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THE TESTING OF STRUCTURAL ELEMENT MOVEMENTS AND DEFORMATIONS, ITS GEODETIC MEASURING INSTRUMENTS AND MEASURING EQUIPMENT

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Abstract

Structural element movements and deformations have a significant influence on the quality of the building work. Their damaging effects can be prevented if the values of the development process of the movements and deformations are known. The test measurements carried out for the determinations took place under different building industry circumstances, so the test results are influenced by numerous factors. In the interest of getting to know these influencing factors the decisive elements of the test measurements need to be studied.

From the decisive elements this study deals with the quality management issues of the geodetic measuring instruments and measuring equipment of movement and deformation testing measurements.

The topicality of the analysis of this group of problems is justified by the demand for the technical development of quality and measuring also asserted in Hungary in the scope of the European Union's (EU) European Quality Program (EQP), and by the necessity of the creation of a uniform system of technical requirements.

Keywords: movement testing, deformation testing, geodetic instruments, measuring instruments, measuring equipment, calibration, confirmation, environmental effects.

1. Introduction

Structural element movements and deformations have a significant influence on the quality of the building work. Their damaging effects can be prevented if the values of the development process of the movements and deformations are known. In order to determine them test measurements of high accuracy need to be carried out with the help of which not only the movement and deformation values, but also their small changes can be traced. Knowing the results of these measurements the movement processes can be described and their expected values can be predicted.

In the interest of preventing the different damaging effects the test measurements are generally carried out in a laboratory or under laboratory circumstances. The testing of the building structure movements and deformations does not take place in a laboratory, but on different places, under different building industry circumstances, in different sizes and according to different demands, so the quality of the test measurement results is influenced by numerous factors.

In the interest of getting to know the effects of these influencing factors the decisive elements and units of the test measurements carried out under building circumstances need to be studied, such as the external effects on the test measuring instruments, the measuring equipment, the measurement methods and the subject of the testing when the test measuring is carried out, as well as the other quality influencing factors.

From the decisive elements of structural element movement and deformation testing measurements the present study deals with the quality management issues in connection with the testing geodetic measuring instruments and measuring equipment.

The topicality of the analysis of this group of problems is justified by the demand for the technical development of quality and measuring also asserted in Hungary in the scope of the European Union's (EU) European Quality Program (EQP), and by the necessity of the creation of a uniform system of technical requirements.

Apart from the special literature the subject is based on the technical development experience relating to the field of quality and measurement affairs and building industry test measurements carried out at Budapest Technical University's departments of geodetic profile and by ourselves, and international and Hungarian standards published so far were also used in the interest of the determination of a uniform system of requirements.

2. Geodetic Measuring Instruments and Measuring Equipment to be Applied in the Course of Test Measurements

The whole sphere of basic geodetic instruments can be applied in the course of testing structural element movements and deformation, such as angle gauges, distance measuring instruments, altitude instruments and electronic total stations.

Beside the basic geodetic instruments, photogrammetric measuring equipment and the GPS technology can also be used.

For the test measurements special measuring instruments for industrial-geodetic purposes are produced by the instrument factories, such as alignment meters, laser setting out instruments, autocollimating equipment, inclinometers and accurate plumbing instruments.

In the case of special demands purpose-built instruments of unique construction need to be produced, and measuring equipment assembled from several instruments can also be used. Combined with measuring equipment operating on the basis of different physical principles, using inductive (route) transmitters continuously measuring, automatically registering measuring instruments can also be constructed, such as built-in automatic hydrostatic level systems.

Every instrument factory produces the geodetic measuring instruments in several grades of accuracy. In the case of each instrument factory there are con-

structional differences between the instruments[1] of the same grade of accuracy or they are fitted with different auxiliary and supplementary equipment. Consequently, their applicability is different per branch.

In the course of the test measurements all the measuring instruments and auxiliary equipment (the determination of the measuring points) apart from the basic and special instruments used, and even the operating instructions influence the test results, so in the case of test measurements it is practical to take into consideration the accuracy influencing the role of all the measuring instruments and auxiliary equipment beside the measuring instruments in general, and to name each of them, or the specifications of the tests must be given using the expression measuring equipment which also defines these. In the international quality standards apart from the expression measuring instrument[2] the expression measuring equipment[3] is also used in more and more cases.

3. The Most Important Factors in Connection with the Measuring Equipment Determining the Accuracy of the Test Measurement Results

The accuracy of the test measurement results is determined by the measuring equipment and its use, in the sphere of the factors listed above:

a. the production features of the measuring equipment,
b. the calibration of the measuring equipment,
c. the testing, adjustment and setting of measuring equipment,
d. the maintenance and repairs of the measuring equipment,
e. the applied measurement method,
f. the operating staff,
g. the environmental effects and other influencing factors, and their changes in time,
h. the special character (specific possibilities) of movement and deformation testing measurements.

Analysing the above it can be stated that in the course of the application of geodetic measuring instruments the accuracy of the test results is significantly influenced by certain factors, such as environmental effects for example, but the accuracy of the test results can be increased by choosing the applied model of determination and the measurement method. This special feature of geodetic measuring instruments makes them different from the other measuring instruments, so special attention shall be paid to these special features.

[1] Instrument: A measuring instrument which gives a signal or displays a value.

[2] Measuring instrument: An instrument, with or without the supplementary instruments (auxiliary devices), which is for the purpose of carrying out the measuring.

[3] Measuring equipment: All the measuring instruments, reference standards, samples, auxiliary equipment and instructions needed to carry out the measuring. This expression includes the measuring equipment used both for the test and the inspection and for the calibration. The definition of measuring equipment also includes the definition of measuring instrument.

Below we shall analyse the most important general factors determining the accuracy of test results, and their special features relating to geodetic measuring instruments and movement and deformation tests.

4. The Choice and Design of Test Measuring Instruments and Measuring Equipment

Measuring equipment the accuracy in use of which suits the requirements of the planned measuring task must be chosen. The measuring procedure shall be so accurate that it does not influence the value of the movement or deformation intended to be detected.

The requirement of the measuring accuracy is determined taking into consideration the purpose to be achieved through measurements. Generally, their value is stated as a function of the expected largest shift or a critical shift value.

The analysis of the triggering causes and effect mechanism of the expected movements and deformations, and the degree of the acceptability of the damaging effects influencing the building work and the functional use of the buildings serve as important information for the dimensioning planning.

In the course of choosing the measuring equipment several aspects must be taken into consideration. Among these the applicable measuring technologies and the measuring accuracy[4] requirements, the possibility of observing the available measuring time and the economic requirements have an outstanding role. Apart from the above the main values of the metrological characteristics must also be considered.

5. The Calibration of the Measuring Equipment

Calibration[5] means all the operations with which help the connection between the value indicated by the measuring instrument or measuring system or the value realised by the standards or the sample and the appropriate values realised with the reference standard[6] can be determined under the prescribed conditions. The result of calibration makes possible to allocate the values of the quantity to be measured to the displayed value, or to determine the corrections of the displayed values.

In Hungary the question of measuring instrument calibration is regulated by Act XLV of 1991 on measuring, Government Decree No. 127/1991 (X.9.) on the

[4]Measuring accuracy: The closeness of the test result and the real value of the quantity to be measured.

[5]Calibration: In the special literature on geodesy the expression comparing is used which is equivalent to the technical content of calibration.

[6]Reference standard (of measuring): Standard, measuring instrument, sample or measuring system the task of which is to define the quantity unit or one or more quantity values and to realise, save or reproduce them for the purpose of transmitting them to another measuring instrument by comparison.

implementation of the act on measuring and Act XXIX of 1995 on the accreditation of laboratories, certifying and controlling organisations, issued in accordance with the EU's legal harmonisation proposals.

In the act on measuring geodetic measuring instruments are not listed among the measuring instruments of compulsory calibration. At the same time it is prescribed in the act that: "Measuring followed by legal consequences shall be performed with a calibrated measuring instrument or a measuring instrument inspected with a reference standard, suitable for performing the measuring task." It is also prescribed in the act that: "On the basis of the authorisation obtained from the OMH (National Measurement Office), the calibrating laboratories are entitled to issue a calibration certificate about the inspection with calibration of the accuracy of the measuring instruments of not compulsory calibration".

According to the implementing decree of the act "Every measuring instrument used for performing measuring followed by legal consequences shall be derived from or traced back[7] to the national reference standard directly or indirectly".

The conditions of operation of the calibrating laboratories are included in the first two standards of the EN 45000 standard series determining the uniform system of requirements made and recommended by the EU. The MSZ EN 45001 standard called "The general conditions of operation of testing laboratories" prescribe the following in the chapter on "Equipment".

"If necessary, the measuring and testing equipment used in the testing laboratory shall be calibrated according to a determined program before and after installation. The whole program of the equipment calibration shall be planned and operated so that the current measurements performed in the laboratory can be traced back to national and international reference standards, if it is necessary.

Where it is necessary, the testing equipment shall also be calibrated in operating condition in the period between the regular re-calibrations."

6. The Determination of the Accuracy in Use of the Test Measuring Instruments, the Testing and Setting of Measuring Instruments

In order to determine the accuracy in use of the geodetic–building industry measuring instruments the tests described in the course books and university lecture notes can be carried out.

In the MSZ ISO 8322-(1-7): 1992 standard series called 'Building construction. Measuring instruments,. Procedures for determining accuracy in use.' procedures are described to test measuring tapes, optical levelling instruments, theodolites, optical plumbing instruments, laser instruments and instruments when used for setting out, and a theoretical basis is also provided in the first standard of the

[7]Traceability: A characteristic feature of the measuring result and the value of the reference standard according to which it can be related to specified references, generally national or international reference standards through an unbreakable chain of comparison of known uncertainty (chain of tracing back).

series. Unfortunately, the standard of the electro-optical distance measuring instruments planned in this series has not been published yet. Presently the No. 18723 DIN standard is available in connection with the testing of electro-optical distance measuring instruments.

Before every task or group of tasks the person carrying out the test measuring can or must make sure with the methods described above that the measuring instrument's accuracy of use suits the requirements of the measuring task. According to the standard the standard deviation (σ) value of the measuring instrument's accuracy of use and its the permitted deviation (S) value should be bigger than 2/5 of the allowed deviation or tolerance (P) of the test measurement, that is:

$$S > \frac{P}{2.5}.$$

Before accepting the general estimate of the accuracy of use it is recommended to make sure that the standard deviation of each given measurement series is right even under specific circumstances.

Beside the qualification of the measuring equipment, the procedures provided by the above standards also provide information in connection with the adjustment and setting of the measuring equipment.

7. Metrological Confirmation

The legal and technical regulation of quality and measurement affairs has primarily dealt with the calibration of measuring instruments so far. All the methods of keeping the appropriate use of the measuring instruments in a condition meeting the requirements are dealt with in the special literature only in parts.

The MSZ EN 30012-1:1998 standard called 'Quality assurance requirements for measuring equipment', in chapter 1 on the 'Metrological confirmation system for measuring equipment' deals with the questions of the maintenance, repairs, testing, adjustment and calibration of measuring equipment.

According to the standard metrological confirmation is a complex of operations needed to ensure that a given specimen of the measuring equipment is in a condition suiting the requirements of appropriate use. Generally metrological confirmation, among others, includes calibration, the necessary adjustment and repairs, the re-calibration following them, and the demanded sealing and labelling.

Among others the standard provides a method for the construction of the confirmation system and the determination of the confirmation periods.

According to the MSZ EN 29001:1992 standard, in the case of the inspecting, measuring and testing equipment:

– it must be ensured that the inspecting, measuring and testing equipment is operated, protected and stored in a way that its accuracy and suitability for use is maintained,

– the inspecting, measuring and testing equipment, including the testing hardware and software, must be protected against adjustments which would invalidate the calibration adjustment.

According to the MSZ EN 45004 standard the permanent suitability of the instruments and equipment for appropriate use shall be ensured.

8. The Applied Testing Measurement Methods

The elimination of systematic measurement errors can be ensured with the measurement method as well as the revealing of gross measurement errors, the performance of self-inspection and making the measurement results more accurate.

In the case of a series of measurements the values δ of the systematic measurement errors load the measuring results with the same sign. If in the course of repeating the series of measurements a measurement arrangement is applied where the error δ is stated with a different sign, then the resultant values calculated from the results of the two series of measurements do not contain the systematic errors, or the systematic error values can be calculated from the results of the two series of measurements.

In the case of the application of the angle gauges and electronic total stations the point positioning and centre angularity error cannot be eliminated directly with the measurement method. Consequently, in order to eliminate their damaging effect, their values shall be determined and correction shall be calculated for the measurement results.

The measurement methods suitable for the elimination of certain measurement errors are dealt with in the course books and lecture notes of higher education, the legal and technical regulations do not deal with these questions.

In the factory's operating instructions the electronic total stations are regarded as adjusted, calibrated measuring instruments, similarly to the measuring instrument of other professions, so generally the operating instructions do not deal with the systematic error eliminating effect of the measurement methods, what is more, in the majority of their built-in programs they do not provide a possibility of using these methods. Due to the high accuracy and stability of these modern instruments they do not even employ surveyors in the case of electronic total stations, although even despite the favourable characteristic features of these electronic total stations the damaging effect of the systematic errors may occur. What is more, the environmental influencing factors occur completely even in the case of these measurements.

The measurement methods suitable for the elimination of systematic measurement errors also make partial self-inspection possible.

If the right measurement method is chosen the measurement accuracy can also be increased, for example in the case of projecting vertical planes using the autocollimation equipment, or repeating the measurements several times at planned points of time.

All the equipment which can be taken into consideration must have measurement instructions relating to the use and operation of the equipment.

9. The Operating Staff

Beside the staff operating the measuring instrument the auxiliary staff also plays a role in achieving test results of the desired quality.

Quality consciousness shall be created at every level.

The following requirements of the MSZ EN 45001 standard in connection with the staff of testing laboratories can be applied generally.

The staff employed in the testing laboratory must have the qualifications, skills, technical knowledge and experience needed for the performance of the tasks entrusted to them. The testing laboratory must ensure that the qualifications of its staff remain at an up-to-date level. The laboratory shall keep a record of the information relating to the qualifications, skills and experience of the technical staff.

10. Environmental Effects and Other Influencing Factors

In the course of the test measurement the measuring equipment and the operating staff are also exposed to the effects influencing the measuring result. Furthermore, the condition of the environment and its changes also influence the accuracy of the measurement. Among the environmental effects and influencing factors the meteorological effects (temperature, sunshine and other one-sided heat effects, wind, the condition and consistence of the air, its factors influencing the propagation of light, refraction effects, light and lighting conditions, the visibility of the measuring signs, and the changes of the above) have an outstanding role as well as the movements of the reference points and the instruments. Beside these occasionally special effects may also have a significant influence on the measuring instruments and their use, for example the operation of compressors and machines, or vibrations caused by the wind, or magnetic effect occurring in the case of automatic levelling instruments near electric cables.

In the interest of the elimination of the environmental effects and reducing their damaging effects, in the course of planning the measurements the choice of the time of the measurement, which can be regarded as favourable from the aspect of the applied measurement technology, shall be taken into consideration as well as the requirement that during the time of the movement and deformation testing measurement the external circumstances should not change. The individual test measurements must be carried out under the same or nearly the same circumstances.

Deviations from this system of requirements is only allowed, if it can be ensured that a repeated measurement within a testing measurement series can be carried out under different circumstances where the error occurring as a result of an external effect has a different sign than in the case of choosing symmetrical

measuring time-points as compared to the morning and evening isotherm time-points in the interest of the elimination of the local refraction effect.

The movement and deformation testing measurements must be carried out by determining the measuring instruments' accuracy of use, and by calibrations under the same circumstances (under the same reference conditions).

In each case the external circumstances must be measured and recorded. If the measurements are carried out at a point of time different from the reference conditions and under different physical circumstances, conversion into the reference conditions may be necessary.

Information in connection with the simplest consideration and determination of the different environmental effects can be obtained by carrying out the measurement repeatedly under the changed circumstances.

11. The Special Character and Specific Possibilities of Movement and Deformation Testing Measurements

Movement and deformation testing measurements demand extraordinary accuracy, but they provide unique possibilities for the elimination of different measurement and environmental errors. In the course of these tests, in the majority of the cases the slight shifts of the points in time must be determined on the basis of the difference between the co-ordinates of test points determined at different points of time.

In the case of the test measurements carried out at different points of time the following factors are the same or can be made the same:

- the place of measurement and the basic environmental effects,
- the used points of reference points,
- the used measuring equipment and its adjustment condition,
- the geometry of the determination model,
- the measuring staff.

As a result of the same reference conditions the measuring errors triggered by the different damaging effects are eliminated from the difference of the determined point co-ordinates, or the shifting values of the test points are burdened in proportion with the amount of the shifting values rather than with the length of the determination directions.

Obviously it is not true in connection with every source of error, like for example in connection with the point positioning and centre angularity error which is different in each case. And in the case of levelling it is valid within a maximum of one station.

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