higher value in the third type of reinforcement can be attributed to the missing geotextile between the woodchip layer and the cover layer, as the woodchips partially mix with the crushed stone. However, this proves to be an advantage when this technology is applied to places where the waterlogging alternates with periods of subgrade drying up. In such cases, the cover layer laid on the separation geotextile in the first type of reinforcement can get cracked by the drought or even break and slide over the geotextile to the side if the cross slopes are too steep. The cover layer proves to be an integral part of the entire reinforcement system. It eliminates the problems by passing over the woodchips alone. Eberly (2004) reported poor adhesion of wheels with woodchips in bad weather and loss of material caused by wheel acceleration – the layer is disrupted and woodchips are thrust to the sides. In this particular case, a thickness of 15 cm proved to be sufficient as opposed to data presented by Russell (2015).

By contrast, in reinforcement technology type 2, where woodchips were used instead of crushed stone to level the surface, the null hypothesis was not confirmed, the p-value is 0.00265. Based on the ANOVA, it can be concluded that there is a statistically significant change in the shape of the cross-section within repeated measurements over time. Additionally, the measured values of deformation characteristics are very low and the modulus of deformation from the second cycle of measurement $E_{\mathrm{def,2}}$ is 9.9 MPa. Even though visually no significant differences can be seen among the three types of reinforcement, the statistical results show that this type of reinforcement cannot be recommended. It turns out that a well prepared and properly compacted and sloped subgrade is crucial for each type of reinforcement. Woodchips applied straight to unprepared and not sloped subgrade have a very poor effect. This corresponds to findings presented by Han et al. (2009) as well as Akay et al. (2007).

The results show that the presented reinforcement method can serve as an alternative technology for forest road reinforcement, in particular for small forest owners, who grow forests mainly as a source of firewood and use mostly farm technologies to transport the harvested timber. Alternatively, it is recommendable for locations where the forest does not perform primarily the economic function, or for protected nature sites. However, it is always necessary to prepare the subgrade first properly, fill in the missing material, and slope it to the required transverse inclination, as well as enclose the chip layer into the geotextile. The advantage of this solution is that the use of wood reduces the crushed stone in the composition. It is advantageous in places with a lack of local sources of crushed stone and when the distance between the material and the construction site is great. To create this type of reinforcement, it is possible to use the wood at the construction site so in the case of forest roads the need for material transport is eliminated. This solution is particularly useful for waterlogged sections of forest roads, where it allows undamaging passage and the presence of water at the same time extends the life of wood in the road formation, as reported by Schmidt et al. (1997). Most of the authors, who are engaged in the use of wood for the construction of forest road reinforcement, use the technology of log corduroy roads (Morris 1995, Wiest 1998, Sessions 2007). However, this technology is historical and manual, therefore time-consuming and laborious. The proposed technology of using woodchips can be implemented by machines, using the common building machinery. It can also be said that it is a qualitatively higher technology than technology of brushmats on operation trails. Labelle and Jeager (2012) pointed out that, for effective load distribution, the branches used to compose the brushmats should have high plasticity and bending strength under loading. Gurau et al. (2008) reported that the average compression strength of Scots pine branches is 56% lower than that of the stem. As the used material in the technology proposed is shredded wood and not only harvest residues, analogically with the technology of crushed stone, the individual particles of woodchips get wedged when being laid and compacted and they form a mechanically contiguous construction layer. This type of reinforcement will improve the load bearing capacity of the roads used in particular for seasonal operations, i.e., those that are formed from road formation or reinforced with operational reinforcement, or those that have unsealed road surface. The main advantages of the use of wood for forest road reinforcement are that it is renewable and that there is no extraction or moving of the ground during its production.

4. Conclusion – *Zaključak*

The solution consists in the use of a layer of woodchips, which is installed with the geotextile inside the reinforcement structure. This technical solution to improve the load bearing capacity of forest roads is especially usable for multifunctional roads, which are not used primarily for timber hauling. From the perspective of implementation, the proposed solution is technically simple, efficient, and environment-friendly, feasible for small owners and road operators. It turns out that the reinforcement technology using woodchips is the most appropriate for forest roads that also perform the recreational function of the forest.

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Sažetak

Mogućnost uporabe prosušene drvne sječke pri mehaničkoj stabilizaciji donjega ustroja šumskih cesta

Tematika rada vezana je uz mogućnost uporabe biotehničkih mjera pri stabilizaciji donjega ustroja šumskih cesta na dionicama gdje je razina podzemne vode vrlo visoka, odnosno gdje dolazi do prekomjernoga vlaženja nosivoga donjega ustroja šumske ceste. Vrlo se često radi o kratkim dionicama koje usprkos svojoj kratkoći mogu otežati ili blokirati pristup većemu i/ili manjemu šumskomu kompleksu. U povijesti su se te problematične dionice šumskih cesta stabilizirale upotrebom višemetarskoga prostornoga drva, odnosno drvenim talpama. Trenutačno u svijetu postoji težnja osuvremenjivanju biotehničkih mjera radi zamjene višemetarskoga prostornoga drva, korištenoga pri stabilizaciji donjega ustroja kritičnih dionica šumskih cesta, prosušenom drvnom sječkom. U ovom je radu istraživana mogućnost stabilizacije kritičnih dionica šumskih cesta u uvjetima prekomjernoga vlaženja upotrebom prosušene drvne sječke. Da bi se utvrdile najbolje metode stabilizacije, u radu su testirane tri različite tehnologije stabilizacije kombinirajući upotrebu prosušene drvne sječke, geotekstila i lomljenoga kamena. Stabilizirane dionice šumske ceste, nakon izgradnje, podvrgnute su prometnom opterećenju nastalom tijekom uobičajenih radnih operacija u šumarstvu: sječa, izrada i privlačenje drvnih sortimenata. Mjeren je modul deformacije kolničke konstrukcije te su utvrđivana ostala svojstva oštećenja uočenih na pojedinoj mjernoj plohi. Naposljetku, promatrane su promjene u izgledu poprečnih profila. Rezultati pokazuju da se ni pri vrlo malim vrijednostima modula deformacija statistički značajno ne razlikuju promjene u izgledu poprečnoga profila kod dviju od triju testiranih tehnologija stabilizacije. Dobiveni rezultati upućuju na to da se dvije testirane tehnologije stabilizacije kod kojih ne postoji statistički značajna razlika u izgledu poprečnoga profila mogu koristiti pri stabilizaciji donjega ustroja na dionicama šumskih cesta koje su izložene prekomjernoj vlažnosti. Glavna prednost upotrebe takve vrste stabilizacije donjega ustroja šumskih cesta očituje se u činjenici da se primjenjuje materijal dobiven iz obnovljivoga izvora te da tijekom stabilizacije ne dolazi do iskopa i transportiranja slabonosivoga materijala koji se nalazi na kritičnoj dionici šumske ceste.

Ključne riječi: šumska cesta, stabilizacija, traktorski put, drvna sječka, provoznost

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