

Horizontal and Vertical Alignments of Forest Roads

Vladimir Petković, Dane Marčeta, Igor Potočnik

Abstract – *Nacrtak*

Forest roads should be in a condition to bear traffic load at every moment. They can endure traffic load only if their dimensions are within the limits prescribed. The dimensions of forest roads depend on: the soil type, category of forest road, and vehicles that use them. In this paper, forest roads constructed on two types of substrates (terrain category 3 and 4; Protić 1970) were observed, and dimensions of horizontal and vertical alignments of forest roads were determined. According to the results of this research, it was concluded that the state of forest roads is satisfactory in terms of traffic. However, it is necessary to pay attention to longitudinal slope of forest road carriageway and cross slope of carriageway in the curves that depend on the longitudinal slope of carriageway and radius of horizontal curve.

Keywords: forest roads, horizontal and vertical alignments, longitudinal slope, cross slope of carriageway

1. Introduction – *Uvod*

Forest roads make forests permanently accessible, and they change forests for a long time or forever. Construction of forest roads is the biggest project in the forest and allows for sustainable management of this natural resource. Forest roads are arteries in a modern forest, but also leave scars on the forest soil (landscape).

Forest roads are planned, designed, constructed and maintained facilities in the forest. The forest road is a formation in the forest, and it consists of:

- ⇒ longitudinal profile or a vertical section in the road centerline;
- ⇒ cross profile or cross section perpendicular to road centerline and;
- ⇒ layout of forest road (Jeličić 1983).

The basic element of longitudinal profile is the roadway longitudinal slope (%). It depends on many factors: type of forest road, type of vehicle that will be used, transport direction, soil on which a road is built, allocation of forest road, traffic load, rainfall, etc. Cross section is made in the station points of the forest road center line. Cross section of forest roads consists of: roadway, cut and fill slopes, shoulders, carriageway and drainage ditch.

Roadway consists of the carriageway width and the width of two shoulders. Forest roads are single-lane roads with minimum carriageway width of 3 m (Jeličić 1983). The cross slope of forest roads carriageway is one of the major elements of surface drainage, particularly in the sections of forest roads with small longitudinal slope. The value of the cross slope depends on: the forest road longitudinal slope, elements of forest road layout, radius of horizontal curves, type of material a carriageway is constructed of, surface roughness, as well as other factors. The type of drainage ditches depends on the type of soil. The slope of cut and fill slopes depends on the type of soil and height of slopes.

The elements of a forest road layout are lines and curves. The line is a part of forest road in where a vehicle does not change its driving direction. The curve is a part of forest road where a vehicle changes its driving direction for the central angle of a circular curve. Radius is the main element of the curve. The curve radius (R) should be larger from the perspective of driving safety and higher driving speed; and however, the cost of the road construction should also be taken into account.

Standard tree clearance width shall be a minimum of 15 m. Formation (road foundation) is the area between the usable limits of earthworks. Formation (roadway) width can be between 4 and 7 m. Carriage-

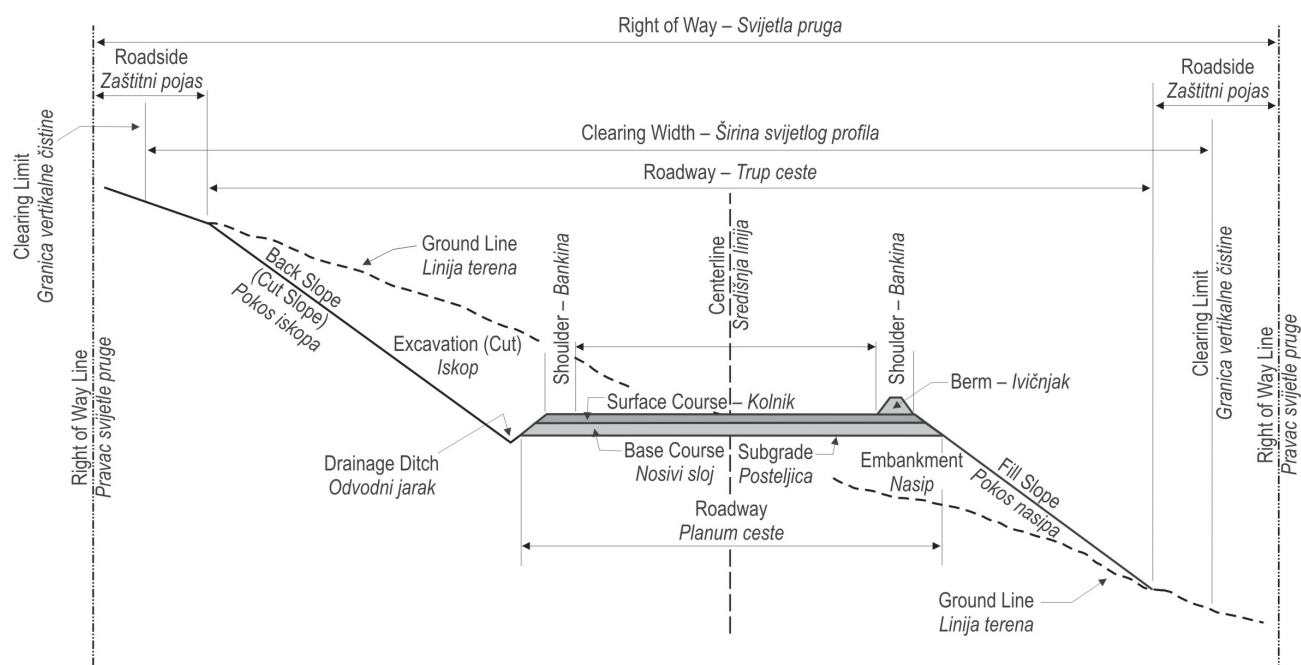


Fig. 1 Typical road section

Slika 1. Normalni poprečni profil

way width ranges from 3.4 to 4 m. Cross slope of the carriageway should be from 4 to 6.7%. Longitudinal slope of the forest road surface ranges from 1 to 10% in the straight sections and 8.3% in the forest road curves. The minimum radius of forest road curves is 20 m and naturally a larger radius should be used where possible considering physical and economic factors (Rayan et al. 2004).

The minimum longitudinal slope of forest road surface is 2%, and maximum longitudinal slope is 12% on compacted rock-surfaced roads. The minimum radius of horizontal curves is 50–60 feet (15–18 m) at the lowest vehicle speeds. Roadway (subgrade) width ranges from 14 to 16 feet (4–5 m), and carriageway (road surface) width is 12 feet (3.7 m). Carriageway widening (off-tracking) on curves is a function of the curve radius, curve deflection angle, and vehicle configuration. Log truck off-tracking on 60 foot (18 m) horizontal curve radius depends on the deflection angle (30–160 degrees) and can be 2–5 feet (0.6–1.5 m) (Kramer 2001).

Longitudinal slope of forest road surface ranges from 12% to 15%. Carriageway width is 3.5–4 m for single-lane roads and 5–7 m for double-lane roads. The minimum radius of horizontal curves is 15 m. The inclination of cut slopes is 3/4:1 (0.75:1), and of fill slopes 11/2:1 (1.5:1). Cross section slope of the carriage-

way ranges from 3 to 5% for longitudinal slope of forest road surface (Keller and Sherar 2003).

When determining the road design standard, the following factors are evaluated:

- ⇒ volume of traffic that will use the road at any given period of time and that will be expected to use the road over its duration;
- ⇒ type of vehicles that will use the road;
- ⇒ topography and soils where the road will be located;
- ⇒ duration of use (permanent, temporary, seasonal, or year around);
- ⇒ public use of the road;
- ⇒ sensitive natural resources that may be affected by the road;
- ⇒ future road maintenance requirements.

Design Standards for Collectors are permanent roads that access multiple logging units and may receive moderate use by the public during some parts of the year. Roadway width is 16 to 20 feet (5–6 m), and carriageway width should be 12–16 feet (3.5–5 m). Road carriageway is made of crushed rock. The minimum radius of the curve is 60 feet (18 m) plus curve widening. The longitudinal slope of the forest road surface is usually under 18% (12% max) (Forest Road Design 2006).

The studies done in 2009 in the Forest Management unit Prosara, on the example of deep soils (terrain category 3; Protić 1970), in the hilly area, showed that the average carriageway width was 3 m, average cross slope of the carriageway was 2.7%, and the longitudinal slope of the carriageway was 4.3% (Petković 2010).

The research was intended to indicate the state of forest roads from the aspect of dimensions of their horizontal and vertical alignments. It should also point to the problem of the lack of an official manual for regulating this part of the forestry profession.

2. Aim of research – *Cilj istraživanja*

This paper should determine the dimensions of forest road elements in the chosen Forest Management Units of »Prosara« and »Potoci–Resanovača«. After that, the obtained dimensions of forest roads should be compared between the selected sections of the same forest management unit and the two selected units. These units have different types of geological origin and soils. There are deep and soft soils in the Forest Management unit »Prosara« (hilly area), and shallow and hard soils in the Forest Management unit »Potoci–Resanovača« (mountainous area). The results of the research will be compared to the dimensions of forest roads determined by other authors.

3. Object of research – *Objekt istraživanja*

3.1 Forest Management Unit »Prosara«

Gospodarska jedinica »Prosara«

This management unit is located in the mountain »Prosara« in the north of the Republic of Srpska and Bosnia and Herzegovina in the area of the municipality of Gradiška. It is managed by the Forest Administration »Gradiška«. The average altitude of this management unit ranges from 103 to 357 m, and hence this is a hilly area. Geological substrate is made of silicate rocks. On this geological substrate, deep and acid soils are developed and their depth is more than 70 cm (terrain category 3; Protić 1970). Forest and forest land cover an area of 3 980 ha. High productive forests with natural regeneration cover the biggest area of 3 449.4 ha. Those are the forests of European beech and sessile oak. Coppice forests cover an area of 169.6 ha, and forest plantations cover an area of 279.9 ha. Areas suitable for forestation cover 74.4 ha, and areas unsuitable for forestation cover 7.3 ha. The length of public roads is 4 km, and the length of forest roads is 34.9 km. The average road density is 7.8 m/ha (Javno preduzeće šumarstva »Šume Republike Srpske« a.d. Sokolac 2013).

3.2 Forest Management Unit

»Potoci – Resanovača«

Gospodarska jedinica »Potoci–Resanovača«

This management unit is managed by the Forest Administration »Ribnik«. It is located in the northern part of the Republic of Srpska in the area of the municipality of Ribnik. The altitude of this management unit ranges from 695 m to 1 620 m, and hence this is a mountainous area. Geological substrate is made of limestone or dolomite. On this foundation, shallow and depth limestone soils are developed and their depth ranges from 30 to 75 cm with stones and rocks on the surface (terrain category 4; Protić 1970). Total forest area is 5 437.6 ha. High productive forests with natural regeneration cover an area of 5 161.6 ha. Those are the forests of European beech, Norway spruce and European silver fir. Coppice forests cover an area of 56.9 ha, and forest plantations cover an area of 62.4 ha. The total length of roads is 85.75 km. Forest road density is 13.9 m/ha (Javno preduzeće šumarstva »Šume Republike Srpske« a.d. Sokolac 2000).

4. Methods – *Metode rada*

4.1 Collecting data on the field – *Prikupljanje terenskih podataka*

Forest road network was recorded by GPS GARMIN GPSMAP 62st. It was divided in sections of 300 m. By the method of random selection, 5 sections of forest roads were selected in the Forest Management Unit »Prosara« and »Potoci–Resanovača«. Then, the selected sections were found on the field by GPS. These sections were marked on the field and points were set up for each 10 m, and three points were selected in the curves, the beginning of the curve (PK), the middle of the curve (SK) and the end of the curve (KK). The following parameters were measured in each point: roadway width B , carriageway width b , cross slope of carriageway i_p (%), slope of cut and fill slopes 1:u and 1:n, ditch depth and width, and distance between tree crowns (clearing width). Longitudinal slope of the road I (%) was measured between each point. Width and distance between the points were measured by the measuring tape. The slope was measured by the inclinometer.

In each curve, the beginning of the curve (PK) was measured as well as the middle of the curve (SK) and the end of the curve (KK). Then the distance was measured from the beginning of the curve (PK) to the end of the curve (KK). Half of this distance was the value x , and the distance from this point to the middle of the

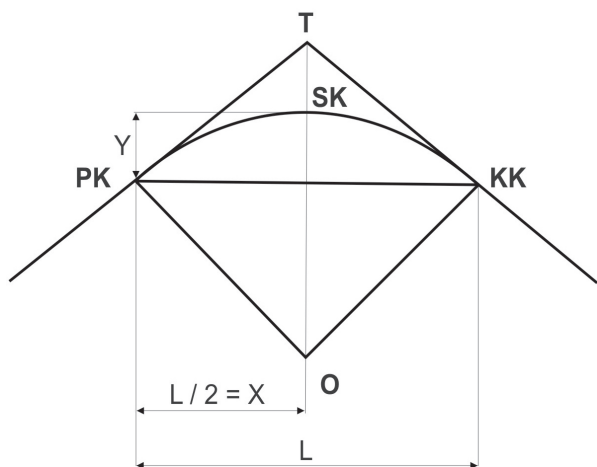


Fig. 2 Measurements of x and y value

Slika 2. Postupak izmjere veličina x i y na terenu

curve (SK) was the value y (Fig. 2). The radius of the curve is calculated by the formula:

$$R = x^2/2y$$

Legend:

R – radius of the curve m,

x – value m, half of the distance from the beginning to the end of a curve,

y – value m.

In 5 selected sections of forest roads, 107 cross sections were set up in Forest Management Unit »Prosarar«, and 83 cross sections in Forest Management Unit »Potoci–Resanovača«, where the above mentioned measurements were carried out.

4.2 Processing of collected data – Obrada prikupljenih podataka

The collected data were processed by Microsoft Excel, and maximum, average and minimum values of horizontal and vertical alignments of forest roads were obtained. The results are presented in figures below. These results are compared to domestic and international regulations concerning forest roads. Hence, some conclusions should be made about the current state of forest roads, and measures should be recommended for improving the state of forest roads.

5. Results – Rezultati

The average roadway width of forest roads in »Prosarar« is 4.3 m and the carriageway width is 2.7 m. The average cross slope of the carriageway i_p is 3.3%, and the road longitudinal slope is 6.2%. The road longitudinal slope of some sections of forest roads is 14%. The

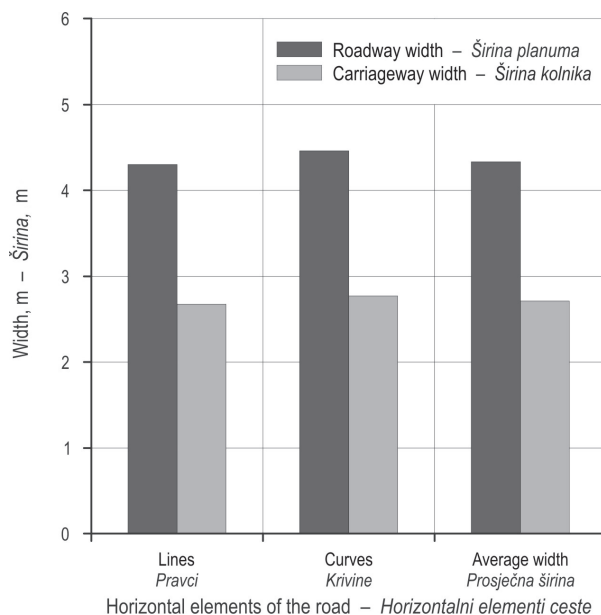


Fig. 3 Average width of roadway and carriageway of forest roads
Slika 3. Prosječna širina planuma i kolnika šumskih cesta

maximum allowed longitudinal slope on deep soils of a road is 8% (10%) and it should be in the transport direction (Jeličić 1983). The average cut slope is 1:1.4 and fill slope is 1:2.2. The selected sections of forest roads are divided into curves and lines and 21 curves

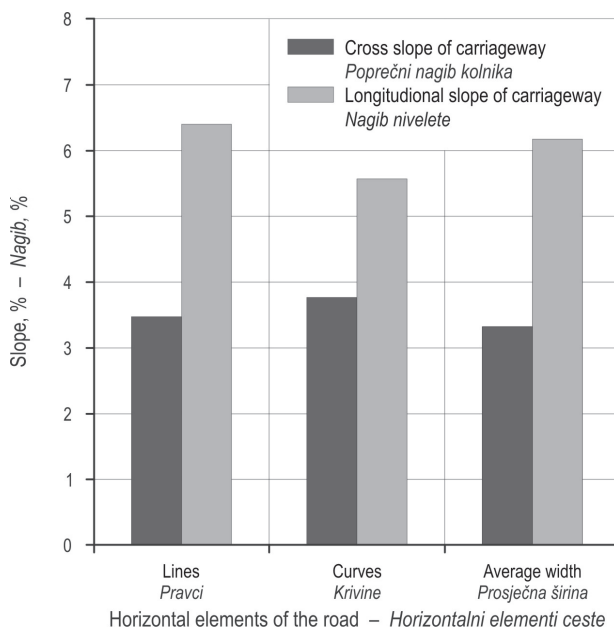


Fig. 4 Cross and longitudinal slope of forest road carriageway
Slika 4. Poprečni nagib kolnika i uzdužni nagib nivelete šumskih cesta

are located. The average radius R is 110 m, and minimum radius of a curve is 15 m. Six curves of forest roads have the radius less than 60 m, and the carriageway widening on the curve (off tracking) should be calculated.

The average width of roadway and width of carriageway is larger on the curves than on the lines of forest roads. This is normal because of carriageway widening on the curves whose radius is less than 60 m (Fig. 3).

Longitudinal slope of forest road carriageway is higher on the lines than on the curves. The cross slope of the carriageway is higher on the curves than on the lines of forest roads (Fig. 4). Longitudinal road slope and cross slope of the road carriageway are inverse; the higher the road longitudinal slope, the lower the carriageway cross slope. On the curves, the carriageway cross slope depends on the radius and road longitudinal slope. The radius and cross slope of the carriageway on the curves are inverse. However, on the curves of forest roads in Forest Management Unit »Prosara«, the carriageway cross slope increases with the increase of the radius of the curve (Fig. 5).

Randomly selected sections are 14, 29, 36 and 50 years old, and on each section the distance between the crown of the trees above the forest roads or clearing width is determined. The average distance be-

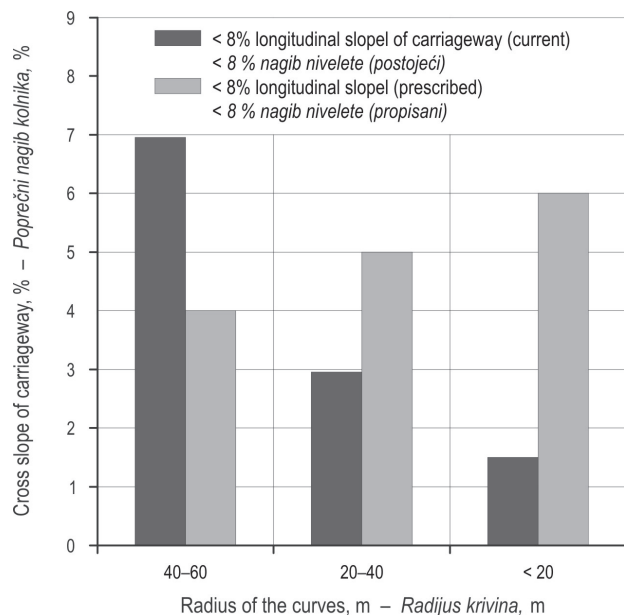


Fig. 5 Dependence of the carriageway cross slope on radius and carriageway longitudinal slope of the curve

Slika 5. Utjecaj poprečnoga nagiba kolnika na radijus horizontalnih krivina i uzdužni nagib nivele

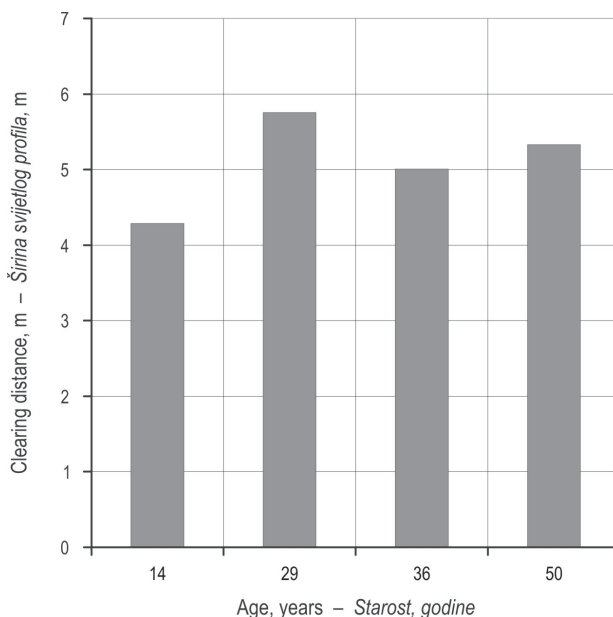


Fig. 6 Dependence of clearing width on the age of forest roads

Slika 6. Ovisnost širine svijetloga profila o starosti šumskih cesta

tween crowns is 5.6 m. This width should be reduced over time, but this is not the case with forest roads in Forest Management Unit »Prosara«. However, the current distance between the crowns is a result of forest roads maintenance, more precisely of removal of the fallen trees over the road due to bad weather conditions and trees fallen by the roadside (Fig. 6).

Forest roads are constructed on terrain category 4 (Protić 1970) in Forest Management Unit »Potoci-Resanovača«. The average roadway width is 4.5 m, and carriageway width is 3 m. The average forest road longitudinal slope is 2.8%, and the carriageway cross slope is 3%. The maximum measured longitudinal slope of a forest road is 8%. The maximum allowed longitudinal slope of a forest road is 14% in this terrain category. The average slope of the cut slope is 1:1.7, and of fill slope 1:0.9. The selected sections of forest roads are divided into the curves and lines, and 21 curves are located. The average radius (R) of curves is 140 m, and minimum radius is 20 m. The roadway width and the carriageway width of forest roads are larger on the curves than on the lines because of the carriageway widening on the curves, whose radius is less than 60 m (Fig. 7).

The forest road longitudinal slope and cross slope of the carriageway are higher on the curves than on the lines. They are higher than the average value of road longitudinal slope and cross slope of the carriageway (Fig. 8).

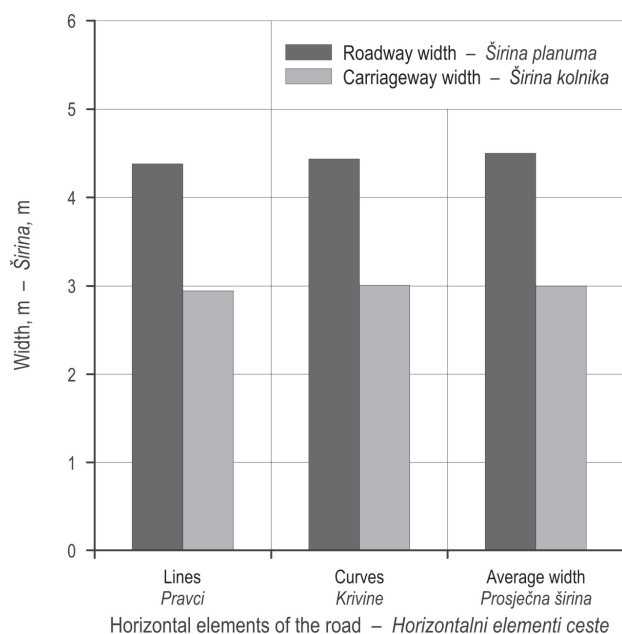


Fig. 7 Width of the forest road roadway and carriageway
Slika 7. Širina planuma i kolnika šumskih cesta

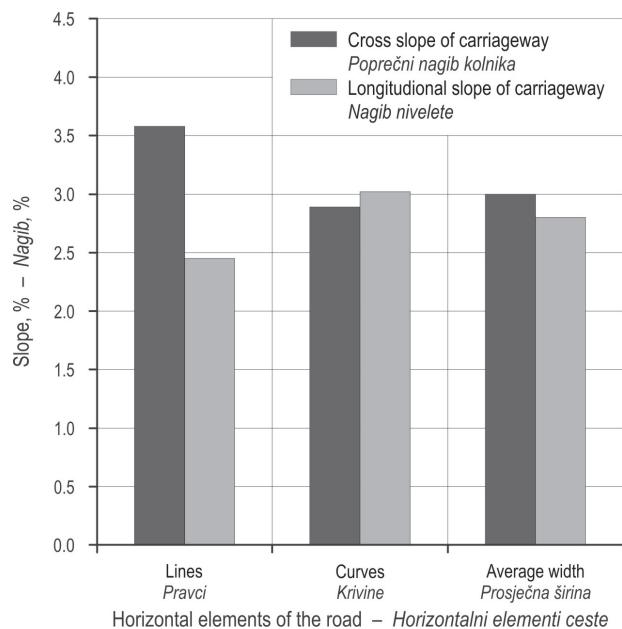


Fig. 8 Cross and longitudinal slope of the forest road carriageway
Slika 8. Poprečni nagib kolnika i uzdužni nagib nivelete šumskih cesta

The carriageway cross slope and radius are not inverse on the curves of forest roads of »Potoci–Resanovača«. The value of the cross slope is lower than the one prescribed by Jeličić (1983) (Fig. 9). The carriage-

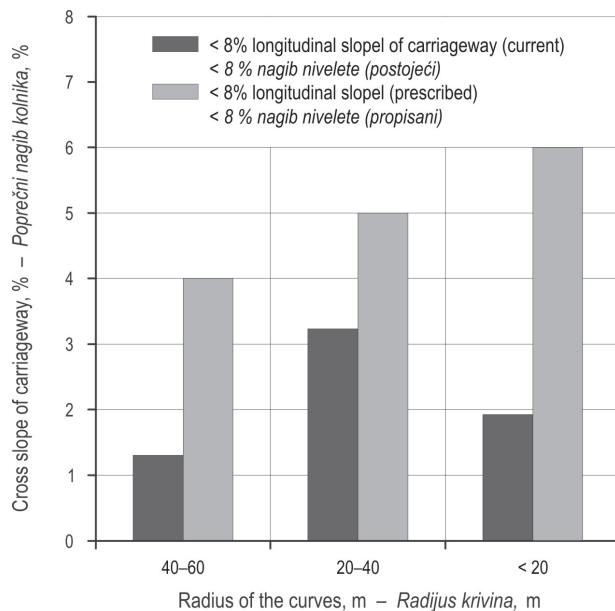


Fig. 9 Dependence of the cross slope of curve carriageway on the radius and longitudinal slope of the curve

Slika 9. Utjecaj poprečnoga nagiba kolnika u krivinama na radijus horizontalnih krivina i uzdužni nagib

way cross slope is 3.1% on the curves whose radius is larger than 60 m.

The ditches are full with stones, earth, leaves and other parts of trees and they cannot absorb the rainfall from the road. There is no clear border between the surface of forest roads and ditches.

Data on the age of forest roads in »Potoci–Resanovača« are unknown, and therefore no conclusion can be made about the influence of the age on the clearing width. According to information obtained by the Forest Administration of »Ribnik«, in this area most forest roads were built in the 70s and 80s of the last century. The average clearing width of these forest roads is 4.3 m. Apart from the age, clearing width above forest roads also depends on: terrain and site conditions, frequency of maintenance of forest roads, distance between forest road sections and public road, and traffic load. According to Fig. 10, the distance between tree crowns above forest roads is smaller in the sections that are further away from the public roads.

6. Discussion and conclusions – Rasprava i zaključci

The results of this research show that the average width of the roadway and carriageway is larger on harder than on softer soil. The roadway width should

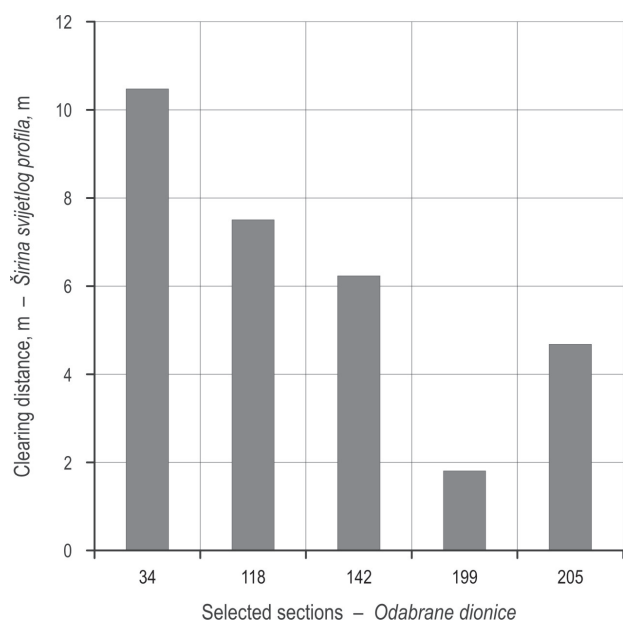


Fig. 10 Dependence of clearing width on the serial number of selected section, i.e. its distance from the starting point of forest road

Slika 10. Utjecaj širine svijetloga profila na redni broj odabrane dionice, odnosno na udaljenost dionice od početka šumske ceste

be 4 to 6 m, and it means that the average width of 4.3 to 4.5 m in »Prosara« and »Potoci–Resanovača« meets the set standards. According to Pičman (2007), roadway width of forest roads should be 5 to 7 m. Roadway width can be 4 to 7 m, according to Ryan et al. (2004), or 4 to 5 m (Kramer 2001), and 5 to 6 m (Forest Road Design 2006). Roadway width of forest roads should be larger on deep than shallow soils, due to smaller capacity of deep soils.

The average carriageway width of forest roads is 2.7 m on deep soils, and 3 m on shallow soils. The carriageway width of forest roads should range from 2.8 to 3.4 m (Potočnik, 2004). Butulija (2000) recommended the carriageway width of 3 m. According to Pičman, the carriageway width of forest roads should be 3.5 to 5 m (Pičman 2007), and according to Rynet 3.4 to 4 m (Ryan et al. 2004), 3.7 m according to Kramer (2001), 3.5 to 7 m according to Keller and Sherar (2003) and 3.5 to 5 m (Forest Road Design 2006). Therefore, the average carriageway width of the selected sections of forest road is acceptable, but again it should be stressed that it should be larger on deep soils in order to distribute the traffic load over a larger area.

From the point of maintenance, the ideal forest road longitudinal slope is from 2 to 4%. The maximum allowed downhill slope in the transport direction is from 8 to 12%, maximum 14%. The maximum allowed

uphill slope in the transport direction ranges from 3 to 5%, maximum 7%. The maximum longitudinal slope of forest roads on deep soils is 8%, maximum 10%. The maximum allowed longitudinal slope of forest roads can range up to 12%, maximum 14% on shallow and hard substrates (Potočnik 2004). The maximum longitudinal slope of forest roads ranges from 8% to 10%, maximum 12% in extreme cases (Pičman 2007). Longitudinal slope of forest road surface should be from 1 to 10% on straight sections and 8.3% on the curves of forest roads (Ryan et al. 2004). The maximum longitudinal slope of road surface is 12% according to Kramer (2001). Keller and Sherar (2003) recommended the longitudinal slope of forest road surface from 12% to maximum 15%. The maximum longitudinal slope of forest road surface should be 12% for collector roads (Forest Road Design 2006). The average longitudinal slope of forest roads in Forest Management Unit »Prosara« is 6% on deep soils, while the maximum measured amounts to 14%. These longitudinal slopes are problematic because of the erosion risk on forest road surface. In Forest Management Unit »Potoci–Resanovača« the average longitudinal slope of forest roads surface is 3% on shallow soils, and the highest measured is 8%. This longitudinal slope is in accordance with the applicable standards and can be considered as ideal from the point of maintenance of forest roads.

On the lines and curves with the radius exceeding 60 m, the cross slope of macadam carriageway is about 3 to 4% (Jeličić 1983, Aćimovski 1997, Butulija 2000). One-sided cross slope of macadam carriageway should range from 2 to 4%. Depending on the longitudinal slope of the forest road, the cross slope of roads with macadam carriageway can be between 3 and 6% (Potočnik 2004). The cross slope of the carriageway is constructed as one-sided and two-sided. On the lines, the carriageway is constructed with two-side cross slope, while on the curves the carriageway is constructed with one-side cross slope directed to the middle of the curves. It is applied on the lines to facilitate the maintenance of the road carriageway. On the curves of radius less than 60 m, the value of the cross slope ranges from 3 to 6% (Jeličić 1983, Aćimovski, 1997, Butulija, 2000). The cross slope of the carriageway on the curves should range from 5 to 7% (Potočnik 2004). The carriageway cross slope should be between 2 and 3% according to FAO (1998). The cross slope on the lines of forest road carriageway should be from 3 to 4%. Cross slope on the curves of forest road carriageway depends on the radius and ranges from 3 to 6% (Pičman 2007). The carriageway cross slope should range between 3 and 5% on longitudinal slope of forest

road surface or less than 10% (Keller and Sherar 2003). The average cross slope of the forest road carriageway in Forest Management Units »Prosara« and »Potoci–Resanovača« is about 3%. The carriageway cross slope on the curves of radius less than 60 m is not inversely related to the radius. On average, the carriageway cross slope on curves is about 3% in Forest Management Unit »Potoci–Resanovača«, and 4% in Forest Management Unit »Prosara«. The cross slope of forest road carriageway in these two Forest Management Units is in accordance with standards, and in the curves it should be aligned with the radius of the curve.

The average radius of horizontal curves of forest roads is from 110 to 140 m in Forest Management Units »Prosara« and »Potoci–Resanovača«. The minimum radiuses range from 15 m in Forest Management Unit »Prosara« to 20 m in Forest Management Unit »Potoci–Resanovača«. The minimum radius of the curves is 8 m for 12 m long trucks and 12 m for 18 m long trucks (Aćimovski 1997). The minimum radius of horizontal curves is 20 m (Butulija 2000). The minimum radius of horizontal curves depending on the possibility of turning of typical vehicles (truck, trailer, etc.) should be 15 m (Potočnik 2004). The minimum radius of horizontal curves is 20 m according to Ryan et al. (2004). Kramer (2001) recommended the minimum radius of horizontal curves of 50 to 60 feet or 15 to 18 m. According to Keller and Sherar (2003), the minimum radius of horizontal curves should be 15 m. The minimum radius of curves is 60 feet (18 m) according to Forest Road Design (2006). Thus, the minimum radiuses of curves of forest roads are in accordance with the recommendations of the above mentioned authors.

The slope of cut and fill slopes depends on: category of soils, material used to build levees, slope height, terrain cross slope and other factors. The average slope of cut slopes is 1:1.4, and of fill slope 1:2.2 on deep soils of Forest Management Unit »Prosara«. The average slope of cut slopes is 1:1.7, and of fill slope 1:0.9 on shallow soils of Forest Management Unit »Potoci–Resanovača«. The slope of cut and fill slopes for an ordinary ground should be 1:1 or 1:1.5, and for compacted soils with stones 2:1, 1:1.3 and 1:1.5, respectively (Jeličić 1983). According to Aćimovski (1997), the slope of cut and fill slopes for ordinary and sandy soils are 1:1 and 1:1.5. The slope of cut slopes of rocky substrates should be 1:0, 1:0.2, 1:0.5 or 1:0.75, and of fill slopes 1:1 or 1:1.25. The slope of cut slopes is 3/4:1 (0.75:1), and of fill slopes 1 1/2:1 (1.5:1) (Keller and Sherar 2003). According to this, the slope of cut and fill slopes in the observed sections of forest roads are

milder than prescribed except the slope of fill slopes on shallow soil in Forest Management Unit »Potoci–Resanovača«.

Finally, it can be concluded that the dimensions of horizontal and vertical alignments of forest roads are in accordance with the standards for forest roads, and that they are able to carry the traffic load. Further research should be focused on the synchronization between the cross slope of the carriageway on the curves and the radius of the curves. Then attention should be directed to the prevention of erosion of the forest road carriageway in Forest Management Unit »Prosara« as much too often the forest road surface has an extremely high longitudinal slope. The roadway and carriageway width of forest roads on deep soils should be larger than on shallow soils in order to distribute traffic load over a larger area. However, the construction of such forest roads and greater care for the environment require more financial resources.

These results show the state of technical characteristics of forest roads in these two management units as well as in the whole Republic of Srpska. There are no significant differences between standards for forest roads in the mentioned references. These recommended standards must be used for making the Manual for planning, design, construction and maintenance of forest roads at the national level.

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Sažetak

Horizontalni i vertikalni konstruktivni elementi šumskih cesta

Šumske ceste trebaju biti u takou stanju da u svakom trenutku mogu prihvatiti prometno opterećenje vozila koja se njima kreću. Da bi izdržale prometno opterećenje, dimenzije šumskih cesta moraju biti u granicama propisa. Dimenzije konstruktivnih elemenata šumskih cesta ovise o brojnim čimbenicima, a neki od najznačajnijih jesu: kategorija terena (građevinska kategorija materijala) na kojem su šumske ceste izgrađene, primarna funkcija šumske ceste, odgovarajuće vozilo koje će šumskom cestom prometovati i sl. U radu su istražene šumske ceste izgrađene na različitim kategorijama terena (III. i IV. kategorija materijala prema Protiću 1970) te su utvrđene dimenzije konstruktivnih elemenata šumskih cesta u horizontalnom i u vertikalnom pogledu. Zaključuje se da istražene šumske ceste mogu prihvatiti prometno opterećenje, ali u budućnosti treba usmjeriti pozornost na najveće nagibe nivelete te na poprečni nagib kolnika u horizontalnim krivinama (koji ovisi o nagibu nivelete i radijusu horizontalne krivine).

Ključne riječi: šumske ceste, horizontalni i vertikalni konstruktivni elementi, uzdužni nagib nivelete, poprečni nagib kolnika

Authors' address – Adresa autorâ:

Vladimir Petković, MSc.*

e-mail: petkovicv1603@yahoo.com

Dane Marčeta, MSc.

e-mail: danemarceta@gmail.com

University of Banja Luka, Faculty of Forestry

Department for Using of Forest Resources

Stepe Stepanovića 75a

78000 Banja Luka

BOSNIA AND HERZEGOVINA

Prof. Igor Potočnik, PhD.

e-mail: igor.potocnik@bf.uni-lj.si

Biotechnical Faculty

Department of forestry and renewable forest resources

Večna pot 83

1000 Ljubljana

SLOVENIA

* Corresponding author – Glavni autor

Received (Primljeno): March 8, 2014

Accepted (Prihvaćeno): April 8, 2014

