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IMPLEMENTATION OF A HIGH-ACCURACY SPATIAL NETWORK FOR MEASUREMENTS OF STEEL CONSTRUCTIONS

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ABSTRACT

The paper deals with a project for the measurement and evaluation of a unique local spatial network with a high degree of accuracy at the MCE Slaný Company. The accuracy requirements were very high; the standard deviation in measuring the components of a steel construction before its final assembly is about ones of millimeters.

KEY WORDS

- Spatial network,
- Steel construction,
- High degree of accuracy.

1. INTRODUCTION

The manufacturing and assembly of a steel construction is a process requiring high demands for accuracy in terms of surveying works, in particular, a need for accuracy in checking measurements using engineering surveying methods. The required standard deviations are in millimeters, and observing them is not a trivial task. The check is usually performed by taking geodetic measurements using the polar method from multiple standpoints, where measurements from individual standpoints are transformed into a common system by means of points measured from more standpoints. In the event that checks are performed more frequently within the same space, e.g., in a production hall, a high accuracy micro-network may be measured in order to achieve easier, faster and more accurate measurements, and check measurements may be made using the free standpoint methods. A necessary precondition for this is the verified stability of the network point's stabilization.

Due to the required standard coordinate deviation of the check measurement at a value of 2 mm to 3 mm, depending on the purpose of the measurements, the requirement set for an accuracy analysis before the measurement is to determine the coordinates of the network points with a standard positional deviation maximally equaling 1.0 mm.

2. ACCURACY ANALYSIS BEFORE MEASUREMENT

A supporting network of standpoints was designed, and the required measurement accuracy was determined using the PrecisPlanner 3D software.

The programme works in Microsoft Windows XP and higher versions of the operating system and serves for planning the measurement accuracy of spatial (free and fixed) networks. Its

Fig. 1 Definition of the measurement in the graphic interface of the PrecisPlanner 3D programme.

graphic environment permits working with approximate coordinates of points, defining new or deleting existing points, and defining measurements and their degree of accuracy. The output of the programme provides, among other things, a covariance matrix of coordinates, which was used for evaluating the suitability of the design of a network of standpoints and measured variables. An example of a graphic interface during the definition of the measurement is in Fig. 1.

More detailed information may be found in (Štroner, 2010) and also in (Štroner, 2011).

An assembly hall plan and the distribution of the target plate network points served as the background for the design of a measurement network with seven points. The standpoints were selected so that both halves of the hall would accommodate three mutually interconnected standpoints and that there would be one central standpoint for the interconnection of the whole network in the middle of the hall. It was presumed that, thanks to the elevated positioning of the instruments on the steel plant's fixtures, all the points in the respective half of the hall could be measured from each standpoint. The design of the required degree of accuracy of the measurement took into account the risk of poorer lighting conditions, considering the higher values of the standard deviations characterizing the measurement of the directions and lengths with the respective total stations in two sets ($\sigma_\phi = 0.5$ mgon, $\sigma_D = 2$ mm). Based on these assumptions and the selected distribution of the standpoints, the expected standard deviations of the coordinates of

the reflective target plates were calculated; they were smaller than 0.5 mm.

3. INSTRUMENTATION

The measurement was performed using the instruments available for highly accurate work at the Department of Special Geodesy of the Faculty of Civil Engineering, CTU, in Prague. They included the Trimble S6 Robotic instrument ($\sigma_\phi = 0.3$ mgon, $\sigma_D = 1$ mm + 1 ppm D - (ČSN ISO 17123, 2005)) with an automatic targeting option and two Topcon GPT-7501 total stations ($\sigma_\phi = 0.3$ mgon,

Fig. 2 Trimble S6 Robotic.

Fig. 3 Topcon GPT – 7501.

Fig. 4 *Leica mini prism GMP 101.*

Fig. 5 *Leica prism GPH1P.*

$\sigma_D = 2 \text{ mm} + 2 \text{ ppm } D$ - (ČSN ISO 17123, 2005)), see Fig. 2 and Fig. 3. Mini prism sets and accurate reflective prisms made by the Leica Company were used for sighting within the supporting standpoint network; see Figs. 4 and 5.

The instruments were tested together with the reflective prisms and foils before the measurement to guarantee the quality of the results; the additive constant was especially tested, particularly because the tools used were produced by different manufacturers.

4. MEASUREMENT DESCRIPTION

The assembly hall plan with the marking of all the points of the measured network is shown in Fig. 6.

The measured network was stabilized using reflective foils with dimensions of 50 mm x 50 mm on massive steep posts (Fig. 7, Fig. 8). The supporting network was stabilized using tripods. To be able to reach the required degree of accuracy, seven (4001 – 4007) standpoints had been designed for the analysis before the measurement. After the hall inspection on the measurement day, one

Fig. 10 *Standpoint stabilized by a steel fixture.*

Stable temperatures in the assembly hall during the daytime and nighttime are maintained by air-conditioning. Unfortunately, the outside temperature during the measurement was around freezing (0°C); therefore, the warm air swirling from the air-conditioning located by the hall's ceiling resulted in great complications for taking the measurements. The air-conditioning effect was the most evident at the standpoints 4004 and 4007, which were stabilized at the greatest height. This posed significant obstacles to the accurate aiming at the reflective foils. Another complication was the oscillation of the tripods while using the Trimble S6 instrument, which was mainly due to the too narrow standing of the tripod's legs in combination with the Surepoint technology, which protects the instrument against the effect of settlements, vibrations and keyboard handling, which may affect the instrument after levelling. The aiming is automatically corrected by means of a continuous monitoring of the inclination and collimation errors, and their compensations are automatically introduced; however, with an unsuitably high and narrow tripod, it started to vibrate. Except for standpoint 4004, the horizontal directions, zenith angles and inclined lengths on all the visible points were measured in at least two sets of standpoints with the Topcon instrument.

Unfortunately, it was impossible to measure lengths in the accurate prism mode with the Topcon instrument as, for unknown reasons, the instrument was unable to measure the reflective foils. The lengths were measured only in the prismless mode characterized by the standard deviation of $\sigma_D = 5$ mm, which significantly exceeds the required degree of accuracy of the measurement. Cranes controlled by wireless radiotechnology with a very strong signal are located in the hall. Among other problems, remote central car locks do not work in the surroundings of the hall; therefore, there is a strong suspicion that this was the cause of the difficulty. Standpoints 4001 to 4007 were therefore also measured with the Trimble instrument at least in one set in order to insert them in the length adjustment with a standard deviation corresponding to the accuracy analyses. Standpoint 4008 was measured only with the Topcon instrument, where the horizontal directions and zenith angles in particular were utilized for additional measurements and an improvement of the accuracy of several points in a corner of the hall.

5. CALCULATIONS

Before the adjustment of all the points of the spatial network, the internal supporting network of seven standpoints had to first be adjusted to be able to maintain the network's strength after adding the additional values. The adjustment was solved using Gama software (Čepeck, 2011), which permits defining the input set for adjustment in a simple file in the xml (Extensible Markup Language) format. Here, the option of inserting various standard deviations of a measurement according to the number of repetitions of the individual variables entering the adjustment (horizontal directions, zenith angles, lengths) is of utmost significance.

5.1 Calculation of the internal supporting network

A total of 24 horizontal directions, 28 zenith angles and 26 inclined lengths were measured in the network. Therefore, there were 55 redundant measurements before the elimination of any outliers. The start of the local coordinate network was inserted in point 4004, and the axis x was oriented to point 4001. The measured values were averaged before their adjustment and, depending on the number of repetitions, the respective standard deviations were assigned to them using the formula:

$$\sigma_i = \frac{\sigma_0}{\sqrt{n}}, \quad (1)$$

where σ_i is the a priori standard deviation of the measured variable; σ_0 is the a priori standard deviation given by the instrument's accuracy with respect to the conditions during the measurement used; and n is the number of repetitions.

The degree of accuracy achieved in the determination of the orthogonal spatial coordinates of the field points is expressed by the values of the standard positional deviations of the individual points. Several indicators were selected for the description of the adjustment results:

- The maximum standard deviation at a position is 0.6 mm.
- The minimum standard deviation at a position is 0.4 mm.
- The mean standard deviation at a position is 0.5 mm.

5.2 Calculation of the coordinates of the external network of the reflective foils

After the completion of the measurements, the field measurement books were processed in a standard way (by testing any possible outliers between the measurements in the first and second groups). After the adjustment of the internal supporting network, 66 observations of the original 78 observations remained, 43 of them redundant.

In order to adjust the network of 58 reflective foils and the one added standpoint, the original xml input file was complemented by the already calculated coordinates entered as approximate ones and by 801 measurements onto the foils (horizontal directions, zenith angles and inclined lengths). Of the total number of 867 observations, 661 were redundant. In this way, 150 measurements with the greatest standard corrections were gradually eliminated. Further elimination of measurements no longer resulted in visible improvements in the accuracy of the resulting coordinates. Such a high number of eliminated measurements had been expected due to the difficult measurement conditions and the required high degree of accuracy. All the measurements of the horizontal directions with the Trimble S6 instrument were eliminated at standpoint 4006 due to the instability during the measurement, where due to a narrow tripod and the Surepoint technology, the instrument started to vibrate. For the resulting calculations, 239 horizontal directions, 200 zenith angles, and 278 inclined lengths remained available. Several indicators were again selected for the expression of the achieved degree of accuracy:

- The maximum standard deviation at a position is 1.0 mm.
- The minimum standard deviation at a position is 0.2 mm.
- The mean standard deviation at a position is 0.4 mm.

5.3 Evaluation of the adjustment results

After an adjustment it is generally desirable to evaluate whether the degree of accuracy corresponds to the degree of accuracy planned in the accuracy analysis before the measurement; this is done by means of the agreement of the standard deviations characterizing

the measurement's accuracy being inserted in a weigh-scale for any adjustments and corrections. There is a simple way of testing the unit's standard deviation after the adjustment (a posteriori) s_0 against the unit's a posteriori standard deviation used for the weight selection by using the limit selective standard deviation (according to (Böhm, 1990)). The limit selective standard deviation is:

$$s_M = \sigma_0 \cdot \left(1 + \sqrt{\frac{2}{n'}} \right), \quad (2)$$

where σ_0 is the a priori standard deviation used for the weight's creation, and n' is the number of redundant variables. The a posterior standard deviation is determined as:

$$s_0 = \sqrt{\frac{\mathbf{v}^T \cdot \mathbf{P} \cdot \mathbf{v}}{n'}}, \quad (3)$$

where $\mathbf{v}$ is the correction vector after adjustment; $\mathbf{P}$ is (here) the diagonal weight matrix. Knowing their standard deviations σ_p , weight p_i for the individual measurements is calculated from the formula:

$$p_i = \frac{\sigma_0^2}{\sigma_i^2}, \quad (4)$$

where σ_0 is the selected constant.

An evaluation was performed for every use of the respective method, and it confirmed the agreement of the assumed and achieved degrees of accuracy. The a priori standard deviation was selected as a value of 4. The a posterior standard deviation after the internal (supporting) network adjustment reached a value of 3.4, which makes it clear that the selected standard deviations for the measurement had been selected slightly more strict than they were in reality. The a posterior standard deviation value for the external network adjustment was stabilized at a value of 4.1 after the elimination of any outliers, which practically corresponds to the estimated accuracy of the measured variables. The limit selective standard deviation according to (2) $s_M = 4.25$.

6. CONCLUSION

Despite the great and previously unknown complications the micro-trigonometric network was measured with the required degree of accuracy; its purpose was to simplify and speed up shop floor checks of the accuracy of mechanical engineering products. In the final account, the accuracy of check measurements should also be enhanced.

The biggest problems during the measurement were the irregularly functioning air-conditioning and the continuation of the construction process. The desired degree of accuracy was accomplished, and it also corresponded to the accuracy analysis before the measurement performed with the PrecisPlanner software. The software was principally made for such a project, and the results proved its applicability.

The measured network was determined with a high degree of accuracy at the time of the measurement. Despite the assumption of

the stability of the points, periodical checks of the point stability are planned based on an agreement with the owner.

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