

HORIZONTAL CONTROL FOR STABLE CADASTRE AND SECOND MILITARY SURVEY (FRANZISZEISCHE LANDESAUFAHME) IN BOHEMIA, MORAVIA AND SILESIA

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The paper deals about significant projects of large scale mapping at the beginning of 19th century in the Habsburg Empire. They have been already based on uniform geodetic horizontal control. Basic parameters and features of Second Military Survey in the territory of the Czech Lands as well as links with project of Stable cadastre are delineated. Technology of establishing the horizontal control (1st order trigonometric networks) is described in detail. Qualitative parameters of geodetically measured data and the survey documentation are analysed. Accuracy analysis of angular measurements and methodology of co-ordinate computations in the Gusterberg co-ordinate system are also discussed.

By means of identical points the horizontal control enables unambiguous transformation from the Gusterberg and St. Stephen co-ordinate systems into the national co-ordinate system (JTSK) or WGS 84 with the accuracy higher than graphical accuracy of original maps. This transformation, published here as the global transformation key (GTK), is of great importance. The results of tests of GTKs compiled separately for Bohemia and Moravia+Silesia together with the analysis of contact zone of both above mentioned historical co-ordinate systems are introduced.

As an example of GTK application georeferenced map sheets from Second Military Survey are presented. GTKs are of fundamental importance in unification of heterogeneous geodetic information files of cadastre of real estates in the Czech Republic.

Keywords: Bohemia; global transformation key; land register; Moravia; Second Military Survey; Silesia; stable cadastre; topographic maps

Introduction

In the first half of 19th century the project of Second Military Survey (1806–1869; Kretschmer et al. 2004) as well as the mapping for establishing of Stable cadastre (1817–1869; Hofstätter 1989) have been realized in Austria. They issued from the newest scientific knowledge, which has not been surpassed in some aspect as yet (mapping works based on uniform horizontal control and unified cartographic means of expression).

In the territory of Bohemia, Moravia and Silesia a modified technology of topographic maps of Second Military Survey has been used, exploiting reduced planimetry from the maps of Stable cadastre. Mapping for this campaign was derived from areal trigonometric network, which was established systematically and geodetically measured networks of 1st–3rd order. It was further densified by graphical triangulation (4th order) with the accuracy higher than the accuracy of measuring table method used in the 1:2 880 cadastral mapping.

Thanks to preservation of the survey documentation — field books with horizontal angles, topographical description of survey stations ("Royal trigonometric cadastral survey... (in German)", 1824–1840), computations (angle adjustment in triangles, co-ordinate computation) and resulting list of co-ordinates ("Bohemian transformation of co-ordinates to the meridian of Prague (in German)") — it was possible to reconstruct horizontal control, analyze the accuracy and to exploit these values for unambiguous transformation of Stable cadastre co-ordinate systems into the national co-ordinate reference system JTSK (Uniform Trigonometric Cadastral Network). This process of exploiting the historical horizontal control has not been published in the technical literature so far.

Cartographic foundations

Transversal cylindrical projection equidistant both in cartographic meridians and one tangential geographic meridian (cartographic equator) has been chosen for construction of maps from Second Military Survey and maps of Stable cadastre. The geographic meridian passed through the centre of mapped area. The origin of co-ordinate reference system was a significant station of the trigonometric network, e.g. Gusterberg or St. Stephen in Vienna (Fig. 1).

Decision to choose more co-ordinate reference systems was motivated by the effort to compile easily the maps of administrative regions, countries and the whole state using reduced original maps of Stable cadastre. Another reason was the necessity to minimize linear distortion of cartographic parallels of selected projection in marginal parts of represented area to the level of graphical accuracy of maps in 1:2 880 scale.



Fig. 1. Choice of co-ordinate systems

Horizontal control

History of horizontal control in Bohemia, Moravia and Silesia is very extensive. As early as 1806–1811 astronomical-geodetical works have been initiated and so in 1819 the whole territory of the Czech Lands was covered with the area trigonometric network that became a base for Second Military Survey project. These works have been further developed for the needs of Stable cadastre applying modern scientific knowledge of that time.

1st order network has been established in Moravia and Silesia (1821–1826) and followed in Bohemia (1824–1825 and 1827–1840) (Fig. 2). 2nd and 3rd order networks have been established according to needs of topographic mapping in Moravia (1822–1829) and Bohemia (1825–1840). 1st order triangulation stations enabled to place the theodolite for angular measurement while church towers were allowed to use in 3rd order triangulation only. Area trigonometric network in Bohemia incorporated 2 623 stations of 1st to 3rd order (5 stations per 100 km²) in the Gusterberg co-ordinate reference system. Similar network in Moravia incorporated 1069 stations (4 stations per 100 km²) in St. Stephen co-ordinate reference system. Sensitive choice of stations, minimal expenses and thorough organization were typical features of that project.



Fig. 2. Station of astronomical triangulation Kohlrang from 1808 (district Cheb, cadastral unit Skalná)

Table I. Number of stations numerically determined in Bohemia, Moravia and Silesia

Type of station	Number of stations		Cartographic representation	
	Bohemia	Moravia	In chart	In the map of SC
Common constructions for signalling, pyramids	1669	784	○	
Church towers	587	120	⊕	
Castles, ruins, chapels, various buildings, masonry and wooden crosses, etc.	47	27	●	
Trees or signal bars	299	102	■	

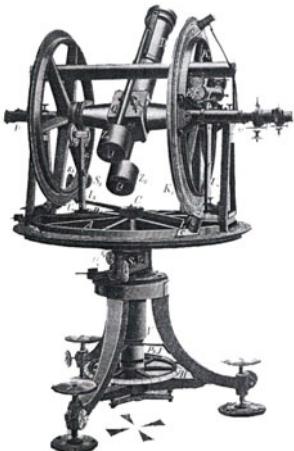


Fig. 3. Reichenbach's repetition theodolite for astro-geodetic measurement



Fig. 4. Reichenbach's repetition theodolite for angular measurement

Number of stations numerically determined in Bohemia, Moravia and Silesia is evident from Table I including type of their signalling.

Reichenbach's repetition theodolites (Figs 3, 4) have been used for angle measurements (horizontal angles of 1st order network twelve times, zenith angles three times). An average closure error after consideration of spherical excess reached $2.1''$, maximum value $9.8''$. All distance measurements have been carried out in the fathom measure. The network dimension was derived from 4 geodetical bases (Wiener Neustadt in Lower Austria, Wels in Upper Austria, Radauti in Romania and Hall in Tyrol). Voluminous documentation of triangulation for Stable cadastral in Bohemia, Moravia and Silesia has been saved in archives and nowadays is accessible at the Land Survey Office in Prague (Fig. 5).

Measured vertex angles were corrected by $1/3$ of spherical excess (average value $2.91''$). The accuracy of measured angles in individual triangulation sections is shown in Table II.

Table II. The accuracy of measured angles

	Triangulator					
	Schmitt 1824-1825	Henner 1824	Brodský 1825	Catharin 1826-1827	Waldhof 1836	Waldhof 1839
Mean error of measured direction	1.36"	2.65"	0.99"	1.91"	2.32"	2.75"
Mean value of triangle closures	-2.33"	-5.22"	-0.50"	-3.58"	-4.88"	1.11"
Mean value of station closure	-2.50"	-5.80"	-0.75"	-	-	-

Resulting accuracy reached in the 1st order triangulation in Bohemia was expressed by the mean error of measured direction 1.91", average mean error of triangle closure 2.40" and average mean error of station closure -2.73".

Co-ordinates of 1st order triangulation stations were expressed in the Stable cadastre systems (plane co-ordinates). The computation has been carried step-by-step in sections so that determining figures contained one central point. Co-ordinate differences from comparing the results of computation in other figures have been adjusted by calculating the averages. Detailed information can be found in (Čada 2005).

Resulting lists of co-ordinates for Bohemia, Moravia and Silesia were accepted from the documentation "Bohemian transformation of co-ordinates to the meridian of Prague (in German)". Tables of co-ordinates of 1st-3rd triangulation station, organized according to administrative region of that time, are stored in the Archives of Land Survey Office in Prague now.

Quality of above mentioned trigonometric network has been verified by Least Square method as the supplementary network in JTSK system. Identical triangulation stations in Stable cadastre and JTSK have been found mostly on church and chateau towers or lookout towers or as stations with original monuments. Former incorrect computation of 1st order network in individual sections caused the fact that a posterior test of adjustment showed larger mean square errors of directions than the errors of original angular measurement. The value of a posterior mean square error of measured direction reached as many as 9" and maximum correction of adjusted direction Bömerwald-Czebon 22".

The adjustment of 1st order network showed also systematically larger corrections of triangulation carried out by Brodsky in 1825 (southwest Bohemia) and by Henner in 1824 (northeast Bohemia). The largest corrections were found in the Loket region triangulated by Waldhof in 1839 twelve years later than in the surrounding regions. Maximum mean square co-ordinate error $m_{xy} = 2.9$ m was detected in the Rossbach triangulation station.

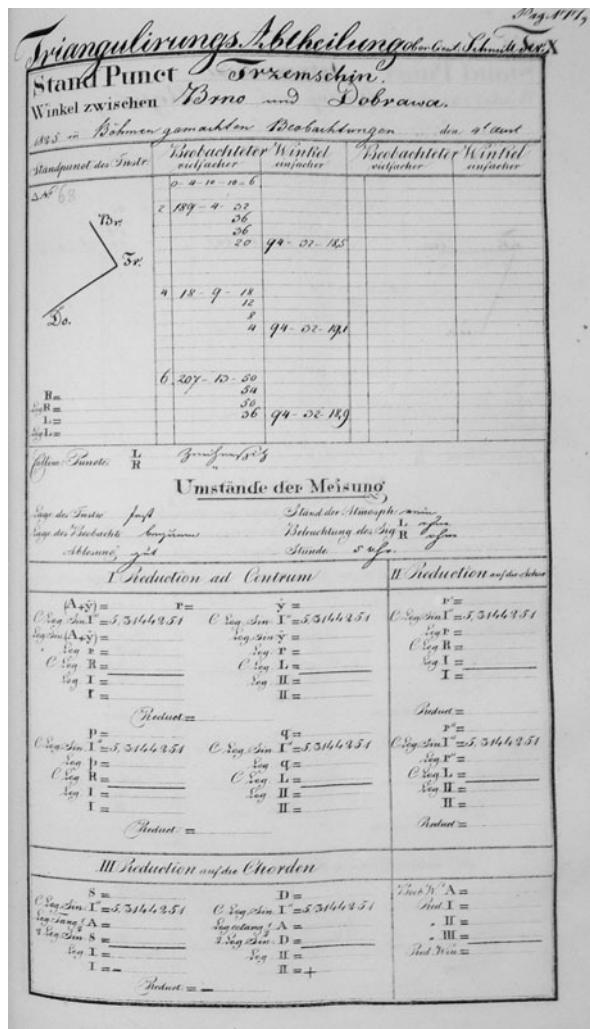


Fig. 5. Field book of horizontal angles in the 1st order trigonometric network (Wesseli station, triangulator Schmitt) ("Royal trigonometric cadastral survey... (in German)", 1824–1840)

The Czechoslovak Uniform Trigonometric Network of Cadastre (JTSK) has been established in 1920–1957 as standard geodetic foundations for all land survey activities. It was bound with the system of Stable cadastre by means of still existing former triangulation stations. Their position has been obligatory determined in the JTSK system, which is based on double conformal conical projection in oblique position. Continuity in establishing the horizontal control in the territory of the Czech Republic facilitated the use of horizontal control to mutual unambiguous transformations of original co-ordinate systems of Stable cadastre into contemporary co-ordinate systems.

Co-ordinates of above mentioned triangulation stations have been used to compilation of “global transformation keys” enabling unambiguous transformation of positional co-ordinates given in Gusterberg or St. Stephen co-ordinate reference systems into contemporary Czech national reference system (JTSK) aptly WGS 84 system. These global transformation keys are important components of technology for digitizing the cadastral maps and georeferencing of topographic maps originated from the Second Military Survey (1806–1869).

More authors have been actively engaged in georeferencing the maps of Second Military Survey in the past. They often used subjectively chosen identical points of planimetry (settlements, crossroads, junction of rivers and things like that) or searched for mutual relation of original and contemporary cartographic foundations (datum and cartographic projections) (see e.g. Timár et al. 2006, 2007).

The use of plane co-ordinates of identical stations in original and contemporary horizontal control of the Czech Republic also enables mutual transformation between both Stable cadastre systems with the higher accuracy than is graphical accuracy of respective cadastral maps (large scale maps). In this way the accuracy expressed by the mean square error from differences between co-ordinates of stations creating the triangulation chain reached the value $m_{xy} = 0.47$ m (more detail see by Čada 2003). The use of GTK method resulted in eliminating of local inhomogeneities caused by systematic errors. Graphical representation of planimetric differences at identical triangulation stations is the topic of Fig. 6.

Conclusion

Applications of global transformation keys (GTK) in digitizing of contemporary cadastral maps in the Czech Republic as well as the results of georeferencing the old maps from Second Military Survey definitely manifest contributions of studies of original horizontal control. Reliable georeferencing of topographic maps from Second Military Survey discovered admirable quality parameters of this state map series of Austrian monarchy in the 19th century.

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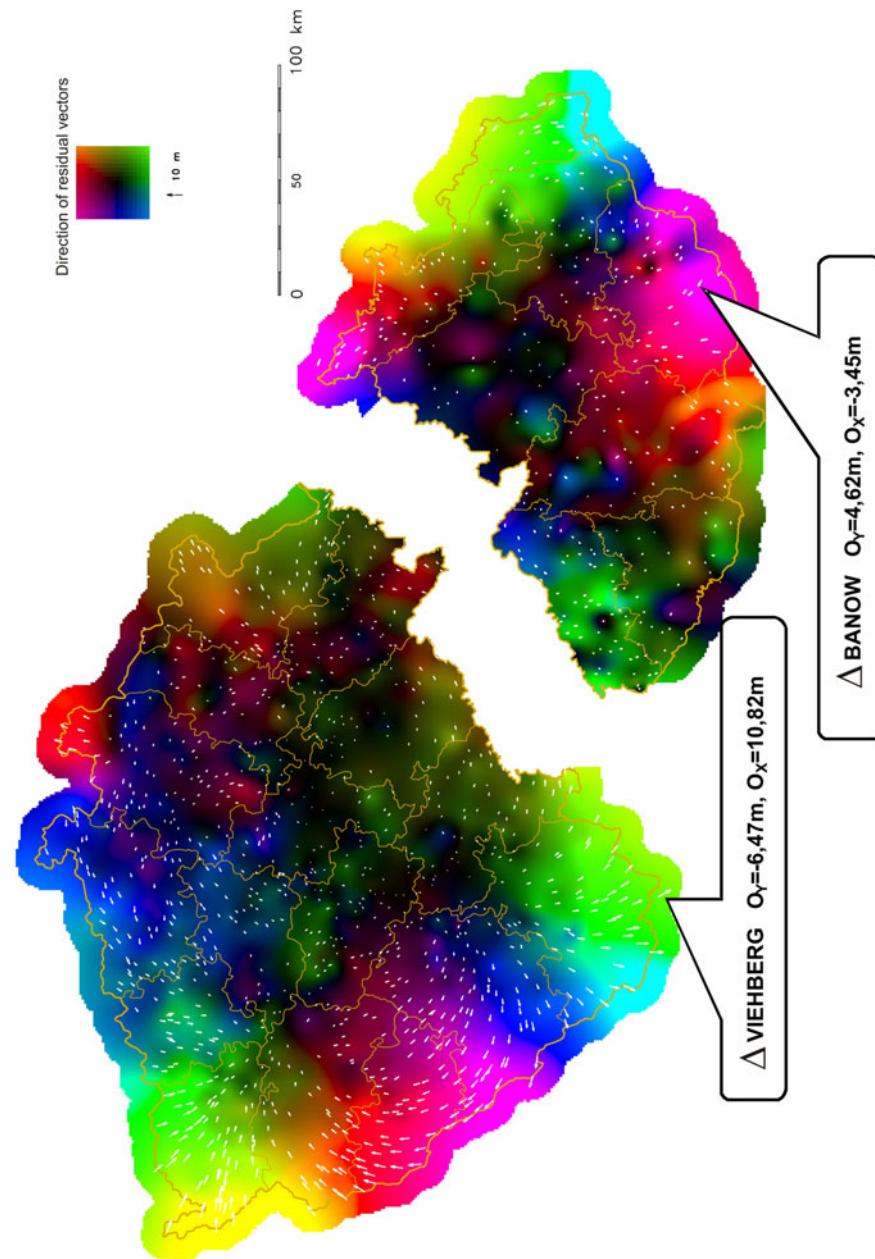


Fig. 6. Visualization of gradients of differences at identical points in Bohemia, Moravia and Silesia (original see by Čada 2003)

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