METHODOLOGY OF GEODETIC SURVEYING FOR CONSTRUCTION IN ACCORDANCE WITH INTERNATIONAL STANDARDIZATION

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Geodetic surveying plays a very important role in modern-day construction. Surveying methodology, including the methods and surveying instruments, their compliance with certain requirements as to the scope and accuracy of the conducted measurements, is the subject of normative regulations recognized by the International Organization for Standardization (ISO).

1. INTRODUCTION

A project of a structure, with size determined according to the rules of modular coordination, is being developed on the construction site with accuracy resulting from assumed tolerance [1]. The tolerance not only specifies the possible variation range regarding the factual size of the structure in relation to one assumed in the project (deviation from project), but also determines the accuracy required for the construction. This accuracy, together with the required range of measurements, has a significant influence on the choice of methods and surveying instruments, as well as the ancillary equipment.

The International Organization for Standardization (ISO) has developed a set of standards regarding surveying for construction, established by the Polish Committee for Standardization (PKN) as standards bearing the PN-ISO symbol. These are consistent and complementary rules which can be helpful while determining the methodology of surveying at the stage of development as well as utilization of a structure (for diagnostic purposes).

2. GENERAL CHARACTERISTICS OF PN-ISO STANDARDS REGARDING GEODETIC SURVEYS IN CONSTRUCTION

PN-ISO standards regarding geodetic surveys in construction include:

- **construction (setting-out) surveys aiming at determination of plane coordinates and the height of control points established within the construction site, constituting a reference system for accurate stake-out of points which mark the designed location of the structure and its construction elements,**
- **as-built surveys with the goal to evaluate the correspondence of the finished development stage with the assumed permissible deviation (e.g. completion of certain elements, stake-out and construction work) and to acquire the so-called accuracy data for the procedure of determining the tolerance and analyzing the influence of specified dimension variation on fitting elements during assembly,**
- **control surveys considered informal, independent surveys aiming at verification of the accuracy of formerly conducted measurements,**
- **test surveys aiming at obtaining data to describe the so-called utilization accuracy of the surveying instruments in a given construction site environment.**

All the above-mentioned surveys are presented in a comprehensive way, first, the interpretation of basic terms is given, and subsequently, the characteristics of given measurement procedure conducted on the construction site, and the documentation including its results follow.

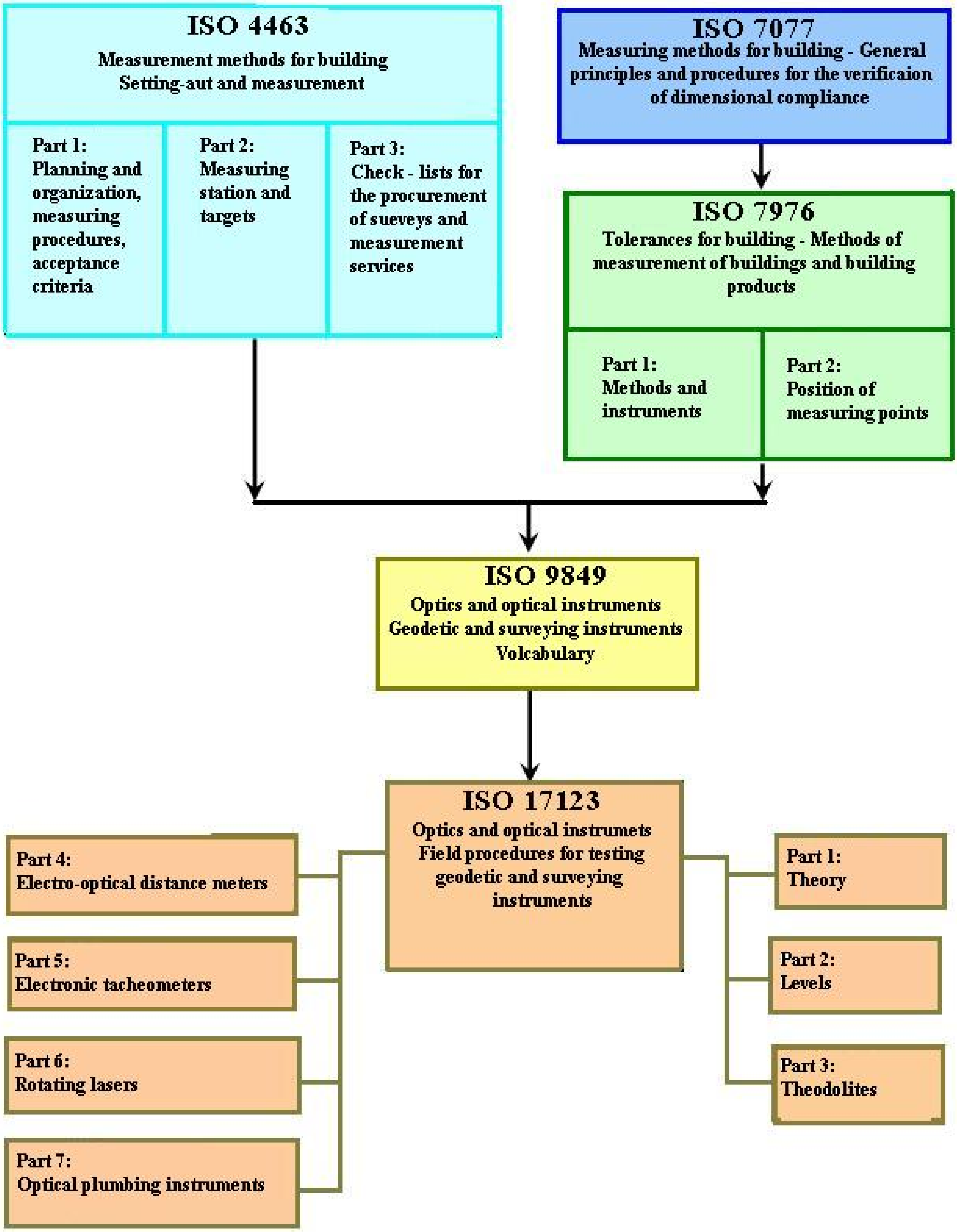

Fig. 1. ISO Standards in Geodesy for Construction; Established as Domestic Standards.

3. PLANNING AND ORGANIZATION OF STAKE-OUT

Stake-out may be understood as a set of surveying actions with the goal to determine geometric system created by interconnected points, lines, and planes, which enables to indicate the location and height of a structure and its elements. In geodetic practice, in case of significant-size and complex objects, the above configuration develops from control network and includes the following:

- **First order network – connected to the country network and covering the whole construction area,**
- **Second order network – being the reference to the realization of a certain structure or set of structures and connections,**
- **Detailed points – indicating the location of chosen structure elements e.g. pillars or walls.**

At the stage of planning and stake-out organization, particular attention must be given to:

- **Information regarding the shape and size of the construction site, present minor control, neighboring objects and legal regulations,**
- **Appropriate site inspection,**
- **Distribution of control network points in places where the danger of their destruction is minimal,**
- **Proper design of networks including: localization network (on the map, for the use of the designers to determine the boundaries, location of buildings, roads, underground utilities), ground control network (having the function of second order network with lines parallel to the structure's construction axes, and corresponding to the localization network in whole or its parts) and construction network (used by the designers to determine the location of construction elements – usually their axes).**
- **Preparation of the stake-out drafts including, among others, data indicating the localization of the designed structures and the coordinates of stake-out points.**
- **Appointing of people or teams responsible for each subsequent stage of stake-out and verification of post-realization accuracy.**
- **Qualifications of teams conducting the stake-out.**
- **Scope and content of the documentation (including, among others, the stake-out drafts, field documentation, computer printouts, characteristics of the surveying equipment and the conditions in which surveying was conducted) and its storage place.**

4. PROCEDURES FOR STAKE-OUT AND SURVEYING

4.1 Approval criteria

The approval criteria are understood as the permissible deviations of distance, angles, and height, obtained from conducted survey, in relation to the reference data regarding, in most cases, the higher order network or resulting from the conducted adjustment. The above deviation is to be interpreted as 2.5 times the value of the corresponding standard deviation or mean square error.

The approval criteria outlined below have been prepared, above all, in the context of post-realization surveys, but can also be applied to verification surveys.

The basis for accuracy verification of given points in regard of the above criteria is in each case the result of post-realization survey, which should be conducted by another survey team, (i.e. not the one establishing the network layout), with a different instrument of the same accuracy class. If the result proves unsatisfactory in regard to the applied approval criteria, either through given distance, angle or height difference, remeasurement is necessary. In case of further inaccuracy, confrontation with the team establishing the network layout at the construction site has to take place.
Approval criteria for surveying results

Table 1

CHARACTERISTICS OF SURVEYED POINTS	FORMULATED ACCURACY CRITERION AS PERMISSIBLE DEVIATION	
	Distance	angle
First order network; Stage one Stage two	 $\pm 0{,}75\sqrt{L}$ at minimum 4mm $\pm 1{,}50\sqrt{L}$ at minimum 8 mm	 $\pm \frac{0{,}05}{\sqrt{L}}$ $or \pm 0{,}075\sqrt{L}[mm]$ $\pm \frac{0{,}10}{\sqrt{L}}$ $or \pm 1{,}50\sqrt{L}[mm]$
Second order network Stages one and two	$\pm 4mm \quad for \quad L : 7m$ $\pm 1{,}50\sqrt{L}[mm] \quad for \quad L \rangle 7m$	$\pm \frac{0{,}10}{\sqrt{L}}$ $or \pm 1{,}50\sqrt{L}[mm]$
Detailed points	$\pm 2 * K_1[mm] \quad for \quad L : 4m$ dla $\pm K_1\sqrt{L}[mm] \quad for \quad L \rangle 4m$ K_1 = 10,5 or 1,5 depending on the type of construction work	
	where L – distance in [m], in case of angles – length of the shorter side	
Second order points leveled to H height from another level	± 3mm for H ≤ 4mm and $\pm 1{,}50\sqrt{H}\ mm \quad for H[m\}$ (regards a single point)	
Leveling – height difference Δh between: Two bench marks of the first order	± 5 mm	
Bench marks of the first and second order	± 5 mm	
Two neighboring bench marks of the second order	± 3 mm for Δh ≤4 m $\pm 1{,}50\sqrt{\Delta h}[mm] \quad for \quad \Delta h \rangle 4m$	
Second order bench mark and a detailed point, and two detailed points determined from the same bench mark of the second order	$\pm K_2$ for K_2 = 30,10 or 3 depending on the type of the construction works conducted	

4.2 Instruments and Methods

Instruments and the ancillary equipment used in surveying for construction purposes should definitely be checked periodically and rectified according to the producer's recommendation. While choosing the instrument type and the stake-out method one should take into consideration, in the first place, the appropriate accuracy requirements determined by the designers and constructors.

In this regard, specific testing procedures designed to assess the so-called utilization accuracy of geodetic instruments in specific field conditions, i.e. on the construction site, can be very helpful. This regards the leveling instrument, theodolite, spinning laser, electronic distance meter, optical plummet, and total station, for which the manner of testing area configuration, surveying organization, and manner of data evaluation in two testing procedures, i.e. simplified and complete, have been determined. [1].

The basic role of testing procedures is:

In case of simplified procedure – determining if the accuracy of the chosen surveying instrument and its ancillary equipment falls within the range of permissible deviation for the planned surveying task,

In case of complete procedure – determining the highest possible accuracy for a chosen surveying instrument and its ancillary equipment under specific field conditions.

Two recommendations have been formulated, regarding the surveying methods conducted on the construction site.

1) **Stake-out should be conducted in a way allowing for the occurrence of redundant observations in numbers allowing detection and elimination of gross errors,**
2) **if possible, surveying should begin and end with survey points of known coordinates.**

First order network created by the network of properly selected points, should be measured by distances and angles together with redundant observations and adjusted by the least square method. The second order points should be determined in relation to the first order network points or second order network points previously verified. Some examples of methods applicable in this case are: method of polar coordinates, resection, and free station.

5. CONCLUSION

The analysis of the scope and content of all 150 standards devoted to geometry of structures [2], leads to the formulation of the following framework of activities for investors, developers, and geodetic surveyors:

a) **determination of the scope and character of the geodetic and cartographic works (in accordance with ISO 4463-3, including the check-list of the above-mentioned activities at the following stages: acquisition with the beginning of construction works, development of the structure, finalization of the construction process),**

b) **preparation of the minor control network project (in accordance with ISO 4463-1),**

c) **test survey of surveying instruments being at the disposal of the team responsible for the geodetic activities of the investment (in accordance with ISO 17123, parts 1 to 7),**

d) **stabilization and premarking of control points (in accordance with ISO 4463-2),**

e) **determining the scope of accuracy regarding the projected location of certain construction elements of the developed structure (in accordance with ISO 4464 and 3443/4) as well as methods and instruments (in accordance with ISO 7976 part 1 and 2),**

f) **Determining the rules and range of geometric control of the construction works (in accordance with ISO 7077 and 3443-6, 3443-7, 3443-8) and documentation of its results (in accordance with ISO 7737).**

None of the mentioned ISO standards developed by Technical Committees ISO/TC 59 and ISO/TC 172 has the equivalent in existing domestic standards.

Their Polish version, being the translation of the English version, without any changes introduced, undoubtedly fills the standardization gap, nevertheless, in many cases, the recommendations are highly controversial.

REFERENCES

Pawłowski W. Normalizacja w budownictwie i geodezji z udziałem Katedry Geodezji Politechniki Łódzkiej. Zeszyty Naukowe Nr 981, Budownictwo zeszyt 54. Łódź 2006.

Pawłowski W. Kształtowanie geometrii obiektu budowlanego w standardach ISO ustanowionych jako normy krajowe. Monografia nt. wykorzystanie metod geodezyjnych w ocenie stany geometrycznego budowli. Wydawnictwo Politechniki Śląskiej. Gliwice 2008.