Accuracy estimate of the paved surface of an automobile road after its reconstruction

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Abstract: The article outlines the importance of engineering and geodetic survey during the reconstruction of automobile roads. The main phases of engineering and geodetic survey, such as the creation of a horizontal and vertical control, topographic plotting, technologies for the detailed staking of circular curves, and softwares for the execution of data processing, are taken into consideration. Possible tolerance limits in building and geodetic operations are reported. Research on the evenness of the upper surface of the asphaltic coating of an automobile road after its reconstruction is carried out.

1. Introduction

Automobile roads are part of the so-called vital support systems; therefore they are of great importance for the social and economic development of a country. Roads with paved surface are of crucial importance, as without their development the recovery of a country’s economy as a whole and of individual areas in particular, as well as the successful implementation of economic reforms, is impossible. At the present time, engineering and geodetic surveys (EGS) and up-to-date applied technologies for the purposes of automobile road reconstruction are particularly relevant, which allows for high performance and efficiency. Automobile roads leading to rural settlements in the Omsk Region are in critical condition and, subsequently, require reconstruction, for this purpose a whole set of engineering and geodetic surveys is being carried out. Engineering surveys for the design planning and reconstruction of automobile roads are understood as an integrated production process on the working site which provides the design planning with source data for the adoption of further decisions. The main task of engineering surveys is to obtain the necessary materials for the development of economically viable and technically grounded solutions for the design planning, construction and reconstruction of working sites.

The initial stage of EGS (engineering and geodetic surveys) is the creation of a horizontal and vertical control. The creation of a reference geodetic network (RGN) on the working site is performed using GNSS technologies. Surveying with the support of GNSS technologies has a whole range of advantages: globality, operativity, all-weather capacity, optimum accuracy, and efficiency. GNSS technologies ensure the accuracy of differential determinations at a level of +(3-5 mm + 1 mm/km), which fully satisfies the accuracy conditions for the creation of a surveying control. Important advantages of such method of determining the coordinates are: fast result reception (i.e. in real time), possibility to determine the coordinates of points at any time of the day, possibility of operation under difficult meteorological conditions, and calculation capacity at significant distances between the source and determined points [1]. Dual frequency and dual system equipment sets GPS/GLONASS Trimble R7 and Trimble R8 were used on the working site. The horizontal and vertical control of points for the
determination of fixed solutions was obtained by means of accumulation over 60 minutes with a recording interval of 15 seconds. The results were processed using the Trimble Geomatics Office software. The accuracy estimate of the determination of the coordinates and heights of the reference points is shown in Table 1.

The measurement of angles and distances in traverses was performed with an electronic total station SOKKIA Set 230RK. Angles were measured applying the ordinary method. Distances were measured applying the repetition method, measurement results were recorded in an electronic storage device.

The vertical study was obtained by means of technical leveling traversing of the points of the geodetic reference network along the points of horizontal justification. In the production of the trigonometric leveling, an electronic total station was used with the following conditions: measurements were taken in forward and reverse directions with two guidances to the reflector, the maximum distance between the total station and the reflector did not exceed 300 m. The equalization of the surveying network was performed using the CREDO_DAT software. The technical characteristics of the traverses are shown in Table 1.

The factual discrepancies in the leveling traverses were as follows: traverse No. 1 «Rp.4, T15, ..., Rp.T5» 0.038 m, with \( f_{kh} \) add = 0.051 m; traverse No. 2 « Rp.4, T12, ..., Rp.8 » -0.061 m, при with \( f_{kh} \) add = 0.066 m. The resulting discrepancies in theodolite and leveling traverses are within tolerance.

The next stage of engineering surveying consisted in the execution of the topographic plotting. The topographic plotting of the road was carried out on a 1:2000 scale with a cross section of the relief at 0.5 m using an electronic total station SOKKIA Set 230RK. Part of the plotting was performed by the specified geodetic satellite equipment in kinematic mode. Engineering and topographic plans were drawn up electronically using the CREDO software package with further export in AUTOCAD format.

During construction, design planning and thorough overhaul of automobile roads, the Construction Norms & Regulations 3.06.03-85. Automobile roads [3] are applied. The term “tracing” should be understood as a complex of engineering and geodetic surveys on the choice of the route according to its technical and economic conditions, while distinguishing cameral and field tracing. The accuracy limits of works on the placement of the route and the main axes of the structure when transferring the construction projects to the site must comply with the design ones. The accuracy of the placement of the individual parts and axes of the structure between themselves and with respect to the main axes and the geodetic support network must comply with the applicable construction tolerances. The processed data were transmitted to form a DSM in the CREDO Linear surveys system.

The method of geometric leveling transfers the main points of the grade line or plane located at all angles of rotation of the grade plane in plan, as well as at all breaks of the grade line and fractures of the plane in profile. The staking and fixing of the route axis involves the determination of the position of the route, the turning points, and the characteristic points of the situation and relief on site. The determination of the position of the route axis is obtained through perpendicul ars and linear crossings from solid contours on site. Staked and fixed elements of the route are marked with temporary signs on site. The staking of cross sections is made on straight lines along the perpendiculars to the road axis and on curves along the normals to the curves. The staking of the boundaries of the road embankment slopes (embankments beds and excavation edges) is made separately at each project site along the cross sections or normals to the curves, continued at all major turning points of the terrain. The staking of the base and coating of the roadway begins with the placement of markers (survey pegs), which serve as reference points. They indicate the thickness of each structural layer of the base and coating. The staking

| Traverse | Point traverse | Distances N, m | Fb fact. | Fb add. | Fx, m | Fy, m | Fs, m | [S]/Fs |
|----------|----------------|----------------|----------|---------|-------|-------|-------|--------|
| 1        | Rp.4, T15, ..., Rp.5 | 1005,636 5 | -0°00’32,65" 0°01’29,44" | -0,009 | -0,046 | 0,047 | 1:21500 |
| 2        | Rp.4, T12, ..., Rp.8 | 1443,847 6 | -0°00'03,47" 0°01’37,98" | -0,009 | 0,040 | 0,041 | 1:35300 |

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of the markers is performed within a uniform area on each cross section. The limiting accuracy of the staking of the shape and size of individual elements of the structure must be 2-3 times higher than the deviations that are set for them upon acceptance of the structure into operation. The limiting relative errors of the line deposition in case of detailed staking of trough-shaped road formation and road embankment and the limiting errors in excess in road embankment staking should not exceed the values shown in [4].

2. Materials and methods
The values of limiting errors should serve as a guide also while taking into account the accumulation of errors in vertical staking that occur when transferring design elevations from one cross section to another. With a detailed staking of the ground embankment, bases and coatings, deviations of factually determined values from design data are allowed within the limits specified in [4].

Trigonometric leveling trials using up-to-date geodetic equipment are presented in [6-11], in these publications objects which constitute non-linear structures are taken into consideration. In the present article, the evenness of the upper surface of the coating is investigated using an electronic total station by means of trigonometric leveling method.

After the completion of the reconstruction process of an automobile road leading to a rural settlement, leveling of the upper surface of the road covering more than one kilometer in length was performed. The leveling was performed along the road axis in order to determine the marks of the surface of the coating, applying a leveling step of 20 meters. According to the marks, using formula (1), the amplitude series is presented in Table 2.

$$\delta H_{i+1} = \frac{H_i + H_{i+2}}{2} - H_{i+1}$$  \hspace{1cm} (1)

where $H_i$, $H_{i+1}$, $H_{i+2}$ – the marks of nearly points of the coating.

| No. | values | No. | values | No. | values | No. | values | No. | values |
|-----|--------|-----|--------|-----|--------|-----|--------|-----|--------|
| 1   | -21    | 11  | 4      | 21  | -14    | 31  | -24    | 41  | -15    |
| 2   | 4      | 12  | 2      | 22  | 2      | 32  | 19     | 42  | -17    |
| 3   | 13     | 13  | 10     | 23  | -9     | 33  | 15     | 43  | -4     |
| 4   | -32    | 14  | -24    | 24  | 13     | 34  | -11    | 44  | -28    |
| 5   | 7      | 15  | 18     | 24  | -15    | 35  | 12     | 45  | -14    |
| 6   | 14     | 16  | -11    | 26  | 16     | 36  | 18     | 46  | -14    |
| 7   | 24     | 17  | 4      | 27  | -7     | 37  | 3      | 47  | 15     |
| 8   | -32    | 18  | -2     | 28  | -6     | 38  | 24     | 48  | 29     |
| 9   | 13     | 19  | -16    | 29  | -20    | 39  | 16     | 49  | -5     |
| 10  | -28    | 20  | 28     | 30  | -3     | 40  | -4     | 50  | 17     |

According to the Set of Rules 78.13330.2012 [6], the values of the amplitude differences were mathematically processed and the coating evenness after the reconstruction of the automobile road was investigated. At the same time, as far as the research component is concerned, the interval difference $h$ of the series was calculated using formula (2), according to the procedure given in [12].

$$h = \frac{R}{I + 3.32 \lg N}, \hspace{1cm} (2)$$
where \( R \) is the peak-to-peak amplitude dispersion, \( N \) is the amplitude number, \( x_{\text{min}} \) and \( x_{\text{max}} \) the characteristics of amplitude variation.

The quantity of intervals in the amplitude series is defined using the formula:

\[
k = \frac{R}{h}.
\]  

(3)

The beginning of the first interval is defined through the expression:

\[
x_n = (x_{\text{min}} - k / 2).
\]

The quantitative characteristics that denote the number of occurrences of the \( x_i \) values in the interval is determined by frequency and labeled as \( n \), whereas its relation to the total number of the amplitude series values is called relative frequency and determined, following [12], by the relation:

\[
W_i = n_i / N.
\]  

(4)

The interval series and its relative frequencies constitute the statistical distribution of the amplitude series. The frequency of the interval is defined as the sum of the frequencies of the amplitudes included in the interval, and their sum is equal to their total number in the series.

The average value is obtained from the thus acquired amplitudes using the formula:

\[
\bar{x} = \frac{\sum_{i=1}^{N} n_i x_i}{N}.
\]  

(5)

where \( N \) is the number of amplitudes in the estimated series; \( n_i \) is the amplitude frequency in the estimated series; and \( x_i \) is the average value in each interval.

Using the according formula, the root-mean-square error (RMSE) for the obtained amplitude series is obtained through formula 6:

\[
m = \sqrt{\frac{k}{\sum_{i=1}^{N} n_i (x_i - \bar{x})^2}} / (N - 1).
\]  

(6)

Following the magnitude of the error obtained using formula 6, the error of the average value of the amplitude series is determined using formula (7); the error value calculated through formula 6 can be determined with an error the limits of which are determined by formula 8:

\[
M = \frac{m}{\sqrt{N}};
\]  

(7)

\[
m_m = \frac{m}{\sqrt{2(N - 1)}}.
\]  

(8)

The accuracy estimate of the series obtained using the presented formulas is called a point estimate. The interval estimate of the amplitudes, which determines not just a single parameter, but allows us to determine two values between which the amplitudes obtained can vary, is taken into consideration. “Confidence intervals” for the mean (mathematical expectation \( \mu \)) from the obtained amplitudes and for the standard deviation value are obtained using formulas 9 and 10. The confidence probability is equal to \( P=0.95 \), and the estimate precision to \( q=0.05 \).
\[ \bar{x} - t_q \cdot m / \sqrt{N} < a < \bar{x} + t_q \cdot m / \sqrt{N}, \]  
\[ m(1 - g) < \sigma < m(1 + g), \]  
where \( t \) is the coefficient applied in the transition to RMSE, determined according to formulas (9) and (10) with a probability value of \( P = 0.95 \) and an amplitude number \( N \); \( m \) is the RMSE of the amplitude variations; \( g \) is the coefficient obtained from Tables [14] and [13] depending on the number of the estimated amplitudes.

3. Research of quality of the asphalted covering of the highway after its reconstruction.

Table 3 presents the statistic characteristics of the series according to formulas 2-8 indicated above; below the table the interval estimate obtained according to formulas 9, 10 is reported.

**Table 3.** Statistic characteristics of the amplitudes of the upper surface of the coating.

| Interval, mm | Frequency, \( n_i \) | Frequency value, \( x_i, mm \) | Average \( \bar{x}_i \) | \( n_i \) \((\bar{x}_i - \bar{x}) \) | \( n_i(x_i - \bar{x}) \) | \( t_1 \) | \( t_2 \) | \( 1 \) | \( 2 \) | \( 1/2 \) | \( 1/2 \) | \( P(x) \) |
|------------|-------------------|------------------|----------------|-----------------|-----------------|------|------|------|------|------|------|------|
| -36 -27   | 4                 | 0.078            | -31.5          | -126 -31.59 -126.35 | 3991.27 | -2.09 | -1.57 | -0.4817 | -0.4418 | 0.039 | 9     |
| -27 -18   | 4                 | 0.078            | -22.5          | -90 -22.59 -90.35 | 2040.91 | -1.57 | -1.05 | -0.4418 | -0.3531 | 0.088 | 7     |
| -18 -9    | 9                 | 0.176            | -13.5          | -121.5 -13.59 -122.29 | 1661.76 | -1.05 | -0.53 | -0.3531 | -0.2019 | 0.151 | 2     |
| -9 0      | 8                 | 0.157            | -4.5           | -36 -4.59 -36.71 | 168.42  | -0.53 | -0.01 | -0.2019 | -0.0040 | 0.197 | 9     |
| 0 9       | 7                 | 0.137            | 4.5            | 31.5 4.41 30.88 | 136.25  | -0.01 | 0.52  | -0.0040 | 0.1985  | 0.202 | 5     |
| 9 18      | 11                | 0.216            | 13.5           | 148.5 13.41 147.53 | 1978.63 | 0.52  | 1.04  | 0.1985  | 0.3508  | 0.152 | 3     |
| 18 27     | 6                 | 0.118            | 22.5           | 135 22.41 134.47 | 3013.72 | 1.04  | 1.56  | 0.3508  | 0.4406  | 0.089 | 8     |
| SUM       | 51                | 1.0              | 1.0            | 4.5   | 14964.35 | 0.962 | 9     |

\[ \bar{x} = 4.5 / 51 = 0.09 \ mm \]

\[ M = 17.30 / \sqrt{51} = 2.42 \ mm \]

\[ m = \sqrt{14964.35/50} = 17.30 \ mm \]

\[ m_m = 17.30 / \sqrt{2 \cdot (51 - 1)} = 1.73 \ mm \]

Confidence interval for “\( a \)”:

\[ \bar{x} - t_q \cdot M < a < \bar{x} + t_q \cdot M, \]
\[ z \sigma e t_q (N = 51; P = 0.95) = 2.01 \]
\[ 0.09 - 2.01 \cdot 2.42 < a < 0.09 + 2.01 \cdot 2.42 \]
\[ 4.77 \ mm < a < 4.95 \ mm \]

Confidence interval for “\( \sigma \)”:

\[ m(1 - g) < \sigma < m(1 + g), \]
\[ z \sigma e g(N = 51, P = 0.95) = 0.21 \]
\[ 17.3 \cdot (1 - 0.21) < \sigma < 17.3 \cdot (1 + 0.21) \]
\[ 13.66 \ mm < \sigma < 20.57 \ mm \]

The step in each interval amounted to \( \pm 9 \), while their number was equal to seven. The error values turned out to be 17.3. The maximum value of the standard was approximately 21, which does not contradict the normative document on road construction [5]. According to the obtained characteristics, a theoretical and practical amplitude distribution was outlined, as shown in Fig. 1.
Figure 1. Practical and theoretical amplitude distribution of the upper surface of the coating

The null hypothesis on magnitude distribution, which characterizes their normal distribution, was adopted. According to Laplace’s formula 11, the probability is calculated:

$$
\Phi(t) = \frac{1}{\sqrt{2\pi}} \int_{0}^{t} e^{-t^2/2} \cdot dt,
$$

(11)

where $t = (a - \bar{x})/m$ or $t = (b - \bar{x})/m$; $a$ and $b$ are the maximum and minimum values in the interval; $\bar{x}$ is the average mathematical value of the amplitudes; $m$ is the RMSE in amplitude determination.

The probability $\Phi(t)$ is obtained from Tables [11] and [12]; their sum must be equal to one. The subsequent amplitudes according to the results of statistical observations comply with normal distribution. As exemplified by the amplitude series, the hypothesis is plausible. The value $\chi^2$ (chi-square) of Pearson’s test, which is given by formula 12, is considered as the measure of deviation of the hypothesis:

$$
\chi^2_{nabl} = \sum_{i=1}^{k} \left( n_i - NP(x_i) \right)^2 / NP(x_i),
$$

(12)

where $n$ are the empirical frequencies; $NP(x_i)$ are the theoretical frequencies; $k$ is the number of intervals; $P(x_i)$ is the theoretical probability.

In the investigated series of amplitude variation, the value of Pearson’s test $\chi^2$ amounted to 5.45; the calculations are presented in Table 4; the obtained characteristics do not exceed the critical value of 11.1.
Table 4. Definition of Pearson’s test $\chi^2$ for the estimate of the coincidence of the trial and normal distribution of the amplitudes of the upper surface of an automobile road coating.

| Interval, mm | Frequency | Probability $P(x_i)$ | Theoretical frequency $NP(x_i)$ | $n_i - NP(x_i)$ | $\left(n_i - NP(x_i)\right)^2$ | $\frac{\left(n_i - NP(x_i)\right)^2}{NP(x_i)}$ |
|--------------|-----------|----------------------|-----------------------------|-----------------|--------------------------|---------------------------------|
| -36 to -27   | 4         | 0.0399               | 2.0349                      | 1.965           | 3.862                    | 1.90                            |
| -27 to -18   | 4         | 0.0887               | 4.5237                      | -0.524          | 0.274                    | 0.06                            |
| -18 to -9    | 9         | 0.1512               | 7.7112                      | 1.289           | 1.661                    | 0.22                            |
| -9 to 0      | 8         | 0.1979               | 10.0929                     | -2.093          | 4.380                    | 0.43                            |
| 0 to 9       | 7         | 0.2025               | 10.3275                     | -3.328          | 11.072                   | 1.07                            |
| 9 to 18      | 11        | 0.1523               | 7.7673                      | 3.233           | 10.450                   | 1.35                            |
| 18 to 27     | 6         | 0.0898               | 4.5798                      | 1.420           | 2.017                    | 0.44                            |
| SUM          | 51        | 0.9629               |                             |                 |                          | $\chi^2_{\text{calc}} = 5.45$ |

4. Conclusion

In conclusion, the set of EGS performed for the reconstruction of an automobile road with the accuracy estimate of the upper surface of its paved coating was examined. The applied technologies and the conducted research were analyzed, the normative requirements for the accuracy of geodetic works were met, and the appropriate findings were taken into account. In case of reconstruction of an automobile road, technological processes which might ensure the specified accuracy and efficiency were established.

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