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IDENTIFICATION OF CURVATURE RADIUS FOR CURVED SECTIONS ON FOREST ROADS IN THE PROCESS OF UTILISATION

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Abstract: *This article reviews the problem of measuring the actual radius of curvature for curved sections of existing forest roads, as forestry enterprises require reliable technical information about the current conditions of operated transport networks. It was identified that at this moment, a selection of methods are used for measuring the radii of horizontal curved sections of roads, which have certain advantages and disadvantages in specific natural production conditions. For calculating the radius of curvature for auto forest road projects it is recommended to apply the method of measured angles by chord angle deviation, which is sufficiently accurate for engineering purposes and does not require usage of special high-precision equipment and tools.*

Key words: *method of chord angle deviation, radius of curvature, field conditions, circular curve, forest road.*

1. Introduction

At the present moment, the major problem of the forestry industry and timber production lies in the rational planning, development inspection,

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restoration, reconstruction, and certification of forest road networks, which is relevant for many world countries. In specific regions, regulations were developed for the forestry industry by government authorities in order to implement systems for forest road monitoring and inventory, application of geoinformation databases, and creating digital road maps.

However, there is a problem in identifying these parameters since not all forest roads have technical documentation available at the forestry enterprises. Moreover, even if there is technical documentation, not all the technical documentation of engineering structures provides reliable information about its actual operating conditions.

Therefore, in production conditions, there is often a need to determine the basic technical characteristics of forest road projects [6]. One of the major elements which characterizes curved sections in projects of forest roads is the radius of curvature [8].

Also, in accordance with current regulations and available recommendations for the safe design and operation of forest road networks [7], it is necessary to systematically identify radii of curvature that are smaller than those allowed for this category (type) of forest road when planning major repairs. At the same time, it is recommended to set the normative radii of curved road sections according to the design and working documentation, and in case of its absence - in accordance with current normative documents. It is recommended to establish actual curvature of forest roads sections with the use of geodetic instruments (methods and means of measurement are not regulated).

2. Objectives

In engineering practice, a number of methods are used to identify curved road sections and calculate the radii of curvature of roads for lower categories and types. However, the feasibility of applying certain methods in the forestry field should be justified by their advantages and disadvantages (accuracy, cost, safety, ease of use, etc.), as well as by the impact of specific natural factors (terrain, level of technical equipment, forestry enterprises, features of work performances by non-specialized work crews, etc.).

For effective performance of employees of forestry enterprises in the field, as well as for the proper identification of curved road sections and the determination of the forest roads` radii of curvature, it is necessary to substantiate theoretical principles, a methodological approach, and recommendations for rational organization and technical support.

3. Material and Methods

In the simplest way for field conditions [2, 3], the radius of curvature is determined depending on the height of a circle's segment, tightened by a chord (Figure 1).

$$R = 0.125 \times l^2 / f_n + f_n / 2 \qquad (1)$$

Since the second term in formula (1) is much smaller than the first term, this value is usually neglected during engineering calculations, assuming that $f_n/2 \to 0$. Therefore, in practice, to calculate a radius of curvature, the formula $R \approx 0.125 \cdot l^2 / f_n$ is most often used.

The length of a chord l is taken equal on average 10-30 m depending on the size of radius R and the length of curve $\widehat{L}$ (larger values of the radius R and curve length $\widehat{L}$ correspond to larger values l and vice versa). The measurement procedure is repeated for several different points on a road (usually taking at least 5 reference stations equidistant from each other) and finally the arithmetic mean of the calculated values is determined.

The disadvantages of this method to determine the radius of a circular R curve are: the need to involve several (two or three) people in the measurement process; possible difficulties in determining the position of the centreline (in the absence of hard surface); centripetal displacement of the tape between base stations; the impact of probable inaccuracy measurements of average shift f_n.

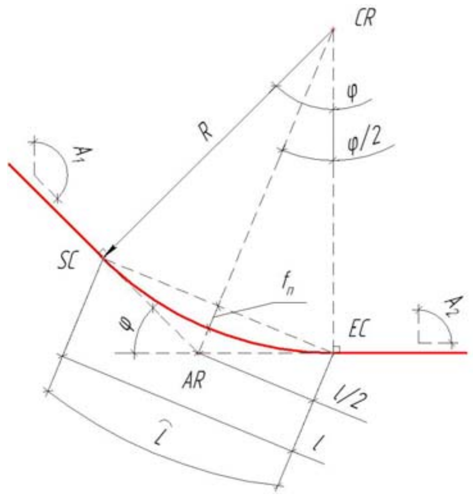

Fig. 1. *Calculation scheme for radius of curvature R: CR - centre of turn; AR - vertex of turn; $\widehat{L}$ - length of curve; φ - centre vertex; SC and EC - start and end of curve; A_1 and A_2 - azimuths of starting and ending sections*

Another method of determining the radii of curved road sections R is the so-called compass method [2], [4]. The essence of this method is to measure the curve's length $\widehat{L}$ while recording the change in direction. The length of a road curve $\widehat{L}$ is usually determined by a measuring wheel (curvimeter, odometer). The orientation of the movement direction along the curve (azimuths A_1 and A_2) in this case is fixed with a compass (Figure 1). The change in the direction of motion is characterized by the central angle φ, which is calculated depending on the quarter of a rectangular coordinate system and the difference between azimuths A_2 and A_1 (at the end EC and starting points of a circular curve SC). Subsequently, the radius of the curve R is calculated according to formula (2):

$$R = 57.3° \cdot \frac{\widehat{L}}{\varphi}. \tag{2}$$

It is clear that on-site, it is easier and safer to measure using devices such as a compass and a measuring wheel than a measuring tape (when measuring outside of a road surface). In addition, the measurement process in this case does not require involvement of other people, and there is no need to go outside the roadside boundaries.

Disadvantages of this method of determining the radius of curvature R are the accuracy of measurements (azimuths in the field are usually determined with an accuracy of 0.5-1°, the road's curve length $\widehat{L}$ - with an accuracy of 2-10 cm / 100 m) and possible difficulties in determining the axial position lines (especially on forest roads without a hard surface).

The mobile system "Radiusmeter" [2], which was developed by the Texas Transportation Institute (TTI) of the Texas A&M University, allows to calculate parameters by passing a vehicle through horizontal curves, to process GPS data in the automatic mode by means of a microcontroller, and to calculate the section radius values of a road. Such a mobile system can be installed in any vehicle that will move at any speed.

Similar mobile systems (but mostly on the basis of smartphones) which are equipped with GPS sensors, gyroscopes and accelerometers to record changes in the centrifugal acceleration of the object in real time are used in some countries when creating detailed inventory databases of lower categories and types [1], [5], [10]. The advantages of such mobile systems are the ability to process large amounts of information and use them as alternative technologies to basic techniques. The disadvantages are the accuracy of the results (especially for forest roads with uneven ground surface), the technological complexity, and the cost (as for non-specialized forest enterprises).

In the study [2], the results of the experimental research and analysis showed basic combined methods` accuracy, cost, safety and simplicity for the calculation of rural roads' horizontal curves radii, in field conditions. In that research, an important conclusion was drawn, namely that for various enterprises and institutions, such as transport agencies, services for the technical investigation of road accidents, engineering, construction and scientific organizations in a field of transport, etc., different methods may be optimal, due to the ultimate goal and an acceptable level of accuracy and material costs.

To determine the forest roads` radii of the curved sections in normal forest operation conditions, we consider it is rational to use the method of measuring angles by chord angle deviation (Figure 2).

For engineering calculations, this method is quite accurate and does not require the use of special equipment. To directly measure angles of deflection for chords in forest conditions, it is rational to use special compasses or other devices, and measuring tapes to measure distances in a field. During the measurement process, base stations were placed at the centerline of a road.

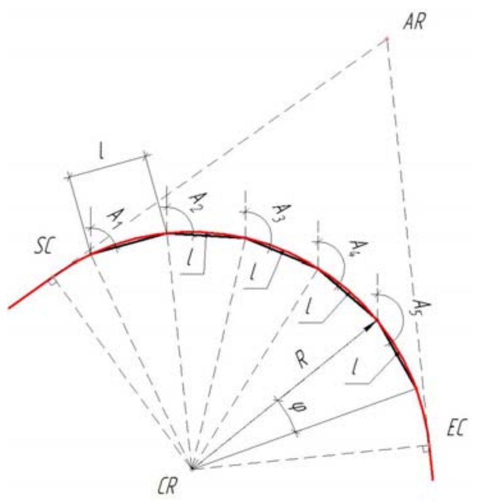

Fig. 2. *Calculation scheme for method of measured angles by chord deviation: A_1 - A_5 - azimuths of chords*

The theoretical basis of the proposed method follows. According to Figure 3, the angle at the base of an isosceles triangle with vertex at the point CR is $90° - \frac{\varphi}{2}$.

Thus, the central vertex point φ is:

$$\varphi = \left| A_{n+1} - A_n \right| = \Delta A \, . \qquad (3)$$

In the case of transitioning chords through one full revolution (from 360° to 0°), the value of the angle must be determined according to the formula

$$\varphi = 360^\circ - \left| A_{n+1} - A_n \right| = 360^\circ - \Delta A \, . \qquad (4)$$

Because $\sin \dfrac{\varphi}{2} = \dfrac{l}{2R}$, thus:

$$R = \frac{l}{2 \cdot \sin (\varphi / 2)} = \frac{l}{2 \cdot \sin (\Delta A / 2)} \, . \qquad (5)$$

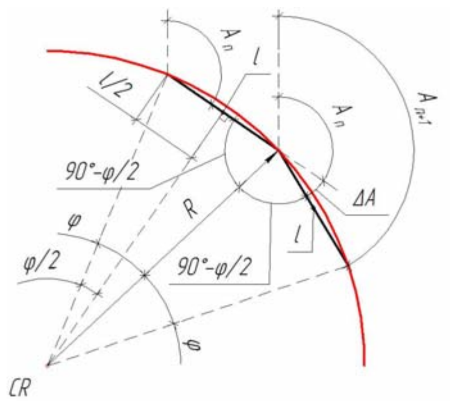

Fig. 3. *Calculation scheme for method of measured angles by chord deviation:*

A_n, A_{n+1} *- azimuths of chords*

The length of chord l in production conditions should be used by focusing on the length of a circular curve and the radius of curvature R: if $R \le 100\ m$ then $l \approx$ 5-10 m; if $R =$ 100-500 m then $l \approx$ 10-20 m, if $R \ge 500\ m$ then $l = 20\ m$. It is important that each curved section have no fewer than 5 base stations, so $l \le \widehat{L} / 5$.

4. Results and Discussions

According to the method of measuring angles by chord angle deviation, this research conducted a set of direct measurements in field conditions of Zhyrychi divison, Ratno State Forestry Enterprise (Ukraine, Volyn Oblast). The objects of the study are road sections *A*, *B,* and *C* (Figure 4).

The selected sections *A* and *C* were designed in 2011 by the Private Enterprise “Lutskkomundorproekt”, and section *B* - in 2012 by the Volyn complex design department of the Ukrainian State Institute of Road Facilities Design “Ukrdiprodor”.

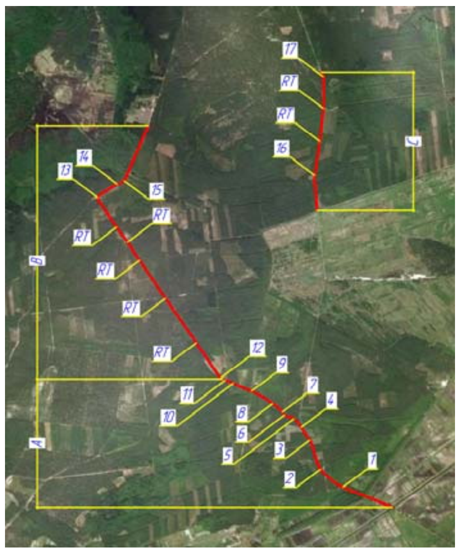

Fig. 4. *Location of forest roads sections: 1-17 - serial numbers of curved sections; RT - road turns with angle $\alpha < 1^\circ$ (without arrangement of curved sections)*

According to the project documentation developed by the contractors in 2012-2013, selected sections of forest roads were constructed and equipped for safe use. Information from the Ukrainian state project forest management production association "Ukrderzhlisproekt" indicates that these sections of forest roads are still in use for forest production (Figures 5 and 6).

Measurements of magnetic azimuths for straight sections of forest roads and angles of chords deviation in natural-production conditions of forestry enterprise were conducted using the manual aiming circle "BSh-1" ("БШ-1"), mounted on a light tripod. This device is characterized by sufficient accuracy (divisions of 1° and the accuracy of measurement is 0.5°) and an acceptable measurement speed compared to a specialized compass. By design of the aiming circle, the limb is fastened to the arrow and rotates with it. Two lenses are attached to the body of the aiming circle, so during aiming, azimuth can be obtained immediately on the limb. However, the angular value is much better to shoot at the eye lens which is shifted by 180° (because of this, the north of the limbus is marked by 180°, the south - 0°). In the measurement process, readings from the compass were shot directly with focus on a milestone (at the bottom of the lens the mirror reflects readings of the compass limb, which is the direct azimuth of an object). To reduce error probability, orientation from following base stations to previous was performed along with measurements of reverse magnetic azimuth, which differs by 180° from directly measured azimuth in direction of this base station.

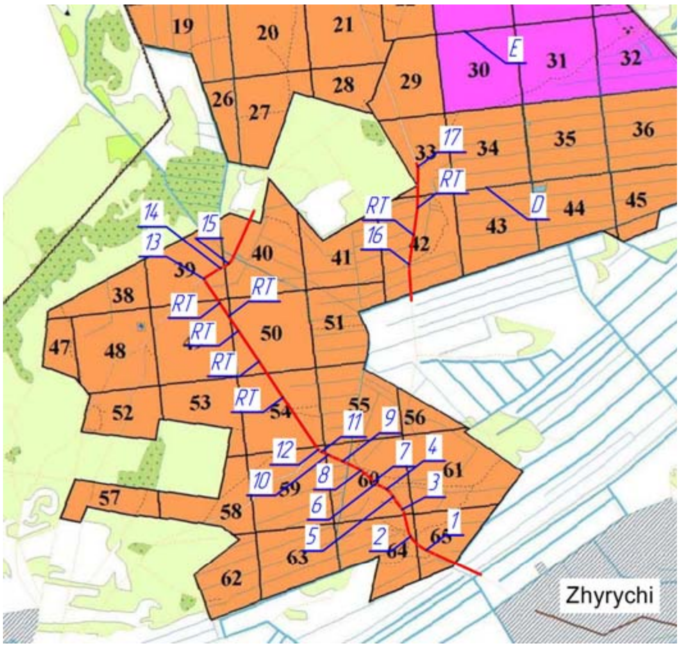

Fig. 5. *Location of forest stands near road: D - forest exploitation area; E - forest of high conservation value*

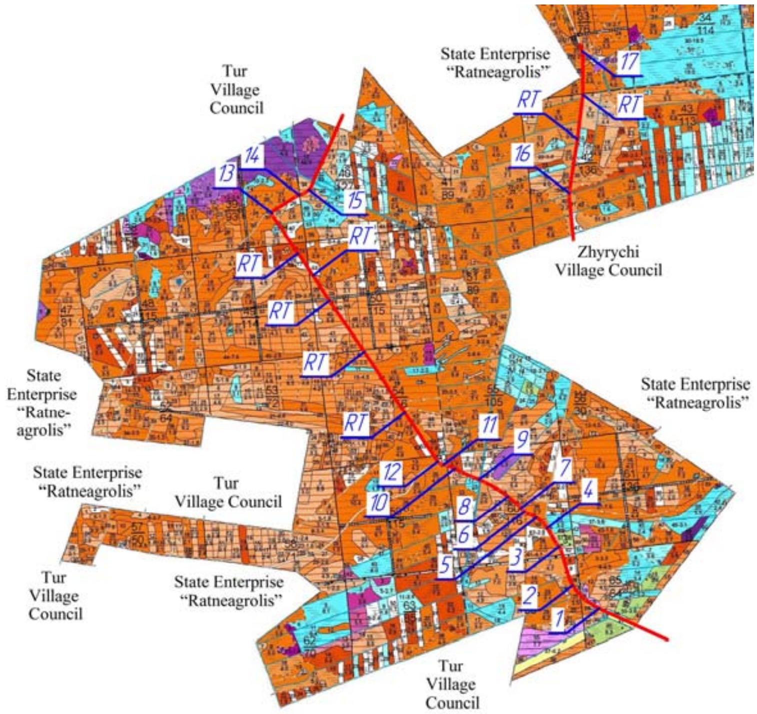

Fig. 6. *Map of forest stands near roads with indication of species, group age, objects of road infrastructure and hydrography, land category, and administrative boundaries*

A tape measure, model "R20UZK" ("Р20УЗК"), was used for linear dimensions (distances) by direct comparison in field research (3rd class accuracy with millimeter scale and length of 20 m).

The results of the conducted calculations are presented in Figures 7 and 8. For the curved sections 1-17, the length of chord was 5-20 m, and the quantity of measures - from 5 to 10.

As can be seen from the results shown in Figures 7 and 8, the deviations of the experimental and design data for the vast majority of road curved sections are insignificant (relative error of arithmetic mean for experimental data and the design value is –12.24-5.49% for angle deviation of chords and –8.04-6.10% for measured curved sections` radii of forest road). The only exception is section 13 (Figure 9), which requires detailed elaboration. The relative error of arithmetic mean for road section 13 and design values is 10.35%, the angle deviation of chords - 153.17%.

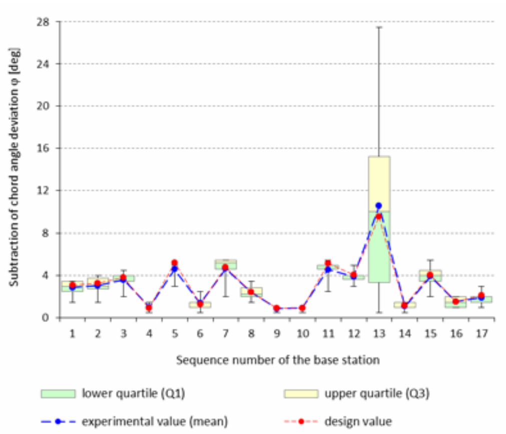

Fig. 7. *Measurement results of angles by chord deviation in field conditions*

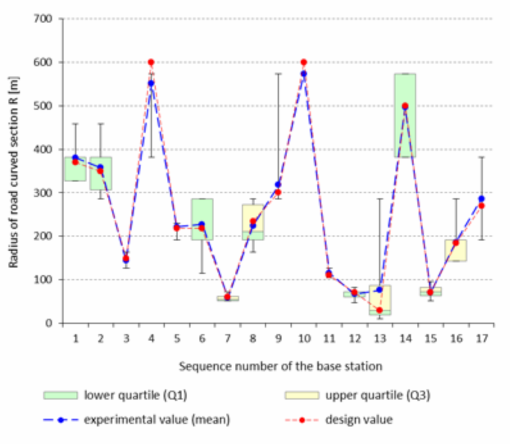

Fig. 8. *Radii measurements of forest roads' curved section*

The blue color in Figure 9 shows the actual path parameters, and red - the design characteristics.

The conducted analysis in the field provides an explanation for the major differences between the actual and the design parameters of the forest road, namely erosion (landslide) processes in the soil from inside the curve. As a result, this road curve is characterized by a variable radius of curvature (Figure 10). The radius from the traffic safety point of view is unacceptably low (lower than $R_d = 30\ m$) especially in some sections (for example, sections between stations 13.5-13.10).

Fig. 9. *Detailed overview of road`s curved section 13: R_d - designed radius of circle curve; α_m, α_d - real and designed angles of road turn; CR_m and CR_d - real and designed centres of road turn; e_1 - extension of forest road on circle curve; l_w - length of transition from straight to curve, in relation to size of loaded timber truck; c - width of roadside; B - width of roadbed*

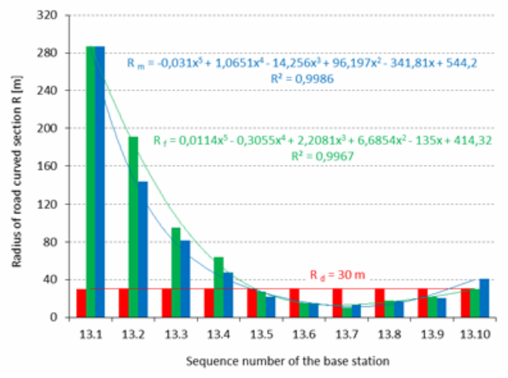

Fig. 10. *Change of radii on curved section 13: R_m and R_f - calculated values of radius for curved section by method of measured angles by chords deviation in the field and application of Bing Maps*

5. Conclusions

The method of measuring angles by chord angle deviation is fully suitable for measuring curved sections radii of roads for forestry and timber production purposes and other lower categories of highways in field conditions. The advantages of this method are: the ability to perform work in different terrain conditions (on the plains, the hills, and in the mountains if favourable circumstances are present); relatively low requirements for staff qualification and technical equipment (which is especially valid for forestry enterprises). In particular, the performance of fieldwork using this method is in no need of high-value geodetic tools or other special equipment, because to measure angles of deviation for chords directly on the ground, it is sufficient to use special compasses or other devices with a measurement accuracy of 0.5° and above, for distance measurements - measuring tapes or equivalent tools with accuracy 2-10 cm / 100 m or above. Clearly, to increase the speed and accuracy of the measurement process, it will be rational to use high-precision surveying instruments (some forest enterprises have instruments staffed by sufficiently qualified personnel with experience in optical and laser levels, optical and electronic theodolites, electronic total stations and other devices).

For identification of circular curves` curvature for forest roads projects in the process of their operation, it is advisable, in addition to field measurements, to use cartographic materials (for example, services of web-cartography like Bing Maps, Google Maps, etc.) and other technical approaches of remote sensing [9].

References

1. Ai C., Tsai Y., 2015. Automatic horizontal curve identification and measurement method using GPS data. In: Journal of Transportation Engineering, vol. 141(2), pp. 1-34.
2. Carlson P.J., Burris M., Black K. et al., 2005. Comparison of radius-estimating techniques for horizontal curves. In: Transportation Research Record: Journal of the Transportation Research Board, vol. 1918, pp. 76-83.
3. Fricke Lynn B., 1990. Traffic Accident Reconstruction. Northwestern University Traffic Institute, Evanston, Illinois, U.S.A.
4. Glennon J.C., Loumiet J.R., 2003. Measuring roadway curve radius using the compass method. Motor-Vehicle Accident Investigation and Reconstruction Services. Crash Forensics. Available at: http://www.crashforensics.com/papers.cfm?PaperID=17. Accessed on: 28 May, 2021.

5. Luo W., Li L., Wang K.C.P., 2018. Automatic horizontal curve identification and measurement using mobile mapping system. In: Journal of Surveying Engineering, vol. 144(4), pp. 1-15.
6. Ryan T., Phillips H., Ramsay J. et al., 2004. Forest Road Manual. Guidelines for the design, construction and management of forest roads. COFORD, Dublin, Ireland. Available at: http://www.coford.ie/media/coford/content/publications/projectreports/ForestRoadManual.pdf. Accesed on: 28 May, 2021.
7. Slincu C., Ciobanu V., Dumitrascu A., 2012. Risks assessment in forest roads design. In: Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 5(54), no. 2, pp. 43-48.
8. Vatankhah A.R., Easa S.M., Mahdavi A., 2013. Alternative solutions for horizontal circular curves by noniterative methods. In: Journal of Surveying Engineering, vol. 139(3), pp. 111-119.
9. Vorovencii I., 2012. Optical and active satellite sensors used in forestry. In: Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, vol. 5(54), no. 2, pp. 63-70.
10. Wood J.S., Zhang S., 2018. Identification and calculation of horizontal curves for low-volume roadways using smartphone sensors. In: Transportation Research Record: Journal of the Transportation Research Board, vol. 2672(39), pp. 1-10.