GEODEZIJA IR KARTOGRAFIJA / GEODESY AND CARTOGRAPHY
2009
35(3): 73–76

UDK 528.45 doi: 10.3846/1392-1541.2009.35.73-76

SOME PROBLEMS OF AN AS-BUILT SURVEY AND SETTING OUT ACCURACY

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Received 03 12 2008; accepted 15 06 2009

Abstract. Nowadays, the accuracy of setting out is stated by the articles of ISO 4463-1, but unfortunately it is not directly associated with permitted deviations from construction works as their accuracy should be assured and assessed by means of construction surveys. An earlier GOST 26433.0-85 states that the error of setting out must not exceed 80 % and the error of an as-built survey up to 40% of corresponding permitted deviations from the construction element. Combining these limits enables deriving permitted deviations for the as-built survey and setting out.

Keywords: surveying with construction applications, setting out accuracy, as-built accuracy.

1. Introduction

Accuracy is the closeness of an agreement between an actual measured value and its true value (СНиП... 1987). Nowadays, the accuracy acceptance criteria of setting out are stated by the articles of ISO 4463-1 'Measurement Methods for Building – Setting-out and Measurement' (ISO 1989).

The present publication deals with the values of permitted deviations only.

Let us have a look at the setting out accuracy of the position points (detailed setting out). There are three groups of requirements (International... 1989), related to:

- earthwork without any particular accuracy requirements, for example excavations, slopes;
- earthwork subject to normal accuracy requirements, for example road works, pipe trenches;
- in situ cast concrete structures, precast concrete structures, steel structures.

The latter one is the examination object of the present paper. In this case, setting out error (δ_{so}) in the position should not exceed $1.5\sqrt{L_m}$ mm; horizontal/vertical angles should be measured and set out with angular reading to 1′ (or better) and optical plumbing error should not exceed $1.5\sqrt{H_m}$ mm (where L_m is the distance from a control point to a position point and H_m is the height from the reference level to the erecting level, both in metres) (International... 1989).

Consequently, the farther is the position point from the control point, the larger are permitted deviations from the carried out measurements. At the same time, permitted deviations from construction works the accuracy of which the survey should assure and assess, should remain independent from the location of the survey control points. Obviously, in this case, the essential conflict exists.

This contribution presents an alternative approach: to the location of the control points and to the selection of equipment and technology so that the error of setting out and the error of the as-built survey should not exceed the predetermined absolute limits.

Formerly, several previous studies have dealt with the problem of what ratio of surveying permitted deviations and what permitted deviations from construction works should be adopted. We suppose that version 2 is the most reasonable as it states that the permitted deviation of setting out makes up to 80% and the permitted deviation of the as-built survey – up to 40% of corresponding permitted deviation from construction works.

However, at present, a new problem arises. Which permitted deviations from construction works are the most important and which are in accordance with achievable and required accuracy? This subject is discussed in the sequel.

2. Accuracy of Surveying the Construction of Single Storey Buildings

2.1. Assembling Permitted Deviations that Might Determine the Accuracy of Setting out and As-Built Survey

This section focuses on examining the buildings of factories, storehouses and super-markets. The geometrical accuracy of construction is determined by permitted deviations from assembling foundations or its anchor bolts and columns. This is due to conceptual design considerations. The cases of the reinforced concrete skeleton and the metal skeleton will be discussed separately.

The most important permitted deviations of assembling δconstr are as follows:

- for prefabricated foundations (СНиП... 1987) – 12 mm;
- for concrete columns in its lower end (RT 02-10102) – 20 mm;
- for steel columns in its lower end (СНиП... 1987) – 5 mm.

2.2. Presumable Accuracy of Surveying

In this case, the evaluation of accuracy relays on some simplified scheme assuming that the as-built survey and setting out are executed in a section between expansion joints (in the majority of cases, an interval of expansion joints is about 70 m). In addition, it is supposed that control points are located about on the diagonal of the section at a distance of 30 m from the buildin. Subsequently, the maximum distance from the control point to the position point is 130 m.

Permitted deviations from construction works are generally presented across the axes. Therefore, permitted deviations from position points are also presented across the axes. As site grid axes are generally parallel to building axes, the mean square errors (MSE) of setting out and the as-built survey are presented by means of its projections on the coordinate axes. Moreover, the use of a total station Leica TC1100 (or an instrument of equal precision) is assumed in the following calculations.

Thus, MSE is computed by the next equations:

$$\left.\begin{aligned} m_x &= \sqrt{m_s^2\cos^2\alpha + \frac{s^2 m_\alpha^2 \sin^2\alpha}{\rho^2} + m_C^2 + 0.5m_M^2 + m_{NS}^2 + m_{ID}^2}, \\ m_y &= \sqrt{m_s^2\sin^2\alpha + \frac{s^2 m_\alpha^2 \cos^2\alpha}{\rho^2} + m_C^2 + 0.5m_M^2 + m_{NS}^2 + m_{ID}^2}, \end{aligned}\right\} \quad (1)$$

where: m_s – the mean square error (MSE) of distance measurement (±2,0 mm); α – medium direction angle in the site grid system (45°); s – average distance to the position point (130/2 = 65 m); m_α = MSE of direction angle (it is presupposed to be equal to the nominal MSE of angle measurement with one full set ±4,5″); ρ – 206 265″; m_C = MSE of centring the instrument on either x or y direction (±0,4 mm); m_M – MSE of marking position points on either x or y direction (±1 mm); m_{NS} – MSE due to natural sources (a priori equal to m_M); m_{ID} – MSE due to initial data (in case it is used as the only control point and initial direction proposing that the error is insignificant).

Equations (1) give:

$$m_x = m_y = \sqrt{2+1+0.2+0.5+1} = 2.2\text{ mm},$$

which indicates that the most influencal errors are due to distance measurement.

By ISO 4463-1 (setting out the position points of concrete and steel structures): $ms = 1{,}5\sqrt{65/2.5} = 5$ mm, $m_\alpha = 1'$ and after putting these values into equations (1) $m_x = m_y = 14$ mm. It is even more than permitted deviations from assembling the accuracy of which setting out should assure. Clearly, this is not acceptable.

2.3. Accordance with Presumable and Required Surveying Accuracy

As already mentioned in the introduction, GOST 26433.0-85 states permitted deviations from setting out up to 80% and permitted deviations from the as-built survey up to 40% in light of corresponding permitted deviations from assembling.

First, the concrete skeleton is examined. Thus, according to section 1, MSE of the foundation as-built survey should not exceed the value $m_{abs} = \delta_{constr} \times 0.4/2.5 = 12 \times 0.4/2.5 = 2$ mm and MSE of setting out position points (axes, centre lines on pockets for columns) should not exceed 4 mm. MSE of the column as-built survey should not exceed $m_{abs} = \delta_{constr} \times 0.4/2.5 = 20 \times 0.4/2.5 = 3$ mm. As it stems from subsection 2.2, it is achievable by using Leica TC1100 or an instrument of equal precision.

Second, the steel skeleton is examined. In this case, MSE of the column lower end as-built survey should not exceed the value $m_{abs} = \delta_{constr} \times 0.4/2.5 = 5 \times 0.4/2.5 = 0.8$ mm. Apparently, it is too difficult to carry out on the occasion of large-lot erecting. In this case, a simpler technology foresees the as-built surveying lower end of the column in relation to centrelines or edge lines previously *had set out* on the foundation for assembling. Naturally, it calls for higher requirements for the persistence of the above mentioned lines.

3. Accuracy of Surveying the Construction of Multi-Storey Buildings

3.1. Erecting Permitted Deviations that Might Determine the Accuracy of Setting out and As-Built Survey

This section focuses on surveying the construction of supermarkets, offices, residential buildings, hotels and light industry buildings. The most important permitted deviations from assembling δconstr are:

- Deviation from the column low end of the in-situ concrete skeleton on the intermediate floor and from the upper end of the column under the inter-mediate floor (mating eccentricity) that generally cannot be directly surveyed. The permitted deviation is d/20 (RAK MK 20743) (d = the cross-section diameter of the column, generally 300 ÷ 400 mm) so $\delta_{constr} = 15 \div 20$ mm.
- Prefabricated multi-storey concrete column deviation from verticality that generally cannot be directly surveyed after assembling intermediate floors. The permitted deviation is h/150 (RAK MK 20743) (h = height of the column). The most common are columns for two storeys. Taking the height of a storey as of 3 m, the height of the column is 2 × 3 = 6 m, and thus the permitted deviation from verticality becomes $\delta_{constr} = 40$ mm.

- Prefabricated single storey concrete column lower end deviation from the designed position. On the occasion of the second class buildings (ordinary dwelling houses, offices etc), δ_{constr} = 20 mm (RAK MK 20743).
- A permitted deviation of the single storey steel column from verticality is h/280 (RAK MK 20844). Thus, if the height of the storey is 4 m, δ_{constr} = 14 mm.

3.2. Presumable Accuracy of Surveying

The designing procedure in this case differs from the procedure of single-storey buildings. First, two orders of control systems are used at multi-storey-buildings: the primary system is established on the ground and the secondary one on assembling or form-work level. The accuracy of position points is found by means of equations (1) where the length of a section is taken for 70 m but maximum width is most likely about 20 m. The control point of the secondary system will be positioned in the middle of the section, so the maximum distance between the control point of the secondary system and the position point is about 40 m. MSE of the secondary system control point in relation to the control point of the primary system can be calculated by

$$\left.\begin{aligned} m_{PR(x)} &= \sqrt{m_s^2\cos^2\alpha + \frac{s^2 m_\alpha^2 \sin^2\alpha}{\rho^2} + m_\tau^2 + m_C^2 + m_R^2 + m_{EC}^2 + m_{ID}^2}, \\ m_{PR(y)} &= \sqrt{m_s^2\sin^2\alpha + \frac{s^2 m_\alpha^2 \cos^2\alpha}{\rho^2} + m_\tau^2 + m_C^2 + m_R^2 + m_{EC}^2 + m_{ID}^2}, \end{aligned}\right\} \quad (2)$$

where: s – the distance from the control point of the primary system to the control point of the secondary system (70 m); α – medium direction angle from the control point of the primary system to the control point of the secondary system (45°); m_τ – MSE due to a deviation of instrument vertical axis from truly vertical (plumb line); m_R – MSE due to the centring error of prism; the other symbols used are spent in equations (1).

First, let us find MSE due to a deviation of the vertical axis of the instrument from true vertical (plumb line) that is computed from

$$m_\tau = \frac{h\tau}{\rho''} = \frac{40000 \times 1}{206\,265} = 0.2 \text{ mm}, \quad (3)$$

where: h – height from construction ground level to erecting level (let us take 40 m, which is relatively high for large-lot constructions in Estonia); τ – MSE of tilt correction (1″ for Leica TC1100).

Thus, equations (2) and (3) give MSE of secondary system control point $m_{PR}(x) = m_{PR}(y)$ = 2.1 mm, equation (1) gives MSE of the position point in relation to the control point of the secondary system (s = 40 m) $m_x = m_y$ = 2.1 mm and the total MSE of setting out/as-built survey column lower end is

$$m_{\sum XL} = m_{\sum YL} = 2.12 = 3.0 \text{ mm}.$$

Column verticality deviation as-built survey error consists of the following components: m_τ = MSE due to a deviation of the instrument vertical axis from plumb line (supposed to be insignificant if vertical axis tilt correction is used); m_p = parallax MSE that occurs due to nonparallel instrument collimation plane and mounting a line of column row (0.2 mm, if the total station is positioned on the mounting surface (the best sighting line) by visual adjustment and column inclination from plumb line towards the line of sight direction not exceeding 30 mm); m_{V1} = primary sighting error (due to instrumental and personal qualities), generally insignificant; m_{V2} – secondary sighting error due to the local asperities of the column (±1.0 mm, considering (СНиП... 1987) with (International... 1989)). Thus, MSE of column verticality as-built survey m_i = ±1.0 mm and the total MSE of setting out/as-built survey column upper end

$$m_{\sum XU} = \sqrt{m_{PR(x)}^2 + m_x^2 + m_i^2} = 3{,}2 \text{ mm},$$

$$m_{\sum YU} = \sqrt{m_{PR(y)}^2 + m_y^2 + m_i^2} = 3{,}2 \text{ mm}.$$

If column mating eccentricity cannot be directly surveyed, then MSE of the mating as-built survey becomes

$$m_{ex} = \sqrt{m_{\sum XL}^2 + m_{\sum XU}^2} = 4{,}4 \text{ mm},$$

and m_{ey} = 4,4 mm

3.3. Accordance with Presumable and Required Surveying Accuracy

The first case in subsection 3.1 is decisive for in-situ concrete skeleton as-built surveying accuracy. Let us assume the column cross-section diameter being 400 mm, thus the promised MSE of mating as-built surveying is $m_x = m_y = 0.4 \times 20/2.5$ = 3 mm. Although in subsection 3.2 it was found that the presumable MSE of mating eccentricity as-built surveying $m_{ex} = m_{ey}$ = 4.4 mm, however, this accuracy is not sufficient. The usage of a more precise EDM (m_s = 1 mm) would not provide sufficient accuracy either. For solving this problem, the following solution is recommended. As-built surveying is not foreseen to assure the accuracy of construction works, except from ascertaining its accuracy, the lower accuracy of as-built surveying brings along further erroneously accepted or rejected deviations. For example, if MSE of as-built surveying does not exceed 40/2.5 = 16% of δ_{constr}, the amount of erroneously accepted deviations is 2% and erroneously rejected deviations is 2.8%. In case $m_{ex} = m_{ey}$ = 4.4 mm (MSE ≈ 24% of δ_{constr}), the amount of erroneously accepted deviations is 3% and erroneously rejected deviations is 4.5% (Egnus 1972). The discrepancy is not large and might be acceptable. The limit to MSE of setting out is more important and makes $m_x = m_y = 0.8 \times 20/2.5$ = 6 mm which is satisfied under the assumed conditions.

In the second case, (prefabricated concrete skeleton construction with multi-storey columns) the verticality deviation of the column is decisive as it cannot be surveyed directly. Verticality deviation ($\delta constr$ = 40 mm) can be found as discrepancy in plane between the projections of the upper and lower end of the column, so deviation from the position in both ends should not exceed $\delta'_{constr} = 40/\sqrt{2} = 28$ mm. Thus, MSE of the us-built survey should not exceed $m_x = m_y = 0.4 \times 28/2.5 = 4.5$ mm. The values of $m_{\Sigma XL}$, $m_{\Sigma YL}$, $m_{\Sigma XU}$, $m_{\Sigma YU}$ (as stated in 3.2) were smaller than this value.

Let us have a look at the third case (prefabricated concrete skeleton construction with a single-storey column). In this case, a deviation of the lower end of the column from the designed position is decisive because the inclination of the column from verticality can be measured directly and with high accuracy. Correspondingly to subsection 3.1, $\delta_{constr} = 20$ mm. Thus, $m_x = m_y = 0.4 \times 20/2.5 = 3.2$ mm which does not create remarkable problems.

Although the fourth case (steel skeleton) is similar to the third one, nevertheless, permitted deviations are much harder. It is expedient to examine accuracy from the point of view of setting out. Thus, if the permitted deviation of the column (h = 3 m) from plumb line $\delta_{constr} = 14$ mm, the column end position permitted deviation $\delta'_{constr} = 14/\sqrt{2} = 10$ mm. and the permitted value of MSE of setting out $m_x = m_y = 0.8 \times 10/2.5 = 3.2$ mm. In subsection 3.2, MSE of setting out/as-built survey of the column lower end $m_{\Sigma XL} = 3.0$ mm was found which is less than the permitted value of 3.2 mm.

4. Conclusions

It was assumed that secondary points at the erection level were carried out every time from the same primary point. In case it is impossible, it must be taken into consideration errors due to the initial data.

At long last one should take into consideration errors due to the thermal expansion of construction, but they are not well researched yet.

The above given information demonstrates that setting out and the as-built survey in particular demand relatively high accuracy to get satisfactory results.

Setting out position points and the as-built survey on assembling concrete or steel skeleton need a total station where MSE of distance measurement is ±2 mm or better and MSE of angle measurement is ±3″ (DIN 18723) or better. However, even such accuracy sometimes does not satisfy and one has to use extra concepts (see 3.3).

It is recommendable that the existing ISO standard (International... 1989) should be revised in order to make it contemporary.

References

International Standard (ISO 4463-1). Measurement methods for building – Setting-out and measurement. Switzerland, 1989. 21 p.

Rak MK 20844. Teräsrakenteet [Finnish Standard. Steel Structures]. Helsinki (in Finnish).

Rak MK 20743. Betonirakenteet [Finnish Standard. Concrete Structures]. Helsinki (in Finnish).

RT 02-10102. Betonirakenteiden toleranssit [Finnish Regulations. Tolerances of Concrete Structures]. Helsinki (in Finnish).

ГОСТ 26433.0-85. Система обеспечения точности геометрических параметров в строительстве. Правила выполнения измерений. Общие положения [National Standard. System of ensuring geometrical parameters accuracy in construction. Rules of measurement. General]. Москва, 1985. 17 с. (in Russian).

СНиП 3.03..01-87. Несущие и ограждающие конструкции [Standards and Regulations in Construction. Supporting and barrier structures]. Москва, 1987. 187 с. (in Russian).

Эгнус, М. и др. *Возведение каркасных жилых и общественных зданий* [Dwelling and communal houses' skeleton erection]. Москва: Строиздат, 1972. 293 с.

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