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Geodetic Measurement of Line Constructions for Control and Security of Construction Reliability

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Summary

The report appropriates to theoretic problems (correct terminology) in the area of geometric accuracy that affecting resulting quality the constructions. Further i tis aimed to the applications of empirically intended tolerant intervals, especially to the non - parametric methods that it is possible bring to bear into verification of geometric accuracy of the roads and highways. These method have more general usage, the calculation is simpler and their characteristics are independent on the distributionof basic set.

In the next parts is described graphic model of geometric parameters like possibility to visualization results of geodetic control measuring of geometric accuracy. The graphic model is given from difference measured and project highs of line constructions by the help of izogram for individual constructional section.

KEYWORDS: Geometric accuracy, tolerance interval, non-parametric methods.

1. INTRODUCTION

The principal criterion influencing the final quality of the construction is the accuracy of geometrical parameters. The knowledge of geometrical parameters ensures the functionality, durability and reliability of constructions.

The methods of statistical checking represent an effective tool for check-up of geometrical accuracy. They bring reduction of geodetic fieldwork and cut in control measurement. They make possible objective decision making about the quality of checked data and at the same time they guarantee with a prescribed probability that only the statistical files will be accepted meeting the predefined requirements between the provider and customer. The utilization of statistical methods is the basic requirement for quality control application in accordance with ISO standards row 9000.

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2. STANDARDS FROM THE AREA OF GEOMETRICAL ACCURACY OF CONSTRUCTIONS AND THE AREA OF APPLIED STATISTICS

The important standards are quoted directly in the text, further standards and sources are listed in the References.

2.1 Terminological standards

ČSN ISO 3534-1:1994 Statistics – Vocabulary and symbols Part 1: Probability and general statistical terms.

ČSN ISO 3534-2:1994 Statistics – Vocabulary and symbols Part 2: Statistical quality control.

2.2 Standards from the area of applied statistics and statistical data interpretation

ČSN O1 0250:1973 1973 Statistical methods in industrial practice – General principles, comments inclusive.

ČSN O1 0253:1976 1973 Statistical methods in industrial practice III - Basic distribution - free methods, comments inclusive.

ČSN ISO 16269-6:2007 2007 Statistical interpretation of data - Part 6: Determination of statistical tolerance intervals.

This standard describes procedures for determination of tolerance intervals that comprise at least a specified portion of the population with a fixed confidence level. Both one-sided as well as two-sided statistical tolerance intervals are offered where one-sided intervals possess either the upper or the lower limit and two-sided intervals are with both limits. Two methods are introduced: a parametrical one for the case when the studied characteristic has normal distribution and a distribution independent method for the case when no information about the distribution is available, but the fact it is continuous.

ČSN ISO 16269-8:2005 Statistical interpretation of data - Part 8: Determination of prediction intervals.

In this standard, prediction intervals are described that are applicable in practice whenever it is required to predict the results of a subsequent retrieval of a given number of discrete units on the basis of results of the previous selection of units produced under the same conditions. The intention of this standard is to clarify the differences between prediction intervals, confidence intervals and statistical tolerance intervals and to provide procedures for some of the types of prediction intervals for which large newly calculated tables exist.

ČSN ISO/TR 10017:2004 Guidance on statistical techniques for ISO 9001:2000.

This technical report is a guide for selection of suitable statistical methods that may be appropriate for development, introduction, maintenance and improvement of quality management systems.

2.3 Standards from the area of statistical control

ČSN ISO 7870:1995 Control Charts – General guide and introduction.

ČSN ISO 8258:1994 Shewhart Control Charts.

The standard represents a guide of utilizing and understanding of the relation of control charts to methods for statistical control of production processes. This international standard is restricted to procedures for applying methods of statistical control via Shewhart Control Charts only.

2.4 Standards from the field of statistical acceptance

ČSN 01 0254:1976 Sampling inspection by attributes, comments inclusive.

ČSN ISO 2859-0:1997 Sampling procedures for inspection by attributes – Part 0: Introduction to the standard ISO row 2859 attribute sampling system.

ČSN ISO 2859-10:2007 Sampling procedures for inspection by attributes – Part 10 Introduction into standards ISO row 2859 for acceptance test by comparison.

This standard describes parts of ISO standards row 2589:
- ČSN ISO 2859-1:2000 Sampling procedures for inspection by attributes - Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection, containing sampling systems for inspection of each lot from a continuous series of lots coming from one process and one provider.
- ČSN ISO 2859-2: 1992 Statistic acceptance by comparison - Part 2: Sampling procedures for inspection by attributes. Part 2: Sampling plans indexed by limited quality (LQ) for isolated lot inspection specifying sampling plans for situations where quality of individual or isolated lots is to be verified
- ČSN ISO 2859-3: 2006 Sampling procedures for inspection by attributes - Part 3: Skip-lot sampling procedures. It makes possible implementation of occasional acceptance for lots creating a continuous series and yielding higher quality levels than the AQL values contracted between the parties
- ČSN ISO 2859-4:2003 Sampling procedures for inspection by attributes - Part 4: Procedures for assessment of declared quality levels prepared for need of acceptance procedures that are suitable for systematic checkups such as screening

and auditing where the quality levels declared for a certain entity is to be verified - ČSN ISO 2859-5:2007 Sampling procedures for inspection by attributes - Part 5: System of sequential sampling plans indexed by acceptance quality limit (AQL) for lot-by-lot inspection. It is concentrated on plans by sequential sampling inspection and with escalated efficiency that corresponds to the efficiency used in ČSN ISO 2859-1 standard.

ČSN ISO 21247:2007 Systems of statistic acceptance with acceptance number zero and procedures of statistical control interconnected for product inspection.

It provides an interconnected system of acceptance plans and a system for statistical regulation of a process, that is worked out for acceptance plans with acceptance number zero together with statistical regulation of a process. It is applicable in all types of processes where acceptance by comparison or by variables is used and where the process has nature of a batch production. This system provides information about efficiency of the inspection system for each of the above mentioned variants. The information is supplied in the form of numerical values of operational characteristics both for acceptance probabilities at given quality levels as well as for quality levels in the process for given three levels (0,95; 0,50 a 0,10) of acceptance probabilities [1].

3. METHODS OF STATISTIC INSPECTION

Among the methods of statistic inspection it is necessary to mention sample inspection embracing statistic acceptance by comparison, by variable and statistic regulation.

For acceptance testing by comparison where no assumption about normal distribution is postulated, the procedure is the following one: When checking geometrical accuracy of constructions, factual deviations are sorted as conforming or nonconforming ones with respect to limit deviation given in the standard, project documentation, in testing and checking plans, in technological standards or in constructional technological procedures.

For acceptance testing by variables, the geometrical parameter is measured and its accuracy characteristics are stated.

In general, statistical regulation is intended for running processes.

When the construction technology is good and all the prescribed principles for measuring are met, but the tolerance interval according to standards, technical specifications etc. is too narrow, it means that the standard cannot be used without modification. In such a case, one should take account of specific properties of the construction process and to use **statistic tolerance limits** established in empirical

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way according to hitherto behaviour of the construction process. Then, the limit deviations of geometrical parameters should result from those tolerance limits.

Statistic tolerance limits can be according to [2] either parametrical ones, when normal distribution is supposed, or non parametrical ones when no such supposition is made.

A reverse case may arise when the production process is not well fitted to limit deviations given in the standard etc. and therefore, it does not fulfil them. **To assess suitability of such a production process** is possible on the basis of statistical analysis and statistical regulation.

3.1 Suitability assessment of a production process

3.1.1 One-dimensional statistical analysis of process capability

Accuracy verification according to [3] is complemented by capability index of the control measurement in accordance with [4].

The capability index is calculated:

$$C_p = \frac{T}{2.u.s} \tag{1}$$

Where T is (construction) tolerance,

u is standardized random variable (u is selected to be 2),

s is standard deviation of a sample.

If $C_p \geq 1$ then the process of control measurement is considered as suitable, for $C_p < 1$ the process is not suitable and it is necessary to proceed to its analysis via control charts [5].

3.1.2 Multi-dimensional analysis

In the real world, one encounters multi-dimensional analysis more frequently than one-dimensional data. E.g. when classificating geometrical parameters of line constructions, then there is, for each point, more than one value (X,Y,Z) measured. It is possible to separate the values and to analyze each of them separately by the methods of one-dimensional analysis, but, in such a way, not all the information available in the data is utilised.

When applying multi-dimensional analysis, it is necessary to consider the values as a random sample from a given distribution. The density of the standardized two-dimensional distribution with components x_1, x_2, zero expectations $\mu_1 = 0, \mu_2 = 0$ and unit variance $\sigma_1^2, \sigma_2^2 = 1$ is of the form

$$f(x_1, x_2) = \frac{1}{2\pi\sqrt{1-\rho^2}}.\exp\left[-\frac{x_1^2 - 2\rho x_1 x_2 + x_2^2}{2(1-\rho^2)}\right] \tag{2}$$

where ρ is correlation coefficient . In case of more variables, matrix notation is used to put down density of m-dimensional normal distribution [6]:

$$f(x) = (2\pi)^{-\frac{1}{2}m} \sum{}^{-\frac{1}{2}}.\exp\left(-\frac{1}{2}(x-\mu)^T \sum{}^{-1}(x-\mu)\right) \tag{3}$$

3.1.3 Statistic control

There exist one-dimensional charts (e.g. Shewhart control charts) as well as multidimensional control charts

One considers the stability of expectation μ, respectively of variance σ^2 with Shewhart control charts.

The analysis of geometrical accuracy via control chart, constructed according to [7] proceeds in such a way that upper control limit S_H is calculated according to:

$$s_H = \frac{T}{5.u}\sqrt{\frac{\chi_\alpha^2(n-1)}{(n-1)}} \tag{4}$$

Where T is (construction) tolerance and T/5 is limit error of the check survey,

u is the value of normalised random quantity (u = 2 if probability that the check survey process error is within limits p = 0,95),

$\chi_\alpha^2(n-1)$ is: α – critical value of χ^2 division, α = 0,05 with (n – 1) degrees of freedom,

n is the number of checked points in one section.

Control charts make possible to analyze stability and grounds for a construction process not to be suitable due to the accuracy deterioration in one individual section or globally [4, 5, 8].

Let us mention, among the multi-dimensional control charts, the Hotelling control chart based on the Mahalanobis distance, the robust Hotelling control chart or PCA – control chart [6].

3.2 Statistical empirical tolerance limits

The boundary values of a statistical tolerance interval are tolerance limits. For an interval, there exists a fixed probability, so-called confidence level ($1-\alpha$), that the interval will cover at least a proportion p of the population from which the sample was chosen. The risk that this interval will cover less than portion p of the population is α (error of the first kind).

In inspection of geometrical accuracy of constructions, this method can be applied only when the units were chosen randomly from the population and are independent. Statistical tolerance interval can be one-sided or two-sided.

3.2.1 Parametrical tolerance interval

Parametrical tolerance limits suppose that the distribution of real deviations of a geometrical parameter is the normal one.

The standard [9] sets down a calculation procedure for two-sided as well as one-sided tolerance interval when the distribution of the observed characteristic is the normal one. Two alternatives are considered here. Namely, the first alternative supposes that standard deviation σ of the population is known and that the mean of the population is unknown. The second alternative supposes that both mean and standard deviation are unknown.

When know just sample characteristics $\bar{x}$ a s^2 of the random sample of size n, it is not possible to set the limits covering the proportion p of the population with certainty. However, in such a case, it is possible to determine at least the limits that will cover the proportion p of the population with a given probability $1-\alpha$. The ignorance of standard deviation σ of the population has to be paid for by certain “taxation” i.e. by extension of the tolerance interval.

Two-sided tolerance limits are of the form:

$$\bar{x} \pm \mathrm{ks} \tag{5}$$

where $\bar{x}$ is sample mean and s is standard deviation of a sample of a random sample of size n.

The constant value k is dependent on n, p a ($1-\alpha$) [10]. The most usual values of confidence level are 0,95 and 0,99 (α = 0,05 a 0,01).

As majority of populations of geometrical parameters does not have the normal distribution, it is necessary to utilize non-parametrical methods for their inspection.

3.2.2 Non-parametrical tolerance interval

The properties of non-parametrical tolerance interval are independent of the population's distribution.

In [9] supplement A, the determination of statistical tolerance interval is described for arbitrary distribution. The method mentioned makes use of extreme values in the sample.

For one-sided limited dispersions, the following formula, between sample size n, confidence level $(1-\alpha)$ and proportion p of the population over x_m (the least value in the sample) or under x_M (the greatest value in the sample), is valid:

$$p^n = \alpha \tag{6}$$

If the values of p a $(1-\alpha)$ are fixed, it is possible to determine the minimal sample size n for which one can claim with probability equal at least to $(1-\alpha)$, that over x_m (the least value) or under x_M (the greatest value) in the sample the proportion of the population will equal at least p.

For two-sides limited dispersions, the following formula, between sample size n, proportion p of the population that lies between x_M (the greatest value in the sample) and x_m (the least value in the sample) and confidence level $(1-\alpha)$, is valid:

$$np^{n-1} - (n-1)p^n = \alpha \tag{7}$$

If the values p a $(1-\alpha)$ are fixed, it is possible to determine the minimal sample size n for which one can claim with probability equal at least to $(1-\alpha)$, that the portion of population laying between the least and the greatest value in the sample will equal at least p.

The sizes n are tabulated as functions of p and $(1-\alpha)$, see tab.1 [10].

Tab. 1 Sample sizes n for proportion p at confidence level (1-α)

$1-\alpha$ \ p	0,90	0,95	0,99
0,90	38	77	388
0,95	46	93	473
0,99	64	130	662

4. GRAPHICAL DEVIATION MODEL

In this part, the graphical deviation model of geometrical parameters is drawn attention to as a possibility for visualisation of results of geodetic measurements of geometrical parameters coming from the differences of measured and project heights with the help of isolines for separate construction levels.

Basically DMT are used for analysis and visualisation of measurement results for geometrical parameters of line constructions. To build the model, software system Atlas DMT KresCom is used.

In the first case, the digital model of the project and of the actual state is created from the project coordinates and heights whereas in the second case, measured coordinates and heights of points for separate construction levels are used.

Further, the deviation model of the project and actual state can be created. The building of the model is more intricate since it is necessary to recalculate all the heights of the project points (as project points coordinates are not identical with coordinates of the points really measured).

The differences between the heights measured and modified in the project form and the original project heights are calculated. Then finally, the deviation model for separate construction layers is built [11].

5. CONCLUSION

The contribution is devoted to the theoretical problems in the area of geometrical accuracy that influences the final quality of constructions. Further, assessment of suitability of a production process (both one-dimensional and two-dimensional), application of empirically found tolerance intervals and especially, non-parametrical methods are discussed. These methods can be used for check-up of geometrical accuracy of line constructions. Their calculation is simpler and their properties are independent of the distribution of the population.

Next, graphical deviation model of geometrical parameters is described as a possibility for visualisation of geodetic inspection results for geometrical accuracy.

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