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A PRINCIPLE OF FORMING AND DEVELOPING GEODETIC BASES IN THE CZECH REPUBLIC

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Abstract. The development of satellite geodesy and creation of geocentric and geodetic bases have become an impulse for the integration and modernization of national geodesic bases into the global continental frame. In the area of cadastral practice classic planar coordinate systems and established figures have been used for a long time. Nowadays, searching for the relationship between standard (classic) geodetic systems and the newly existing geocentric system is still the current issue of geodetic practice.

Keywords: Stable Cadastre, geodesic bases, spatial reference system, classic coordinate system and cadastral system.

1. Introduction

Development of the GPS technology and establishment of geocentric geodetic bases represents an impulse for integration of national geodetic systems into global continental frame. In the Czech Republic, the geocentric system ETRS89 is performed using the points of NULRAD and DOPNUL networks coordinates. DGNSS (Differential Global Navigation Satellite System) and the network of permanent stations CZEPOS (Czech Position System) became further component of global spatial network.

For searching mutual relationships between classic planar coordinate systems (S-SK, S-JTSK) and geocentric system (ETRS89) it is the most important to find out suitable identical points. These points should meet following conditions:

- to find out coordinates in all three coordinate systems (SK, JTSK, ETRS89),
- arose thru determination from direct survey, i.e. point coordinates were not derived,
- are original (were not re-stabilized),
- it is possible to estimate the accuracy for point coordinates determination.

To meet the above mentioned terms stipulated for the properties of identical points, it is necessary to study and familiarize the origin of coordinate systems SK, JTSK and ETRS89 in detail, it means both with general principles and with the history of establishment the coordinate systems at the territory of interest (territory of Brno), to deepen knowledge on applied surveying methods, instrumentation and used cartographic imaging. To facilitate seeking for both contemporary and historical basic documents, it is necessary to remember the position of sheets of maps for particular systems, even though marginally.

2. Origins and Development of Stable Cadastre

First idea to establish stable cadastre is dated on 1800 (Cafourek 1967). However, the trial of performance took place not before 1805. Thru rule of ordered by the emperor Franz I, the joined Office of the Court was called, to elaborate a proposal of uniform tax allocation. However, said office was very busy due to Napoleon wars, so Emperor Franz I thru a Cabinet letter on land – tax treatment established the Commission of the Court headed by president – count Kristian Wurmser (Šimek 1941).

Objective for the commission was to evaluate contemporary cadastral documentation and to choice suitable templates for establishing a purposeful system to improve the land tax revenue collection. Basic criteria for selection of suitable cadastral documentation were to be accuracy, reliability and the efficiency of a work, planned for long term utilization.

Commission had two templates available: *French and Bavarian ones.*

French type of cadastral survey, executed within the ratio scale 1:2 000 was based on numerous local triangulations ensuing from bases measured for each particular municipality separately. However, this way appeared quite unsuitable in the moment, when continuous general map was to be compiled from several municipal maps, since the mutual position of long distance points was not determined exactly.

Bavarian type of survey was based on triangulation of the whole country with step-by-step densifying into smaller areas, up to the particular municipalities. This type has met the requirement of mutual continuity of particular territorial units.

In 1817 the Commission of the Court submitted to the Emperor detailed instruction in writing, involving application of trigonometric network coordinates of the military triangulation of Ist and IInd orders, deriving more detailed network such a way, that three points determined by a theodolite had been allocated to each square mile, and 57 points were determined by a plane table. For drawing the trigonometric points into maps map the scale 1:14 400 was chosen, while for delivering the points determined by table plane method the scale 1: 2 880 had been chosen such a way, that 1 acre (of Lower Austrian type) – (40×40 fathoms [six feet]) was depicted using one square inch[1].

Commission of the Court proposed performance of a trial at the territory of 1 square mile in the surroundings of Vienna, where appropriate terrain with all kinds of plots was available. Above Commission of the Court drew attention to the insufficiencies of French mapping as done in the Lombardian-Venetian Kingdom approving the Bavarian survey method. Commission achieved, that emperor Francis I approved its proposals and on the day of 23.12.1817 was issued an edict, implementing the stable cadastre as a base for proper land tax assessment.

However, trigonometric cadastral triangulation did not represent any innovation. In 1614 mynheer Snellius tried to measure the distance between two points at the same meridian. His survey procedure was applied step-by-step in measuring determining the Earth perimeter (Provázek 2000). In Austria, the pioneer of gradual survey was Josef Liesganing, who surveyed the base of Wiener Neu Stadt using a metal fathom in 1762, deriving this way a network of triangles serving for finding the length of 1° at the Vienna meridian between Brno and Varazhdin.

2.1. Structure of Land Cadastre Authorities, Authorized to Keep Cadastral Survey in 1818–1827

Commission of the Court had its head office in Vienna; from here the commission managed surveying the stable cadastre. It received reports from provincial commissions, to which the decisions and requirements as made by the said commission has been conveyed thru decrees. Commission of Court had appointed president, assessors and an officer with appropriate number of office clerks (Šimek 1941).

Land Commission managed the cadastral surveying within each of regions. This Commission governed all regional commissions for tax assessment and inspectorates, and its head offices were situated in provincial capital. High representative of the Land used to be appointed to be president of the Land Commission, as a rule. Land president and in the same moment the governor of Moravia was Antonín Bedřich count Mitrovsky. Furthermore, the Land Commission involved a deputy to president and two assessors. Head office was situated in Brno, in palace of counts Kaunitz.

Moravian inspectorates were established in 1824. Moravskoslezská Land has been divided into 4 inspectorates, and had 8 regions as follows: Brno, Olomouc, Přerov, Jihlava, Hradiště, Opava (Troppau), Těšín, and Znojmo. Regional Commission for Tax Assessment managed the cadastral survey within appropriate region. Commission was headed by a commissioner and/or his deputy, while members were appointed by Land Commission upon a proposal given by regional commissioner.

For managing the triangulation process both Triangulation Directorate and Triangulate Computation Office were established in Vienna. Triangulation works were managed in appropriate Lands by the Triangulation Deputy Director. Triangulation system has been surveyed and established by junior officers. Surveyors established the system of Ist order, or IInd and IIIrd Orders, situated inside the "big net" triangles, so called „des grofsez Netzes". At the territory of Moravian-Silesian Land here belonged Messrs. Schmitt, Brodski, and Ellger. Their activities were checked by military authorities. Course and graphic triangulation survey procedure were supervised by Land Director for Mapping.

2.2. Surveying Instructions

First valid instruction for stable cadastre listed in the manuscript was dated 1818. It was printed not before 1820. Subsequent surveying instruction for stable cadastre (Instruction 1824) was issued in 1824, named „Instruction on 1824 for performing the provincial survey for general cadastre as prescribed in §§ 8 and 9 of the superior patent dated November 23, 1817".

Above mentioned instruction involves two parts. First represents the appropriate instruction consisting of 518 paragraphs on 86 pages, the other involves appendices, of which 25 represents samples of different deeds and one sample of the list of map signs. Issuance of further instructions resulted from the cadastre development. List of cadastral laws, instructions, and prescriptions is listed in (Cafourek 1967) and (Mašek 1948).

2.3. Cadastral Coordinate System

Coordinate systems (Čada 1999) have been chosen such a way, that initial cadastral maps may be used for compilation the regional maps, provincial ones and the national one, as well. Mapped territory has been projected to the cylinder surface, which contacts the reference ball surface at the local meridian. This apposing meridian has been chosen as passing thru depicted territory, and passing thru a considerable point of trigonometric minor control.

An arbitrary meridian as base having the geographical longitude λ_0 is a projection base, on which the O (φ_0, λ_0) line origin was chosen, and a straight line intersecting the basic meridian approximately in the middle of the mapped territory. Basic tangent was not adjusted and

[1] Fathom has measured 72 inches, square side was 40×72 = 2880 square inches. Should acre is projected by the square with side of 1 inch, it is reduced preserving the scale 1:2880.

was projected as the axis "x", having the origin within the selected trigonometric point featured with positive orientation southwards. Coordinates "y" were positive westwards from the tangent.

Coordinates were transformed to the plane unchanged that is why considerable scale error took place in locations more distant from the axis "X". Scale error values increased upright to the cartographic meridian and maximum values had been reached at the periphery of selected meridian belts.

Since Austrian Empire contained the area of longitudinal 18°, it had to be divided into several north-south belts; each of them had represented a special coordinate system. The whole monarchy has been divided into nine coordinate systems (Fig. 1):

Tower of the St. Stephen cathedral in Vienna was chosen as the start point for coordinate system of the Moravian-Silesian Land. Geographic coordinates were determined astronomically (Semerád 1918) $\varphi = 48°12'32,75''$, $\lambda = 34°02'21,60''$ eastwards from Ferro.

Base for orientation had been created by side azimuth (St. Stephen–Leopoldsberg (165°55′20,0″ southwards) surveyed astronomically. In 1902, St. Stephen's cathedral tower coordinates were derived from recent military triangulation geodetically. These coordinates of system origin were determined trigonometrically from the triangle of first order of the military step triangulation Hermanskogel–Hundsheimer–Anninger (Fig. 2).

Measured data were compensated using the least squares method and values of derived directions were introduced into system compensation. Mean error of direction correction was of $\pm 0{,}644''$.

St. Stephen–Leopoldsberg azimuth was determined as 345°55′15,065″ from the North and geographic coordinates of the St. Stephen's were modified as follows $\varphi = 48°12'31,54''$, $\lambda = 34°02'27,32''$ eastwards from Ferro[2].

Fig. 1. The distribution of monarchy to nine coordinate systems

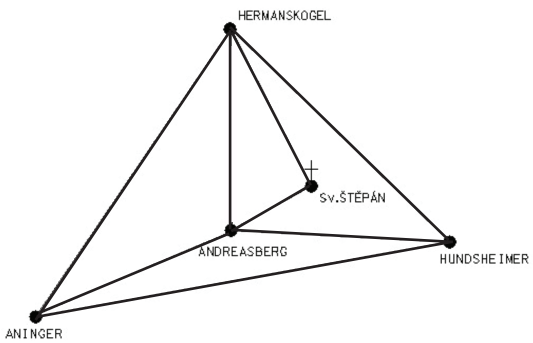

Fig. 2. Triangle of first order of the military step triangulation Hermanskogel–Hundsheimer–Anninger

[2] Coordinates were derived thru calculation

In calculations using Cassini–Soldner projection the Earth curvature was not considered (bearings were not reduced to a plane). Based on this predication defines the projection (Ryšavý 1955) to be a projection – free coordinate system. It is asserted in Čada (2003), that identification project-free has no foundation: "Depicting equation, describing the relationship between spherical coordinates (y, x) andplane ones (Y, X) for S-SK are described explicitly thru relationship Y = y, X = x. This opinion could be propagated within scientific community without detailed explanations and maybe with different meaning of the word, if compared with current usage of this term". Triangulation network was adjusted approximately only. Cylindrical projection for cadastral survey is described in more details in (Fiala 1921).

2.4. Triangulation Network of the Cadastral Triagulation

Coordinates of trigonometric points were calculated regardless to Earth curvation, as mentioned above, heading angles were calculated from straight lines with the "*x*" axis, being marked as plane azimuths or bearings from south counted network (Südwinkel).

Dividing Particular Territories to Triangulation and Section Sheets

Parallel lines are drawn towards the axis "x", being congruent with the meridian at the beginning of the coordinate system, as well towards the axis "y" at the distance of 1 mile = 4000° = 7585,9 m (Novotný 1912). These establish a network of square miles, which represents a base for dividing into particular sections. Straight lines with axis "x" will create columns from West towards the East (colonne), which are divided to Eastern ones (oestliche) and Western ones (westliche). Straight lines with axis "y" will then create from the South to the North so called layers (schichte). Northernmost layer is marked with Arabic numeral one. Furthermore the numbering continues with Arabic numerals from North towards the South. Each square mile establishes one Triangulation Sheet (hereinafter TS only). TS is divided eastwards – westwards to 4 parts (a, b, c, and d), while northwards – southwards 5 parts (e, f, g, h, and i). This establishes a sheet of a list cadastral map, so called section sheet (hereinafter SS only).Trigonometric triangulation was to cover the area of surveyed countryside (Cafourek 1967) with continuous net of triangles such a way, so that 3 points identified using the most precise method – calculation, were allocated to the area of one Austrian square mile. It was possible to keep this principle for plateau territories and/or for hilly country. However, for mountains surveyors had to manage with determination of two points only.

Ellipsoid of rotation became the base for processing, featured with following parameters:

main half-axle a = 6376045 m, oblateness i = 310, named Zach's ellipsoid (Čada 2001). Other parameters, and consequently different ellipsoid is mentioned e.g. in (Cafourek 1967), where i = 302,87.

Trigonometric triangulation was processed applying double ways.Network of Ist, IInd, and IIIrd order was surveyed using trigonometric triangulation by means of theodolite, and network of IVth order has been processed applying graphic method by means of plane table. Cut off deviations of the detailed survey were stipulated by instructions for both trigonometric and polygonometric point marking out as per (Novotný 1909).

2.5. Trigonometric Network of Ist, IInd, and IIIrd Order

Point position was calculated both from measured angles and from calculated lengths of triangle sides establishing the trigonometric network. Only one of lengths has been measured, so called base.

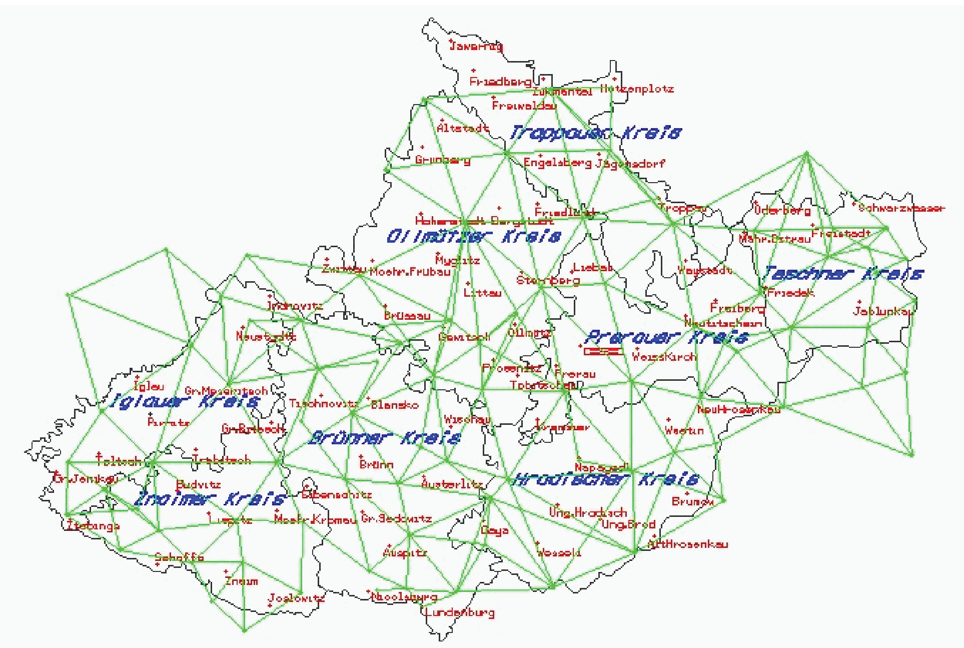

Fig. 3. Trigonometric Net of Ist order

Four directly surveyed bases have been established at the Territory of Austrian Empire

- around Wiener Neustadt, of 6,410.903 fathom length = 12,158.174 m, being measured by Abbé Liesganing in 1762,
- around Wels in Upper Austria, of 7,903.812 fathom length = 14,989.452 m, being measured by major Florian Babel in 1806,
- around Radouc in Bukovina, of 5,199.597 fathom length = 9,860.952 m, being measured by Alois Hawliczek in 1818,
- around Hall in Tyrol, of 2,990.384 fathom length = 5,671.215 m, being measured by H. M. the College of Military Engineers (i.e. pioneers/sappers in many armies) in 1851.

Base length had to be determined with a high accuracy. Bas length has been reduced to the zero horizon (to the sea level), while temperature and scale inclination corrections were considered. No recommended procedure was stipulated for base survey, and that is why the survey methods and procedures were chosen as per the territory and apparatus construction. Some principles for proper base survey and further information on base survey were listed in (Novotný 1909) and (Böhm 1945).

Ist Order (Primary Network)

Big Network called in German "Grosse Netzen" has been created from triangles derived directly from surveyed bases and/or adjacent to them. In boundary areas the net was, based on possibilities, bound with neighboring states, and in the inland was joined to significant observatories.

Astronomic survey was used for identification of certain points (Laplace ones), and this way the net was oriented to the ellipsoid. Triangle side lengths were of 15–40 km, where the mountain peaks and high hills were selected for trigonometric points. Works took 60 years.

Horizontal angles were measured using the multiplication method, while zenith angles were surveyed 3x to eliminate errors of vertical collimation. Survey of both horizontal and zenith angles took place in v Ist and IInd telescope position always. Average misclosure (angular) deviation (Čada 1999) corrected by triangle spherical excess was of 2.1″ (max. 9.8″).

Particular parts of net were not adjusted mutually, thus particular areas (approximately within the boundaries of administrative regions) have different convolutions[3].

As per (Novotný 1912) the net of Ist order has been constructed alongside the Carpathian Mountains both to the Transylvania and Upper Italy (Fig. 3). Upon joining to the trigonometric net of Lombardy considerable deviations were found that is why it was necessary to start the survey of Ist order trigonometric net once again in 1839.

IInd Order (Secondary Network)

"Small network" used to be joined to the Ist order ones. Such points were selected to become the triangle apices that could be connected mutually and with the points of the Ist order. Network has been surveyed within the scope of one region and/or its part. Triangle sides were of 9–15 km.

IIIrd Order (Tertiary Network)

Network was derived from the one of the IInd order. Triangle sides were of 4–9 km, and trigonometric points were selected such a way, that 3 points determined thru calculation were allocated to 1 square mile (1 TS). At least one of these three points was to be usable as the standpoint, from which the other two ones were visible well.

IVth Order (Quaternary Network)

Network of the IVth order was processed using graphic triangulation by means of plane table. Fixed points were selected to become triangle apices of the graphic network (towers, chapels, crosses, trees) and/or standpoints (mounts and hills). Point density was selected such a way that for each SS 3 points were allocated, of which one of them was to be used as the standpoint. Lengths of equilateral triangle sides did not exceeded 500 fathoms, i.e. 950 m.

Numerous points were sought out alongside the boundaries of municipalities, so that has been ensured the continuity among TS at contacts of cadastral maps of neighboring municipalities. Points of graphic network were determined via intersections forwards, while intersections backwards were not permitted. As a rule, three areas did not intersect in one point establishing a small (error) triangle. Median point of a triangle has been determined within this triangle and the point determined this way has been considered to be a correct one. More details on graphic triangulation see in (Cafourek 1967) and (Novotný 1912).

Reason for implementing the graphic triangulation was work acceleration using this method. However this did not bring a success, since error corrections, caused thru inaccurate protraction and quintuplicate magnifying, took too much time. This working method was used within 1858, while later the network of the IVth order was determined using calculations.

"Graphic network of the IVth order represented a serious mistake done by stable cadastre creators, since surveying using manually shifted ruler can not be always of the same accuracy like using the theodolite, and results of work done in the scale of triangulation sheet had to be for needs of detailed surveying magnified fivefold, magnifying this way the errors five times, as well", is mentioned in (Cafourek 1967).

As per (Ryšavý 1955) the main fault of said network, where angles were measured relatively well, that neither during the surveying, nor during adjustment the points of different order were not distinguished, and triangulation took place part by part always at the locations, where it was needed for detailed surveying.

2.6. Applied Instrumentation and Aids

12th and 8th inch Reichenbach theodolites and theodolites of Utzschneider–Frauenhofen type from Bavaria were used for angle surveying. Later on, 8th and 9th inch theodolites made in the workshops of Polytechnical

[3] (History of Cartography in Austrian Monarchy, Mittheilungen des k.k. militaer-geograf. Institutes, Ist Annual Volume 1881)

Institute of Vienna and theodolites manufactured by Eril company in Vienna were used. Nonic[4] differences for these instruments were of 4″ to 10″. Also theodolites of Austrian provenience were used, which enable surveying accuracy up to 4″.

Bigger plane tables were used for graphic triangulation (Novotný 1909), featured with peep-sight alidades and telescopic level diopters. Wooden plates were later replaced with glass ones. First the coordinates were projected using compasses, later applying the ordinatograph featured with nonic unit of 0.001 inch (0.026 m).

For detailed survey plane tables of Morinoni and Kraft trademarks has been used, fitted with peep-sight alidade, first with diopter, later with a telescope. Geodets used for surveying the level, plumb, compass, eightfold and tenfold surveying chains and drawing set, as well. Areas have been calculated by means of planimeters. Following planimeters were used: of Fallon type, Posemer type, and later the thread planimeter of Alder type.

First of fathom measurement standards for surveying in stable cadastre (Cafourek 1967) was manufactured in Vienna in 1817, showing the length of one Lower Austrian fathom at the temperature of 13° as per Réaumur[5]. Several duplicated were procured for comparing the fathom with local gauges, where each Land Commission achieved one of them. More details concerning the fathom etalon you may find also in (Mašek 1948).

2.7. Stable Cadastre in Numbers

Cadastral surveying started in 1817 in Lower Austria and was completed in 1861 in Tyrol. Surveying took 45 years with an interruption due to financial reasons in 1831–1833. During this period surveying works were suspended in Bohemia, Moravia, and Galicia.

Triangulation of the Ist order was done in Bohemia in 1824–1825 and amended in 1826–1828, and 1836–1840. Both in Moravia and Silesia, like in Brno region, it took place in 1821–1829.

Total 30,556 municipalities were surveyed, having the total area of 5,214.6 square miles, otherwise 300,000 km^2, total costs achieved 18 million Austrian florins = 36 million crowns (written in 1911).

Total 164,357 SS has been made in scale of 1:2,880.

Total 3,724 municipalities were surveyed in Moravia and Silesia, having the total area of 475.7 square miles = 27,375 km^2. 1,069 trigonometric points were established. After the stabilization which took place in 1850–1852 the total of 833 trigonometric points were determined.

Similar survey took place in 1833–1836, and 17,181 SS were made.

[4] Nonius (as per Pero Numes) as mentioned in (Müller 1894). Under the term "nonius" we understand, besides roughly divided scale, also other small movable scale, divided such a way, that (n + 1) sections (the smallest units) of the first (main) scale are divided into "n" sections.

[5] Réaumur was French scientist, inventor of the thermometer divided into 80° [Příruční knížka vysvětlující význam cizích slov a poučující o vědomostech obecných, sestavil Fr. V. Pokorný, v Brně 1922. – Manual explaining ther meaning of foreoign words and illuminating matters of general knowledge, compiled by Fr. V. Pokorný, in Brno, 1922].

2.8. Stable Cadastre in Moravia

Cadastral trigonometric network of the Ist order concerning the South-West part of Moravia was derived from the base by the Wiener Neustadt (Semerád 1918). From this base the length has been transferred trigonometrically up to the boundary side Pálavský vrch – Leskoun. Thru deducting the lengths from this side was in 1822 elaborated a network within the perimeter of South-West Moravia, region of Znojmo, up to the Czech boundaries. Within the territory of central Moravia the trigonometric triangulation was completed since the time of gradual survey done in Vienna meridian in 1806 and 1807.

To interconnect this triangulation with existing triangulation of the Ist order in Western Galicia was the assignment for surveyor Schmitt in 1824. Joining to the sides of triangle Swinoschitz–Nebovid–Pratzen resulted in benchmarking the lengths of Galicia triangulation with the base by Vienna.

In residual territory of Moravia the triangulation took place in 1823–1824, thru region of Jihlava to Bohemia, and thru region of Olomouc to Silesia, respectively, where the triangulation connected Prussian triangulation Kralický Sněžník–Biskupská Hora–Anenská Hora–Hradov–Pšov. Trigonometric triangulation of IInd and IIIrd order was connected to the triangulation of the Ist order. In Moravia these activities were performed by nine departments of geodets during 1822–1829.

Dimension of the triangulation network in Moravia was deduced from the side of triangle between locations Pálavský vrch–Leskoun. Length of this side in fathoms is expressed thru logarithm 4,1445585. Length was reduced to the sea level and to the chord. Logarithm value was reduced thru later gradual network adjustment by 0,0000174. Network orientation was in 1806 established by astronomically measured azimuth (bürgem) of side St. Stephen–Leopoldsberg.

3. History of S-JTSK (Datum of Uniform Trigonometric Cadastral Network), Construction, Reasons and Origins

Cadastral networks of trigonometric points of different origin and accuracy existed at the territory of the Czechoslovak Republic In 1918 (Křovák 1924).

In these times, *Cadastral Networks in Bohemia, Moravia, and Silesia* were not in compliance with their purpose thanks to both their diversity and accuracy.

In Slovakia and in Carpatho-Russian region *Hungarian cadastral network* was applied, related to the initial point located in Gellertégy. This network was impossible for studying, since Hungarian government did not provided Czechoslovakia with triangulation documentation. However, it was obvious from their instructions, that in the above mentioned countries was used a trigonometric network in three projections, i.e. portrayal without mathematical projection, in stereographic projection, and in conform cylindrical projection.

Other separate part of the cadastral network was mathematically projected *trigonometric network related to initial point Pšov in Prussia* interfering to the region of town of Hlučín. However, this network had to be remade, since instructions of Prussian cadastre did not correspond to our ones.

Military network of the I^{st} order dated 1860–1898 related to the basic triangulation point Hermanskogel by Vienna was processed on Bessel ellipsoid. In contrast to the position of trigonometric points, identified in rectangular coordinates of appropriate coordinate systems, the positions of military trigonometric points were identified in geographical latitude and longitude. Average triangle size was of about 50 km that is why it did not suit for local triangulation, furthermore this network was not established for great part of Slovakia, nor at the part of Moravia around Brno.

Triangulation office of the Ministry of Finance was authorized to evaluate these networks. Its task was to perform a new triangulation to be used for establishment of future uniform network.

3.1. Project of New Basic Cadastral Network

Triangulation for the basic network of trigonometric points was done in 1920–1926. In 1920 was established project of a new trigonometric network for North-Eastern Moravia, Opava (Troppau) region, and North-East part of Slovakia. Two years later for the residual part of Moravia with connection to the boundary trigonometric points of the I^{st} order in Austria. In 1923 was elaborated a project for enlargement the network in Slovakia.

Objective of this project was to establish a trigonometric network, consisting of equilateral triangles having the sides of 25 km length. Other objective was to involve into the network all trigonometric points of the I^{st} order of the military triangulation, further suitable points of cadastral triangulation, and points situated in boundary areas of the republic. Triangulation documentation of elder trigonometric networks and so called military maps represented an aid for project of the trigonometric network. Network project considered even both further network concentration and/or pertinent enlargement. Network project involved in Moravia and Silesia total of 87 basic trigonometric points at the area of 28,000 km^2, and 37 points for smaller trigonometric networks of towns of Brno, Olomouc, and Vsetín.

Before the inherent surveying started, triangulation area recognizing took place. Signalization and stabilization of trigonometric points took place after recognizing. Stones of cadastral trigonometric points were small and were of irregular shape that is why said stone were replaced with new ones. Stones of military trigonometric points of the I^{st} order, having the dimensions of 0.32×0.32×1.20 m were left and if needed, were repaired.

Stone prisms featured with a machined head of 0.26×0.26×1.00–1.20 m dimensions, marked with the sign of a little cross on the top and with letters K.V. and identification of a year on sides were used for new trigonometric points. Furthermore with underground square stone slab of about 0.50×0.50 m dimensions, featured with central positioned little cross and a second underground sign.

Stabilization was ensured using another three to four fixation stones of 0.20×0.20×0.70 m dimensions, seated mostly on property borders[6]. Mutual positions of fixation stones established a regular shape with the main stone situated in its center, and were located angularly and longitudinally. From two fixation stones were surveyed directions to neighboring church towers.

Topographic description has been compiled on any and each trigonometric point, involving the point name, layout of its position as well as position of fixation points, photo of the signal (beacon), featured with its elevation, way of stabilization, and other data for orientation.

Signalization of trigonometric points was performed based on a design made by Ing. V. Kolomazník, on 1925. It consisted of quadrilateral pyramids featured with and elevated apparatus stand. Pyramid consisted of two structures, being mutually independent each against the other. Black prism seated at the tip of signal was an integral part of said signal. To prevent that at some trigonometric points extremely high observation towers had to be construed forest paths had had been executed. Forrest paths of 200 m length had been done towards Nebovid–Červený vrch, and Nebovid–Rapotice, respectively.

More detailed information on the project of new basic cadastral network may be found in Provázek (2000), Křovák (1924), Křovák (1938) and Křovák (1928).

3.2. Surveying Methods and Instrumentation

Observed direction took place in 1920–1924, direction observing was of double sided type, and three basic methods of direction observation were applied as follows:

- Schreiber's method,
- repetition method of direction observation,
- measuring of angles in one face.

Double second repetition theodolite with screw microscopes manufactured by "Neuhőfer and Son" in Vienna were used for direction observing, as well as theodolites manufactured by company "Josef and Jan Frič" in Prague. Also one-second theodolite with two microscopes, having the diameter of azimuth dial of 0.25 m, manufactured by company "Otto Fennel" in Cassel, and theodolites having the diameter of azimuth dial of 0.235 m, manufactured by company "Breithaupt" from Cassel, as well, was also used for the observing. For target signalization thru the heliotropic reflection, heliotropes served with telescopes manufactured by company "Neuhőfer and Son". For more details see Křovák (1924), Křovák (1938) and Křovák (1928).

3.3. Network Calculation and Adjustment

Network construction took place in three stages (Provázek 2000):

- surveying the "Basic trigonometric network of the I^{st} order (1920–1927)",
- surveying and processing the "JTSK of I^{st} order (1928–1937)",

[6] Survey marks of trigonometric points were protected by law dated JUN 30, 1921 No. 254 of Law Digest and by Cadastral Law dated DEC 16, 1927 No. 177 of Law Digest.

– surveying and processing other points of JTSK, i.e. points of IInd, IIIrd, IVth, and Vth order (1928–1957).

Due to time and technical reasons:

– New astronomic surveying was not done,
– Geodetic bases were not surveyed,
– Network was not interconnected with networks of neighboring states.

42 points in Bohemia and 22 points in Carpatho-Russian region were surveyed direction bases handed over from military triangulation. Network contained 237 points, was adjusted as per the condition surveys, where 559 normal equations were solved using gradual approximation. Slovak network was connected to this one in 1926. Thus, this network contained total of 268 points and 456 triangles.

Basic characteristics of accuracy were:

– mean misclosure of 1.62″,
– mean error in observed direction of 0.64″,
– mean error in observed direction from the adjustment of 0.81″.

Network shape was determined thru the adjustment. Dimension and orientation were determined indirectly from Austrian military triangulation, with which the network had total of 107 identical points. Cartesian coordinates in Křovák´s univers conform conic projection were calculated to geographic coordinates for these points.

Detailed information on further calculations you may find e.g. in Vykutil (1982) and Staňková (2006).

3.4. JTSK Coordinate system

For compilation new cadastral maps the Ministry of Finance stipulated principles for new projection method. Said was to follow these properties Křovák (1938):

1. uniformity for the entire state territory,
2. it was to follow longitudinal shape of our at the time Czechoslovak Republic,
3. it was to be conform,
4. angle deformation in a triangle having the sides up to 5,000 m was not allowed to exceed the value of 1″,
5. scale error value was to be of 1 : 10000,
6. the whole territory of the Czechoslovak Republic was to be depicted in a single quadrant,
7. calculation of direction adjustments was to be as simple as possible,
8. gaussian sphere was to be applied for projection to simplify the calculations.

More authors discussed the choice of projection, however the proposal of Ing. J. Křovák had been chosen, since said had met all the 8 above mentioned preconditions.

More detailed and further information concerning the S-JTSK we may find e.g. in Vykutil (1982), Křovák (1924), and Křovák (1938), while cartographic projection in Křovák (1928) newly e.g. in Cimbálník *et al.* (1997), respectively.

3.5. Relationship between SK and JTSK Systems

Mutual relationship between SK and JTSK systems is described e.g. in Křovák (1924), and newly, in more details in Čada (2003). S-JTSK trigonometric network, built in 1920–1957, relates to the SK system thru new surveying the points of stable cadastre in the JTSK system.

Constructing the network consisting, as much as possible, of equilateral triangles, involving into the network all trigonometric points of military triangulation of the Ist order, as well as all suitable points of the network of stable cadastre, that had been the guidance in construction of the JTSK. Surveying the points of stable cadastre took place simultaneously with construction of the JTSK. Mostly these points were surveyed radius bar from newly stabilized point of the JTSK. Subsequently, the direction towards a point of the stable cadastre has been listed in the field book as a part of basic grid of directions under the note of "point KV".

Newly indicated JTSK points and points of detailed point fields determined for new mapping as per Instrukce A (1933) had to be filed into network existing already of the stable cadastre, e.g. for the purpose of drawing into valid land maps.

Transformation coefficients were calculated from excessive number of identical points on condition of the least squares method. This procedure did not solve inverse transformation, for example for land map planimetry conversion in scale of 1: 880 into map section within the JTSK system.

Transformation keys were compiled in 1935, where fundamental sheet corners were selected to become identical points. FS corner coordinates are deductible easily in the SK system, while in S-JTSK system these coordinates were identified thru the transformation. These transformation keys were called to be *general transformation keys***.** Transformation keys were calculated from identical points the joins of which was of triangular shape. Points of trigonometric network known in both systems were selected to become triangle vertices. Points were selected from numerical triangulation of the Ist - IIIrd order (Grosse Networkzen). For further details see in Čada (2003).

4. European reference Frame – EUREF, ETRS89 Coordinate System

EUREF (European Reference Frame) is connected with the first performance of the ITRF (International Reference Frame).

Proposal to build up a uniform frame for Europe arose independently in 1987 by international organizations like IAG (International Association of Geodesy) and CERCO (Comité European des Responsables de la Cartographie Officielle).

Proposed project was to result in a uniform reference system, which would represent as follows:

– reference frame for random geodetic and geodynamic project with high accuracy at the European plate,
– reference frame close to WGS-84 system for geodetic works and navigation in Europe,
– continental reference frame for data location of digital cartographic database in Europe.

ETRF89 reference frame is a part of ITRF-89 global international terrestrial reference frame. Coordinates of the set of definitive stations, as a resulted from tectonic movements of the Earth plate, are varying upon the velocity of approximately 2.7 mm/p.a. To preserve relationships between stations, the decision had been made, that ETRF89 would be created using the definite stations at the European plate, and would rotate together with stable part of the Europe.

Initial campaign of the EUREF project took place at the territory of Western, South-Western, and Northern Europe in 1989, while in subsequent year EUREF was enlarged to the territory of states of Central, Southern and Eastern Europe. For further information see Kolektiv autorů (Team of authors 1998), and Černohorský *et al.* (2004).

ETRS89 Performance in the Czech Republic

For processing the GPS campaigns being done at the territory of the Czech Republic the EUREF subcommission recommend to apply the ETRS89 geocentric coordinate system.

ETRS89 (European Terrestrial Reference System) creates a uniform geocentric coordinate system. As per Kostelecký (1996) it is defined thru a system of constants, algorithms, and reference frame ETRF (European Terrestrial Reference Frame), being executed using coordinates of stabilized points at the terrestrial surface.

In the Czech Republic, the ETRS89 is determined thru the adjustment of EUREF-CS/H-91campaign results, which took place in 1991. Within the framework of this campaign, at the territory of the Czech and Slovak Republics, total 6 points were surveyed being identical with AGS points (Astronomic geodetic network), and 5 points in Hungary.

NULRAD – Network of the Zero Order

First concentration represented a network of 6 points of the zero order, which at the territories of Czech and Slovak Republics consists of 19 points as a whole. This network bears the name NULRAD. Processing of the campaign is described in details e.g. in Kostelecký (1996).

Decision was made in 1993, to concentrate the network such way, that average distance of the points determined thru GPS method, was of about 25 km. Name DOPNUL was accepted for this concentration of the NULRAD network.

DOPNUL Network

DOPNUL network (amendment the zero order) was executed in 1993 and 1994, using the GPS technology exclusively. Total 176 points were surveyed, identical with trigonometric points of the JTSK system.

Point concentration of the DOPNUL reference network (average 1 point per 450 km^2) was in sufficient for most of geodetical works. That is why it was necessary to build up a reference system, which would meet following requirements Černohorský *et al.* (1997):

- direct utilization of GPS technology (would involve ellipsoidal coordinate points in ETRF),
- utilization of terrestrial surveying techniques (theodolites, distance meters, level instruments),
- utilization of existing sets of maps.

Thru an agreement achieved between the department of the Czech Office for Surveying, Mapping and Cadastre (ČÚZK) and Topographic Service of the Czech Army has been stipulated the concentration of existing points (176) via the method of trigonometric points coordinates transformation in S-42/83 system, to the reference ETRF89 system.

Concentration methodic involved two stages as follows:

1. spatial similarity transformation of trigonometric point coordinates from S-42/83 system to the ETRF89 reference frame,
2. deviation distribution at identical points after the transformation to the neighboring points thru the method of weighted averages for coordinate deviations, whereas the weights are proportional to reciprocal square of the distance of the transformed point into identical one.

Quasi-geoid determined via the astronomical method in the Research Institute of Geodesy, Topography, and Cartography (VÚGTK) has been applied for transformation of altitudes above the sea level to ellipsoidal ones (1994).

This performance is considered to be the zero stage in constructing the geocentric system in the Czech Republic.

Pilot versions of all S-JTSK/95 and transformation relationships among ETRF89 and S-JTSK, pertinently S-42/83 belong among working versions.

Further information on performance of subsequent stages of the S-JTSK/95 system, on European elevation system and the Czech State Level Network (ČSNS) and further projects (GEODYN, CZEPOS, GNSS-EUPOS) are listed in Černohorský *et al.* (2004).

Administration of geodetic bases is executed by the geodetical authority. Nowadays, several projects are completed within the sphere of geodetic bases and in other point fields, focused to maintenance and recovery of basic point fields. Among these projects belong also following ones:

- project covering selective maintenance of the Czech State Trigonometric Network (ČSTS). Within the framework of this project, being completed in 2006, using the GSP method 3,500 points were identified in ETRS system. Both in Moravia and Silesia the selective maintenance took place in 2005 and 2006. More details concerning the selective maintenance project you may find e.g. in Provázek (2001) and Řezníček (2006),
- completing the „concentration“ project, the result of which are about 35,000 of preliminarily newly stabilized concentration points with measured geocentric coordinates. More details on concentration project see e.g. in Kolář (2009).

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