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Determination of Length Correction from the Projection and Deformation of Geodetic Controls in the Realization of Precision Linear Structures—A Case Study of the Coordinate System S-JTSK, Czech Republic

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Featured Application: A method for improving geodetic networks for the precise layout of high-cost, large-scale structures such as high-speed railway lines.

Abstract: Long linear constructions, particularly high-speed railway lines, place very high demands on the accuracy of the fundamental geodetic controls on which they are based. In general, national reference coordinate systems possess deformations (relative inconsistencies) due to historical factors—primarily the low accuracy of the measurement methods that were used at the time of their development. The reference coordinate system S-JTSK used in the Czech Republic comprises local deformations that are determined using a modern space geodesy method—the Global Navigation Satellite Systems (GNSS). An analysis of the local deformations revealed that, in the Czech Republic, 99% of the length corrections from the coordinate system deformations are in the interval of −1.4 to +1.4 cm/km with a standard deviation of up to 1.4 cm/km. The extreme value in this regard is the length correction from the deformation of +2.5 cm/km and the standard deviation of 3.6 cm/km. These values exceed the required accuracy of 1 cm/km, and the length corrections from the deformations, together with the length corrections from the used projection, must be taken into account when undertaking surveying work on high-speed railway lines in the Czech Republic (also with the height correction for lengths). The magnitude of the scatter also indicates the distortion of the S-JTSK projection conformality due to the deformations.

Keywords: S-JTSK; length correction; coordinate system deformation

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1. Introduction

Reference coordinate systems are the basis for most geodetic work. They are primarily used for mapping, but they are also used for delineating engineering work and maintaining land registers. Historically, leveling represented a more accurate method of measuring elevation; as a result, coordinate systems are generally divided into horizontal and vertical parts. The first coordinate systems originated from measuring horizontal angles in triangles, i.e., triangulation.

In the territory of the Czech Republic, the first positional coordinate systems were created in the Austro-Hungarian empire in the 19th century using triangulation for the second military mapping [1], for the mapping of the stable cadaster [2], and subsequently for the Central European degree measurement and third military mapping [3].

Based on the military triangulation for the third military mapping, the System of the Unified Trigonometric Cadastral Network (S-JTSK) reference system was created in the 1920s based on the Bessel reference ellipsoid. The measurement of horizontal angles at some of the triangulation stations was adopted from military triangulation, and, in particular, the scale and orientation of the network were adopted.

The reference system S-JTSK is still in use today in the Czech Republic as a geodetic basis for the mapping of new cadastral maps [4], the conversion of older cadastral [5] and topographic maps [6,7], the delineation and surveying of infrastructures (e.g., railways) [8], the connection of mine operations [9], the monitoring of the impact of mining on the surface [10], and other uses. The reference system S-JTSK uses Křovák's cartographic projection [11] for planar coordinates. The Křovák projection comprises two conformal projections: In the first step, the geodetic coordinates based on the Bessel ellipsoid are conformally projected onto a sphere with a reduced diameter using the Gauss conformal projection of the ellipsoid to a sphere; in the second step, the coordinates on the sphere are projected to the mapping surface by a conformal conic projection in the general position, which is a special subtype of the Lambert conformal conic (LCC) projection. The Křovák projection was optimized for the territory of the Czechoslovak Republic in the period 1918–1938, i.e., the general position of the conic projection was optimally selected for the territory of the Czechoslovak Republic. The length scale of the Křovák projection takes values from −10 cm/km on the tangential cartographic parallel in the center of the territory to +14 cm/km on the edges of the territory of the Czechoslovak Republic [12].

With the advent of space geodesy methods—in particular, Global Navigation Satellite Systems (GNSS) technology, the Real-Time Kinematic (RTK) method of measurement [13], and virtual stations implemented by using the networks of permanent stations, i.e., CZEPOS [14]—surveyors have a tool at their disposal that enables rapid and efficient positioning with an accuracy that is sufficient for most applications, in addition to highly efficient delineation, the mapping of unforested and undeveloped areas and linear structures [13], and the monitoring of geodynamics on local [15] and regional scales [16,17].

In contrast with other countries, where the advent of GNSS has resulted in a fundamental change in reference coordinate systems (e.g., Oman) [18] or in countries that are preparing for fundamental changes (e.g., Serbia) [19], in the Czech Republic, the binding reference coordinate system remains the S-JTSK. The use of GNSS is linked to networks of permanent GNSS stations that have coordinates in the European Terrestrial Reference Frame 2000 (ETRF2000). This factor makes it necessary to ensure the transformation of coordinates determined by the GNSS in the ETRF2000 reference frame into the S-JTSK system [20].

The transformation procedure is determined using the S-JTSK/05 working reference system with a modified Křovák projection [21]. The S-JTSK/05 is defined with the geodetic coordinates on the GRS80 ellipsoid of the European Terrestrial Reference System 1989 (ETRS89). For the planar coordinates, the S-JTSK/05 uses the modified Křovák projection, which is defined as the Křovák projection with the addition of biquadratic re-transformation coefficients, using the procedure, e.g., in [22], and re-transformation coefficients, e.g., in [23,24]. The coordinates in the S-JTSK/05 are close to those in the S-JTSK (within 20 cm on average); thus, they are identical to the S-JTSK under the resolution of the cartographic works [25]. In order to obtain the S-JTSK coordinates, differences defined in the territory of the Czech Republic in a regular grid with a step of 2 km must be added to the S-JTSK/05 coordinates. The latest version of the table of differences has the designation 1710 [26], and it was published in 2017. The scheme of transformation from the ETRS89, ETRF2000 geodetic coordinates B, L, H to the planar coordinates Y, X in the S-JTSK is shown in Figure 1.

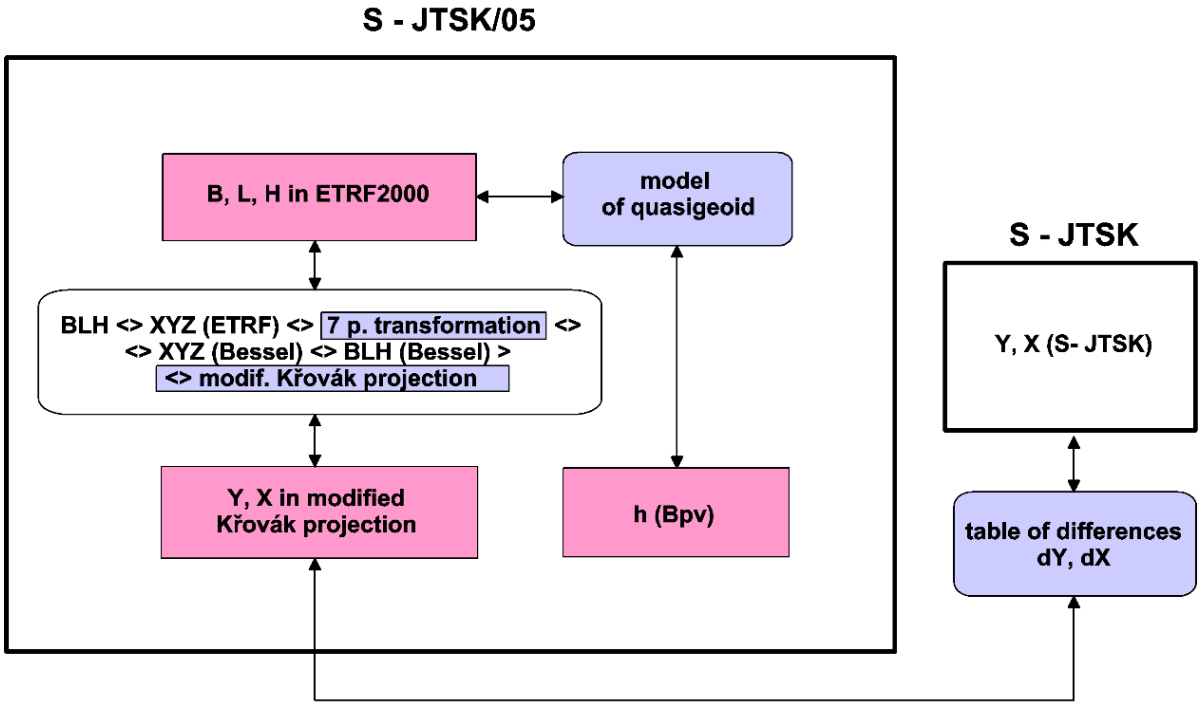


Figure 1. S-JTSK/05 transformation scheme [21].

In the first step, the geodetic coordinates B, L, H (latitude, longitude, and height) in the ETRF2000 reference frame on the GRS80 ellipsoid are converted to the rectangular Cartesian coordinates X, Y, Z. A seven-parametric similarity Helmert transformation with three translations, three rotations, and one scale change is then applied. In this step, the 3D rectangular coordinates are transformed from the ETRF2000 reference frame to the S-JTSK/05 reference frame. Subsequently, the rectangular Cartesian coordinates are converted into the geodetic coordinates B, L, H on the Bessel ellipsoid. Using a modified Křovák projection including the re-transformation, the planar coordinates Y, X are obtained. The ellipsoidal heights H are converted to heights h in the Bpv reference height system using the undulation of the quasi-geoid over the ellipsoid—model CR2005-v1005; see [26].

The S-JTSK system is unsuitable for higher precision work due to local deformations, e.g., for the delineation of linear railway structures [13], especially modern high-speed lines. In such cases, it is necessary to focus on the influence of the S-JTSK deformations on the positioning accuracy—in particular, local changes in the length scale and non-conformities (i.e., the dependence of the length scale change on the azimuth).

In this paper, we present an evaluation of the changes in the S-JTSK length scale when considering the deformations of the system. The method employed is outlined in the following section, and the results obtained are summarized and evaluated in the final section.

2. Calculation of the Length Correction from the Projection and Deformation

There are several techniques for calculating the length correction. In the present case, we used the procedure in which, for a given distance in the S-JTSK coordinate system, the distance in the ETRS89 system on the GRS80 ellipsoid is calculated based on the method presented in [21] or [22]. First, we define two points A and B by their planar coordinates in the S-JTSK. The height of points A and B is assumed to be zero; the length will not be corrected from the convergence of the tangents due to the height (because we assume that the height correction for the lengths will be introduced in the case of construction work

in the field). The distance between points A and B in the S-JTSK will be d_{AB}. The S-JTSK coordinates of points A and B will be converted to planar coordinates in the S-JTSK/05 system using the table of differences and, subsequently, by using the modified Křovák projection and transformations to obtain the geodetic coordinates B, L, H on the GRS80 ellipsoid within ETRF2000; see Figure 1. We performed the transformation using the program *etrf00-jtsk_v1801* [26], which uses the quasigeoid model *cr-2005_v1005.dat* and the table of differences S-JTSK versus S-JTSK/05 *table_yx_3_v1710_TB-obd.dat*—both obtained from [26].

The distance between points A and B on the GRS80 ellipsoid is calculated by solving the second geodesic problem [27]. From the numerous solutions to this problem (e.g., ref. [28–30]), we used the sphere transition solution method, e.g., the method presented in [31], Section 3.3.4.–Solving the second geodesic problem. We calculated the length of the arc and the azimuths at the end points of the curve; however, the azimuths were not required.

The radius of the auxiliary sphere is determined using the following formula:

$$R = \sqrt{MN}, \tag{1}$$

where M is the meridional radius of the curvature, and N is the transverse radius of the curvature at the center point between points A and B. The meridional radius of the curvature is calculated using the following formula:

$$M = \frac{a(1-e^2)}{W^3}, \tag{2}$$

where a is the major axis of the ellipsoid, e is the eccentricity of the ellipsoid, and W is the first geodesic function given for latitude φ, determined by the following formula:

$$W = \sqrt{1 - e^2 sin^2 \varphi}. \tag{3}$$

The eccentricity e is determined by the major a and minor b semi-axes of the respective ellipsoid:

$$e^2 = \frac{a^2 - b^2}{a^2}. \tag{4}$$

The transverse radius of curvature is calculated using the following formula:

$$N = \frac{a}{W}\,. \tag{5}$$

Both radii M and N depend on the parameters of the ellipsoid and the latitude used. For the GRS80 ellipsoid, the basic values of the constants are known, which are the lengths of the semi-axes of the ellipsoid. Therefore, $a = 6378137\ m$ and $b = 6356752.31425\ m$. For the Bessel ellipsoid, the lengths of the semi-axes are $a = 6377397.15508\ m$ and $b = 6356078.96290\ m$.

The auxiliary sphere touches the ellipsoid at the center point P_0; see Figure 2.

The center point is chosen so that

$$P_0(\varphi_0)\ :\ \varphi_0 = \frac{\varphi_A + \varphi_B}{2}. \tag{6}$$

Next, we choose for (P_0):

$$N(\varphi_0) = N_0\ ,\ M(\varphi_0) = M_0 \tag{7}$$

and

$$(\varphi'_B - \varphi'_A)N_0 = (\varphi_B - \varphi_A)M_0, \tag{8}$$

$$\frac{\varphi'_B - \varphi'_A}{2} = \frac{M_0}{N_0}\frac{\varphi_B - \varphi_A}{2} = \omega. \tag{9}$$

The last choice is as follows:

$$\frac{\varphi'_B + \varphi'_A}{2} = \frac{\varphi_B + \varphi_A}{2} = \varphi_0 \tag{10}$$

Adding and subtracting these two equations gives the following:

$$\varphi'_A = \varphi_0 - \omega\ ,\ \varphi'_B = \varphi_0 + \omega. \tag{11}$$

The problem is further solved as a problem on a sphere with the radius R and the coordinates of the points A and B lying on the sphere ($\varphi_{A'}, \lambda_A$ a $\varphi_{B'}, \lambda_B$).

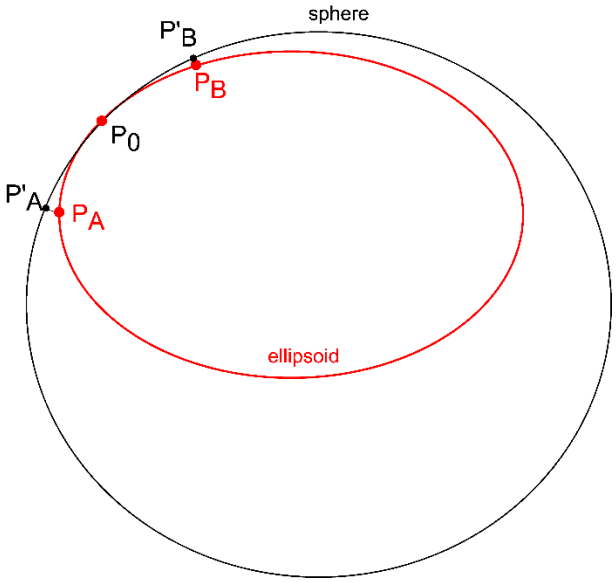


Figure 2. Solving the second geodesic problem by transitioning from an ellipsoid to a sphere R [32].

The length of the arc with s_{AB}, see Figure 3, is calculated using the cosine theorem on a sphere in the following form:

$$\frac{S_{AB}}{R} = arcos\left(sin\varphi'_A sin\varphi'_B + cos\varphi'_B cos\varphi'_B \cos(\lambda_B - \lambda_A)\right). \tag{12}$$

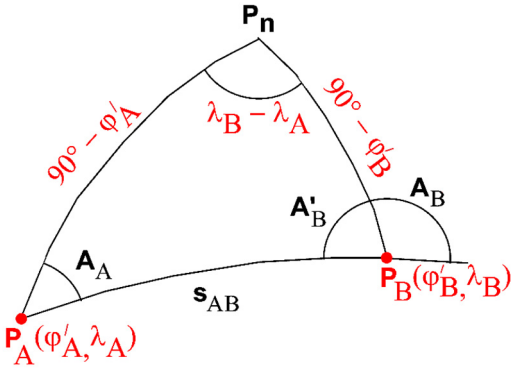


Figure 3. The second geodesic problem on a sphere [32].

To determine the length correction from the projection and the deformation, i.e., the global length correction, the resulting lengths s_{AB} calculated on the ellipsoid using the second geodetic problem were compared with the lengths in the Křovák projection d_{AB}. The desired length correction from the S-JTSK projection and deformation in meters per 1 km of length is calculated from the following relation:

$$\frac{d_{AB} - s_{AB}}{d_{AB}\ [\mathrm{km}]}. \tag{13}$$

The calculation is performed for the entire territory of the Czech Republic in a regular network. Since the deviation table is defined in the S-JTSK coordinate grid with a step of 2 km, it is convenient to choose this S-JTSK coordinate grid as the regular grid. This decision avoids the error in the interpolation of deviations between the S-JTSK and S-JTSK/05. At each node of the grid, we define four points on parallel lines with S-JTSK coordinate axes at a distance of 2 km; see Figure 4.

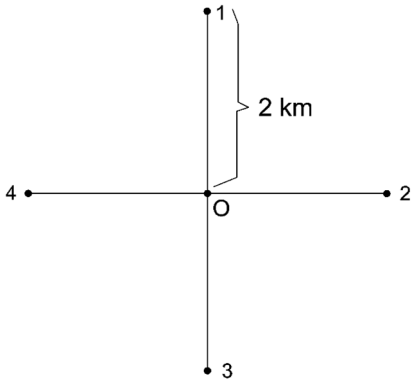


Figure 4. Definition of segments around node [32].

The calculations for the length correction from the S-JTSK projection and deformation at each *O* node for all four links *O-1*, *O-2*, *O-3*, and *O-4* were performed. For the nodes on the edge of the Czech Republic, only three links were defined. The resulting length correction from the S-JTSK projection and deformation at a given node *O* is obtained by averaging all of the defined links (three or four) calculated according to relation (13). In parallel, the standard deviation of the corrections is calculated, which characterizes the variability of the length correction depending on the direction, i.e., the effect of the non-conformity given by the S-JTSK deformation at node *O*. It is possible to study the change in the length correction in north–south vs. east–west directions, but we can't perform that study.

3. Results

If the aforementioned calculation were performed by ignoring the table of differences and using the (original, not modified) Křovák projection, only the corrections to the lengths of the Křovák projection would be presented in the results. The corresponding result is continuous smooth lines; see Figure 5 in [11]. By subtracting these results from the global length correction, i.e., the length correction from the projection and from the deformation, we obtain the length correction from the deformation only.

Using the procedure described in Section 2, the resulting length corrections from the S-JTSK projection and deformation, i.e., the global length corrections, are shown graphically in Figures 6 and 7.

It can be seen that after adding the S-JTSK deformation (from the table of differences and using the modified Křovák projection) to the length correction from the (original)

Křovák projection, the smooth lines (see Figure 5) become "twisted isochores"; see Figure 8 in the axonometric view.

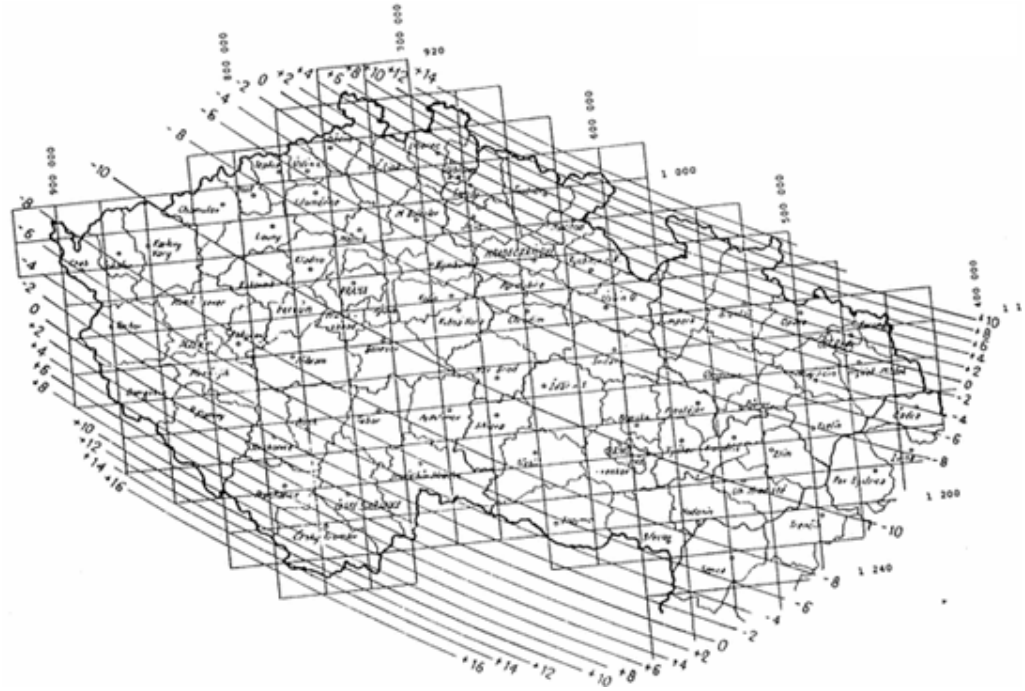


Figure 5. Length distortion in Křovák projection in cm/km [11].

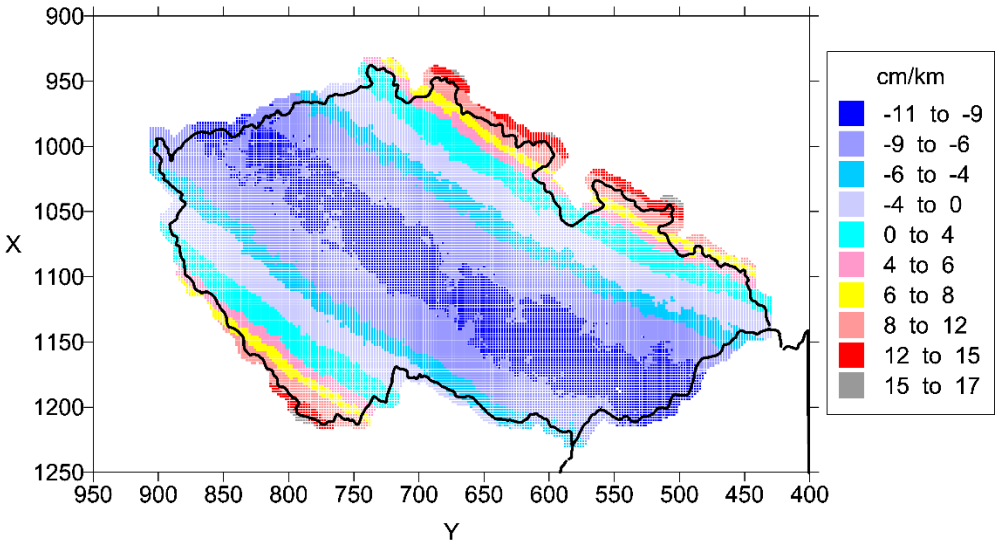


Figure 6. The global length corrections, i.e., the length corrections from the projection and the deformation. A color representation of the correction values at nodes in the 2 km grid [32].

Because it is possible to study the influence of the deformation of the S-JTSK reference system, in the following paragraphs, we do not use the global length corrections; instead, we use only the aforementioned length correction from the deformation. The numerical statistics of the length correction from only the deformations of all nodes with a 2 km step are summarized in Table 1. In Table 2, the frequencies of the length correction values in each interval are shown.

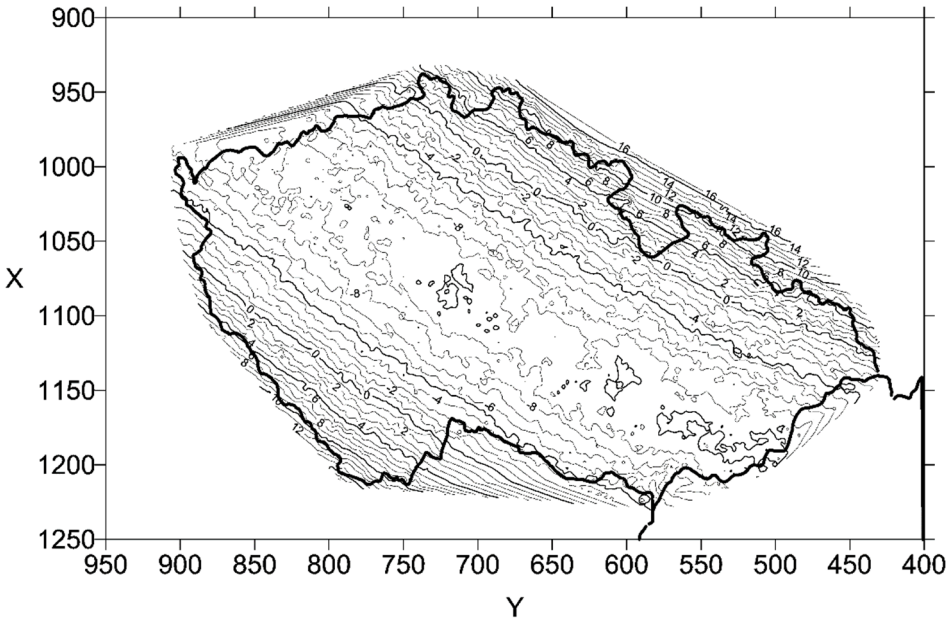


Figure 7. The isolines of the global length corrections, i.e., the length correction from the projection and deformation in cm/km [32].

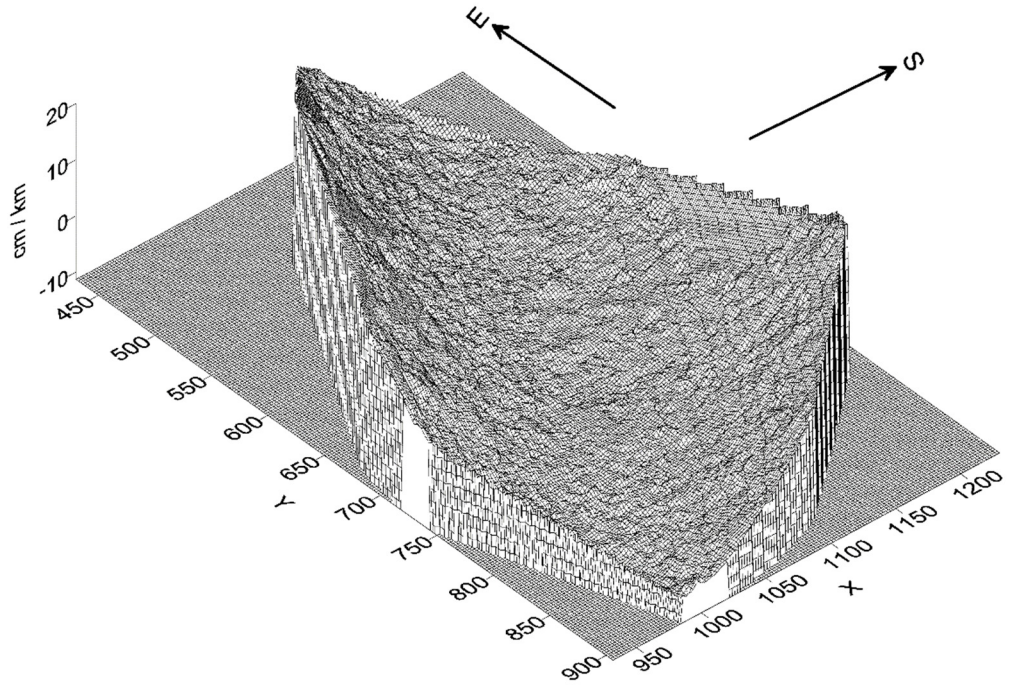


Figure 8. An image ("washbasin") of the global length corrections, i.e., the length correction from the projection and deformation in cm/km [32].

Table 1. Deformation length correction statistics in cm/km.

Average	0.36
Minimum	−1.63
Maximum	+2.50

Table 2. Class frequencies of length corrections from deformation.

Interval of Classes in cm/km	Frequency of Corrections in Classes	Representation in [%]
<−2.0; −1.8>	0	0.00
<−1.8; −1.6>	1	0.00
<−1.6; −1.4>	3	0.01
<−1.4; −1.2>	8	0.04
<−1.2; −1.0>	25	0.11
<−1.0; −0.8>	89	0.39
<−0.8; −0.6>	252	1.11
<−0.6; −0.4>	625	2.75
<−0.4; −0.2>	1263	5.55
<−0.2; 0.0>	2181	9.59
<0.0; 0.2>	3332	14.7
<0.2; 0.4>	4296	18.9
<0.4; 0.6>	4366	19.2
<0.6; 0.8>	3134	13.8
<0.8; 1.0>	1760	7.74
<1.0; 1.2>	819	3.60
<1.2; 1.4>	360	1.58
<1.4; 1.6>	155	0.68
<1.6; 1.8>	49	0.22
<1.8; 2.0>	13	0.06
<2.0; 2.2>	8	0.04
<2.2; 2.4>	1	0.00
<2.4;2.6>	1	0.00
<2.6; 2.8>	0	0.00
<2.8; 3.0>	0	0.00

Figure 9 shows the frequencies from Table 2. The results show that 99% of the length correction values from the coordinate system deformations lie in the interval of −1.4 to +1.4 cm/km. However, the mean value is not zero; it is approximately +0.3 cm/km. This result is expected from the statistics presented in Table 1 and indicates a residual change in the scale of the S-JTSK reference system relative to the ETRF2000 reference frame, which was not removed within the seven-parameter Helmert similarity transformation. However, it corresponds to the accuracy of the S-JTSK implementation.

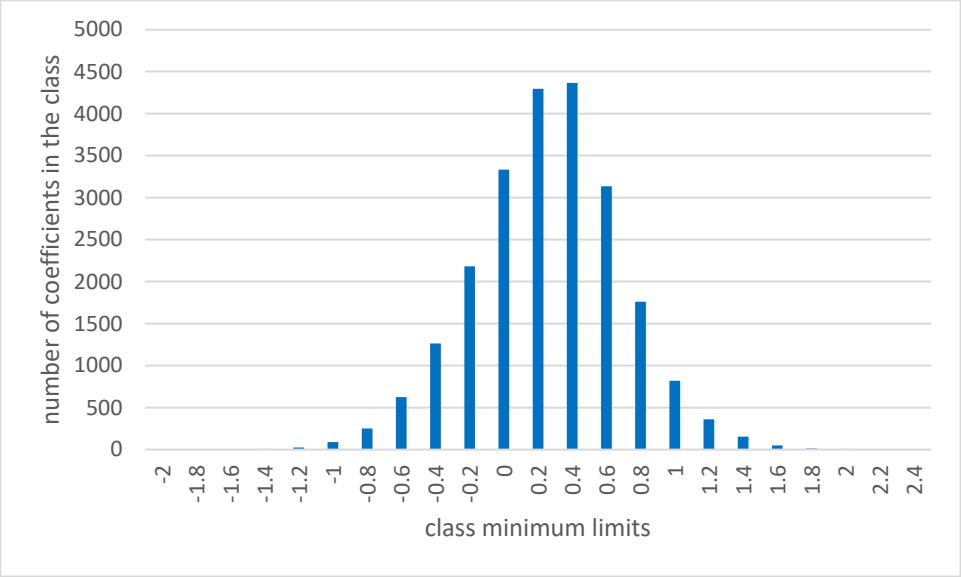


Figure 9. Class frequencies of length corrections from deformation.

Figure 10 is a graphical representation of the resulting standard deviations from the length correction average at each node. As in the case of the graphical plot of the resulting corrections, the standard deviations have been color-coded according to the values obtained and expressed as dots. It was not possible to determine the systematic behavior of the standard deviations.

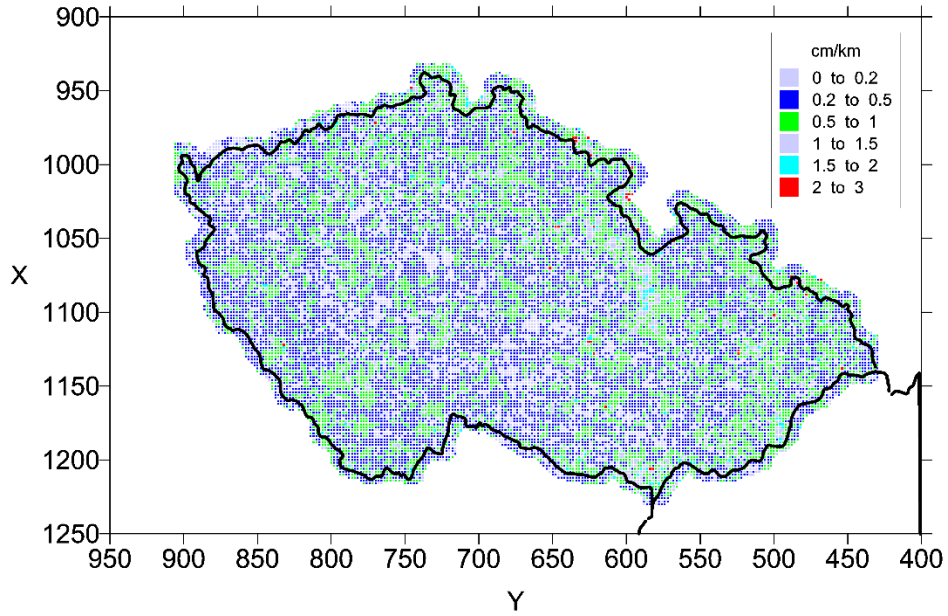


Figure 10. A graphical representation of the resulting standard deviations from the length correction averages at each node [32].

In Table 3, the standard deviation statistics from all nodes after 2 km are shown. In Table 4, the frequencies of the length corrections in each interval are displayed.

Table 3. Statistics representing the standard deviations from the length correction averages at the nodes in cm/km.

Average	0.47
Minimum	+0.01
Maximum	+3.61

Table 4. The class frequencies of the standard deviations from the length correction averages at the nodes.

Interval of Classes in cm/km	Frequency of Standard Deviations in Classes	Representation in [%]
<0.0; 0.2>	3017	13.3
<0.2; 0.4>	7960	35.0
<0.4; 0.6>	5916	26.0
<0.6; 0.8>	3089	13.6
<0.8; 1.0>	1506	6.62
<1.0; 1.2>	623	2.74
<1.2; 1.4>	329	1.45
<1.4; 1.6>	151	0.66
<1.6; 1.8>	76	0.33
<1.8; 2.0>	31	0.14
<2.0; 2.2>	21	0.09
<2.2; 2.4>	10	0.04
<2.4; 2.6>	6	0.03
<2.6; 2.8>	2	0.01
<2.8; 3.0>	2	0.01
<3.0; 3.2>	1	0.00
<3.2; 3.4>	0	0.00
<3.4; 3.6>	0	0.00
<3.6; 3.8>	1	0.00

In Figure 11, the frequencies from Table 4 are displayed. It can be seen that 99% of the standard deviations of the length corrections from the deformations of the coordinate

system lie within the interval of up to +1.4 cm/km. The mean value of the standard deviations is approximately 0.2 cm/km.

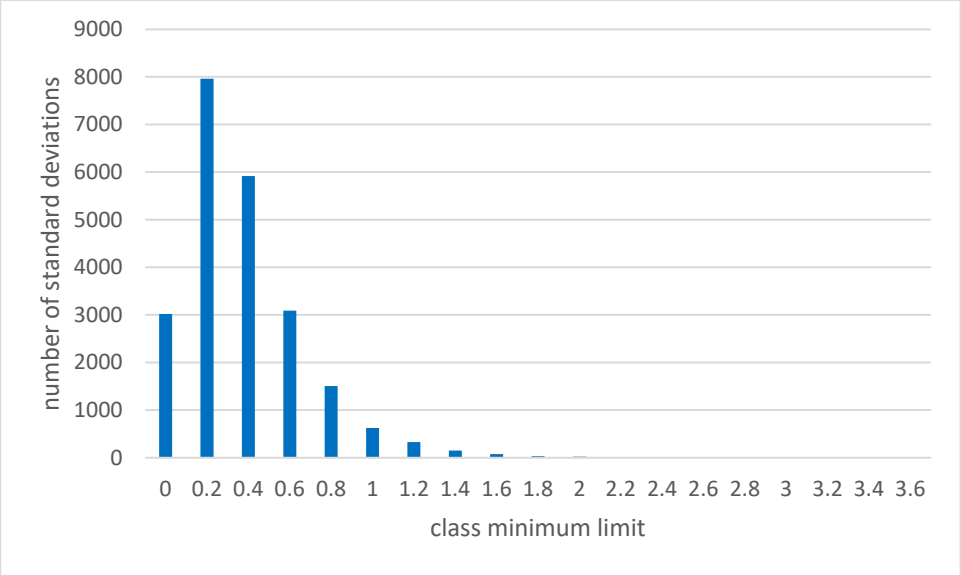


Figure 11. The class frequencies of the standard deviations from the length correction averages at the nodes in cm/km.

4. Evaluation and Conclusions

The results presented in Figures 6 and 7 show that the dominant influence is the length correction from the projection, which takes the values of −10 cm/km on the tangential cartographic parallel running through the center of the Czech Republic and +14 cm/km on the edges of the Czech Republic [11]. The average value of the length correction from the deformations of the reference system is 0.36 cm/km; in the extreme case, the value is +2.5 cm/km; see Table 1. The above value is a negligible value for most common surveying work. An exception involves work in the field of railway surveying [13], where (particularly for high-speed lines) there is a requirement for an accuracy level of 1 cm/km. Therefore, it is necessary to combine the length corrections from the (original) Křovák projection and S-JTSK deformations (along with the introduction of the height correction for lengths, a factor that was not considered in the present study).

Based on the results presented in Figure 9, the standard deviation of the determination of the length correction, which characterizes not only the accuracy of the determination but also the dependence of the length correction on the azimuth, i.e., the non-conformity, takes values in 5% of the area up to 1.0 cm/km. The results presented in Table 4 show that 99% of the values of the standard deviation of the length corrections from the deformations of the coordinate system lie in the interval up to ±1.4 cm/km. The average standard deviation is 0.47 cm/km, with an extreme value of 3.6 cm/km; see Table 3. The scatter is characterized by the variability of the length correction with the azimuth, i.e., the non-conformity of the projection caused by the deformations in the coordinate system. For linear constructions that demand high precision, it is necessary to take this fact into account in geodetic works in locations with a standard deviation greater than 1 cm/km, which can be identified in Figure 10. In such a case, it should be considered whether it would be more beneficial for developers of a given project to define a local coordinate system with planar coordinates using a low-distortion map projection.

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Abbreviations

The following abbreviations are used in this manuscript:

CZEPOS	State network of permanent stations for localization in the Czech Republic
ETRF2000	European Terrestrial Reference Frame 2000
ETRS89	European Terrestrial Reference System 1989
GNSS	Global Navigation Satellite Systems
GRS80	Geodetic Reference System 1980
LCC	Lambert conformal conic projection
RTK	Real-Time Kinematic
S-JTSK	System of the Unified Trigonometric Cadastral Network
S-JTSK/05	Working version of S-JTSK

References

1. Cada, V.; Vichrova, M. Horizontal Control for Stable Cadastre and Second Military Survey (Franziszeische Landesaufnahme) in Bohemia, Moravia and Silesia. *Acta Geod. Geophys. Hung.* **2009**, *44*, 105–114. [CrossRef]
2. Berkova, A. Digitized Cadastral Map from a Point of View of Compiler from Geometric Plan. *Acta Montan. Slovaca* **2007**, *12*, 318–324.
3. Cechurova, M.; Veverka, B. Cartometric Analysis of the Czechoslovak Version of 1:75 000 Scale Sheets of the Third Military Survey (1918–1956). *Acta Geod. Geophys. Hung.* **2009**, *44*, 121–130. [CrossRef]
4. Gasincova, S.; Gasinec, J.; Hudeckova, L.; Cernota, P.; Stankova, H. Analysis of the Usability of the Maps from the Former Cadastre of Lands in Terms of Parcels Area Registered in the Cadastral Documentation. *Inz. Miner. J. Pol. Miner. Eng. Soc.* **2018**, *2*, 191–200.
5. Berkova, A. Cadastral Map Supersession Acording New Instructions. *Acta Montan. Slovaca* **2009**, *14*, 12–18.
6. Skokanova, H.; Havlicek, M. Military Topographic Maps of the Czech Republic from the First Half of the 20th Century. *Acta Geod. Geophys. Hung.* **2010**, *45*, 120–126. [CrossRef]
7. Mackovcin, P.; Jurek, M. New Facts About Old Maps of the Territory of the Former Czechoslovakia. *Geografie* **2015**, *120*, 489–506. [CrossRef]
8. Bartonek, D.; Bures, J.; Svabensky, O. Optimized GNSS RTK Measurement Planning for Effective Point Occupation via Heuristic Analysis. *Eng. Comput.* **2017**, *34*, 90–104. [CrossRef]
9. Cernota, P.; Stankova, H.; Fecko, P.; Pospisil, J.; Bedrunka, M. Connecting and Orientation of the Horizon of Mine Workings. In Proceedings of the 11th International Multidisciplinary Scientific Geoconference (SGEM 2011), Albena, Bulgaria, 18–24 June 2011; Volume I, pp. 735–742.
10. Kovanic, L. Geodetic Monitoring of the Mine Activities Impact Using GNSS Technology and Ensuring Visualization of Results in GIS. In Proceedings of the 13th International Multidisciplinary Scientific Geoconference (SGEM 2013), Geoconference on Informatics, Geoinformatics and Remote Sensing, Conference Proceedings, Albena, Bulgaria, 16–22 June 2013; Volume II, pp. 221–228.
11. Veverka, B. Krovak's Projection and Its Use for the Czech Republic and the Slovak Republic. In *50 Years of the Research Institute of Geodesy, Topography and Cartography: Jubilee Proceedings, 1951–2004*; Holota, P., Ed.; Research Institute of Geodesy, Topography and Cartography Publications: Zdiby, Czech Republic, 2005; Volume 50, pp. 173–179.

12. Gasinec, J.; Gassincova, S.; Trembeczka, E. Derivation of Simplified Formulas for the Approximate Calculation of the Meridian Convergence and Scale Error in Krovak Projection. *Inz. Miner. J. Pol. Miner. Eng. Soc.* **2014**, *15*, 77–84.
13. Bartonek, D.; Bures, J. Usage of Heuristic Algorithm for Optimization of Precise GNSS RTK Measurement. In Proceedings of the 15th International Multidisciplinary Scientific Geoconference (SGEM), Informatics, Geoinformatics and Remote Sensing, Albena, Bulgaria, 18–24 June 2015; Volume I, (SGEM 2015). pp. 899–906.
14. Nevosad, Z. To RTK points in CZEPOS Network. *Acta Montan. Slovaca* **2007**, *12*, 482–486.
15. Svabensky, O.; Weigel, J. Long-term Positional Monitoring of Station VYHL of the Sneznik Network. *Acta Geodyn. Geomater.* **2007**, *4*, 201–206.
16. Pospisil, L.; Svabensky, O.; Rostinsky, P.; Novakova, E.; Weigel, J. Geodynamic Risk Zone at Northern Part of the Boskovice Furrow. *Acta Geodyn. Geomater.* **2017**, *14*, 113–129. [CrossRef]
17. Weiss, G.; Gasinec, J.; Zeliznakova, V.; Gasincova, S. Using the Total Least Square Method by Deformation Strain Analyses of the Eastern Edge Eastern Tatras. *Inz. Miner. J. Pol. Miner. Eng. Soc.* **2014**, *1*, 213–226.
18. Al-Toobi, Y.; Al-Hashmi, S.; Al-Busaidi, B.; Al-Balushi, I.; Ses, S. Establishment of new Oman National Geodetic Datum ONGD14. *Surv. Rev.* **2015**, *47*, 418–428. [CrossRef]
19. Ristic, K.; Tucikesic, S.; Milinkovic, A. Inventarization of the Benchmarks NVT II Network in the Field of the Republic of Srpska and Application of DGNSS Technology. In *Advanced Technologies, Systems and Applications III*; Lecture Notes in Networks and Systems; Springer: Cham, Switzerland, 2019; Volume 60, pp. 213–223. [CrossRef]
20. Seidl, M.; Trasak, P. PPROJ.4 Cartographic Projection Library as 3D Transformation Tool in Czech Context. In Proceedings of the 14th International Multidisciplinary Scientific Geoconference (SGEM), Geoconference in Informatics, Geoinformatics and Remote Sensing, Albena, Bulgaria, 17 June 2014; Volume II, pp. 395–401.
21. Kostelecký, J.; Cimbálník, M.; Čepek, A.; Douša, J.; Filler, V.; Kostelecký, J.; Nágl, J.; Pešek, I.; Šimek, J. Implementation of S-JTSK/05. *Geod. Cartogr. Rev.* **2012**, *58*, 145–154. Available online: https://uazk.cuzk.cz/mrimage/vademecum/proxy/cz/others/zeus/knih/dao/documents/0001/4ee053f6-83e6-46ac-8081-d257ce19e221.pdf (accessed on 2 February 2025). (In Czech)
22. Kostelecký, J.; Kostelecký, J.; Pešek, I. Conversion Methodology Between ETRF2000 and S-JTSK. VÚGTK and ČVUT in Prague, July 2010. Available online: https://docplayer.cz/34890599-Metodika-prevodu-mezi-etrf2000-a-s-jtsk-varianta-2.html (accessed on 2 February 2025). (In Czech)
23. Nágl, J.; Řezníček, J. Calculation of the new version of the conversion tables for the refined global transformation between the S-JTSK and ETRS89 reference systems (version 2017-10). *Geod. Cartogr. Rev.* **2018**, *64*, 213–221. Available online: https://uazk.cuzk.cz/mrimage/vademecum/proxy/cz/others/zeus/knih/dao/documents/0001/804dc8f9-8cbb-455a-bebb-06d8a6323b94.pdf (accessed on 2 February 2025). (In Czech)
24. Kostelecký, J. *Global Position Coordinate Systems*; Czech Technical University in Prague: Prague, Czech Republic, 2019; ISBN 978-80-01-06571-6. (In Czech)
25. Cimbálník, M.; Veverka, B. Czech Technical University, Faculty of Civil Engineering, Prague, Czech Republic. Personal communication, 1996.
26. State Administration of Land Surveying and Cadastre. Principles for the Use of Programs etrf00-jtsk_v1012, etrf00-jtsk_v1203 and etrf00-jtsk_v1801 for the Transformation of the Results of Measurement Activities for the Needs of the Real Estate Cadastre of the Czech Republic. State Administration of Land Surveying and Cadastre. Prague. Available online: https://www.cuzk.cz/Zememerictvi/Geodeticke-zaklady-na-uzemi-CR/GNSS/etrf00-jtsk-v1012-a-etrf00-jtsk-v1203.aspx (accessed on 2 February 2025). (In Czech)
27. Vincenty, T. Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. *Surv. Rev.* **1975**, *23*, 88–93. [CrossRef]
28. Sjobeg, L.E.; Shirazian, M. Solving the Direct and Inverse Geodetic Problems in the Ellipsoid by Numerical Integration. *J. Surv. Eng. ASCE* **2012**, *138*, 9–16. [CrossRef]
29. Panou, G.; Delikaraoglou, D.; Korakitis, R. Solving the geodesics on the ellipsoid as a boundary value problem. *J. Geod. Sci.* **2013**, *3*, 40–47. [CrossRef]
30. Karney, C.F.F. Algorithms for geodesics. *J. Geod.* **2013**, *87*, 43–55. [CrossRef]
31. Vykutil, J. *Advanced Geodesy*; Kartografie Praha: Prague, Czech Republic, 1982; 544p, ISBN 29-620-82. (In Czech)
32. Pacinek, E. Relationship Between ETRS89 and S-JTSK: Determination of Length Correction from Projection and from S-JTSK Deformation. Diploma Theses, Technical University of Ostrava, Faculty of Mining and Geology, Department of Geodesy and Mining Surveying, Ostrava, Czech Republic, 2022. (In Czech)

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