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Navodilo za uporabo statističnih metod za določanje lastnosti zidarskih proizvodov

Guidance on the application of statistical methods for determining the properties of masonry products

Leitfaden für die Anwendung statistischer Methoden zur Bestimmung der Eigenschaften von Mauerwerk Produkten

Guide pour l'application de méthodes statistiques pour la détermination des propriétés des éléments de maçonnerie

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Guidance on the application of statistical methods for determining the properties of masonry products

Guide pour l'application de méthodes statistiques pour la détermination des propriétés des éléments de maçonnerie

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This Technical Report was approved by CEN on 24 August 2015. It has been drawn up by the Technical Committee CEN/TC 125.

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European Foreword

This document (CEN/TR 16886:2016) has been prepared by Technical Committee CEN/TC 125 “Masonry”, the secretariat of which is held by BSI.

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Introduction

This document is informative for the guidance of manufacturers and Notified Bodies (NBs), who want to use statistical methods for the evaluation of conformity and Factory Production Control of masonry products. Its use is optional. Other statistical methods and non-statistical methods may be used.

Quality control of building materials and components is an indispensable part of an overall concept of structural reliability. As quality control is generally a time-consuming and expensive task, various operational techniques and activities have been developed to fulfil safety requirements in buildings. Properly employed statistical methods are one way to provide efficient, economic and effective means of quality control.

Background: "The terms and definitions in EN 1990 (*Eurocode: Basis of structural design*) are derived from ISO 2394 (*General principles on reliability for structures*). For the design of structures, EN 1996-1-1 (*Eurocode 6: Design of masonry structures — Part 1-1: General rules for reinforced and unreinforced masonry structures*) is intended to be used together with EN 1990. ISO 12491 (*Statistical methods for quality control of building materials and components*) gives general principles for the application of statistical methods for the quality control of building materials and components, in compliance with the safety and serviceability requirements of ISO 2394. ISO 12491 is applicable to all buildings and other civil engineering works, existing or under construction, whatever nature or combination of materials used, e.g. concrete, steel, wood, bricks. The EN 771 series specifies that one method of satisfying the conformity criterion laid down in these product standards is to use the approach given in ISO 12491."

This Technical Report gives guidance on how a statistical evaluation can be put into practice based on the background of ISO 12491.

A simplified method is also given based on information obtained from practice about the possible distribution in production for specific product characteristics.

The method may also be used for the evaluation of different properties at the different stages of the factory production control (FPC) with the aim to minimize testing costs for the manufacturer and to ensure that the requirements are fulfilled.

Detailed examples are given in Annex C. For other more sophisticated techniques and specific problems, other international standards can be applied.

The initial draft of this document was prepared by the joint working group CEN/TC 125/TG 5 and the Sector Group 10 of Notified Bodies under the Construction Products Directive. The CEN/TR is a tool available for manufacturers and Notified Bodies.

It is laid down in the hEN's of masonry products that the manufacturer should demonstrate compliance for his product with the requirements of the harmonized product standards.

The purpose of this Technical Report is to put statistical evaluation into practice. Detailed examples are given in the annexes.

1 Scope

In the masonry unit standards and in national legislation, some properties need to be declared based on a certain fractile and confidence level. To demonstrate compliance with that a statistical tool can be used.

The purpose of this Technical Report is to exemplify how a statistical tool can be used in practice. This document should not contradict nor extend the scope of the work and role of a Notified Body, nor impose additional burdens on the manufacturer, beyond those laid down in the Construction Products Regulation and the product standards.

Mechanical and other properties of building materials and components are in the report described by random variables with a certain type of probability distribution. The popular normal distribution (Laplace-Gauss distribution) is given in Annex A. Normal distribution may be used to approximate many actual symmetrical distributions. When a remarkable asymmetry is observed, then another type of distribution reflecting this asymmetry should be considered, leading to a more complex method to demonstrate compliance with the product standard. More information on the normality test of Shapiro-Wilk is given in Annex D.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1990, *Eurocode - Basis of structural design*

EN 1996 (all parts), *Eurocode 6 — Design of masonry structures*

3 Terms, definitions and symbols

For the purposes of this document, the following terms, definitions and symbols apply.

3.1 Terms and definitions

3.1.1
unit
defined quantity of building material, component or element that can be individually considered and separately tested

3.1.2
population
totality of units under consideration

3.1.3
variable
X
variable which can take any of the values of a specified set of values and with which is associated a probability distribution

3.1.4
probability distribution
function which gives the probability that a variable X takes any given value (in the case of a discrete variable) or belongs to a given set of values (in the case of a continuous variable)

3.1.5
distribution function
Π(*x*)
function giving, for every value of *x*, the probability that the variable *X* is less than or equal to *x*:

$$\Pi(x) = P,(X \leq x)$$

3.1.6
(probability) density function
f(*x*)
derivative (when it exists) of the distribution function

3.1.7
parameter (population)
quantity used in describing the distribution of a random variable in a population

3.1.8
fractile
x
if *X* is a continuous variable and *p* is a real number between 0 and 1, the *p*-fractile is the value of a variable *X* for which the distribution function equals *p*

Note 1 to entry: Thus x_p is a fractile if $P,(X \leq x_p) = p$

3.1.9
population mean
μ
for a continuous variable *X* having the probability density *f(x)*, the mean, if it exists, is given by:

$$\mu = \int \times f(x)dx$$

the integral being extended over the interval(s) of variation of the variable *X*

3.1.10
population variance
σ²
for a continuous variable *X* having the probability density function *f(x)*, the variance, if it exists, is given by

$$\sigma^2 = \int (x - \mu)^2 f(x)dx$$

the integral being extended over the interval(s) of variation of the variable *X*

3.1.11
population standard deviation
σ
positive square root of the population variance σ^2

3.1.12
normal distribution
probability distribution of a continuous variable *X*, the probability density function of which is

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right]$$

3.1.13
random sample
one or more sampling units taken from a population in such a way that each unit of the population has the same probability of being taken

3.1.14
sample size
n
number of sampling units in the sample

3.1.15
sample mean
$\mathbf{x_m}$
sum of *n* values x_i of sampling units divided by the sample size *n*

$$x_m = \frac{\sum x_i}{n}$$

3.1.16
sample variance
$\mathbf{s^2}$
sum of *n* squared deviations from the sample mean x_m divided by the sample size *n* minus 1

$$s^2 = \frac{\Sigma(x_i - x_m)^2}{n-1}$$

3.1.17
sample standard deviation
s
positive square root of the sample variance s^2

3.1.18
estimation
operation of assigning, from observations on a sample, numerical values to the parameter of a distribution chosen as the statistical model of the population from which this sample was taken

3.1.19
estimator
function of a set of the sample random variables used to estimate a population parameter

3.1.20
estimate
value of an estimator obtained as a result of an estimation

3.1.21
confidence level
γ
given value of the probability associated with a confidence interval

3.1.22
lot
definite quantity of units, manufactured or produced under the same conditions which are presumed uniform

3.1.23
isolated lot
lot separated from the sequence of lots in which it was produced or collected, and not forming part of a current sequence of inspection lots

3.1.24
conforming unit
unit which satisfies all the specified requirements

3.1.25
non-conforming unit
unit containing at least one non-conformity which causes the unit not to satisfy specified requirements

3.1.26
sampling inspection
inspection in which decisions are made to accept or not accept a lot, based on results of a sample selected from that lot

3.1.27
sampling plan
plan in accordance with which one or more samples are taken in order to obtain information and the possibility of reaching a decision concerning the acceptance of the lot

3.2 Symbols

k_n	is the acceptance coefficient
k_1	is the acceptance coefficient one-sided tolerance interval
k_2	is the acceptance coefficient two-sided tolerance interval
k_c	is the corrected acceptance coefficient
k_k	is the acceptance coefficient for known standard deviation
k_u	is the acceptance coefficient for unknown standard deviation
n	is the number of test samples within the spot sample
x_m	is the mean test result
x_i	is the test result for test sample i
i	is the number of the individual test sample
x_{est}	is the test result of the estimated normal distribution of the spot sample
s	is the standard deviation of the test results

s_s is the standard deviation of the test results of a spot sample

σ is the known standard deviation

l is the number of inspection lots

$\lambda_{10,dry,unit}$ is the thermal conductivity of the unit

p is the fractile

γ is the confidence level

4 General

It is specified in the product standards that the manufacturer should demonstrate compliance for his product with the requirements of the relevant European standard and with the declared values for the product properties by carrying out both:

a) product type determination, which can be type testing, type calculation, reference to tabulated values or descriptive documentation of the product;

b) factory production control (FPC).

If a manufacturer of masonry elements intends to declare that the units are Category I units, then the units shall fulfil the definition of Category I units which is 'Units with a declared compressive strength with a probability of failure to reach it not exceeding 5 %', which means that the manufacturer is declaring that the customer can be 95 % confident that the delivered units fulfilled the declared compressive strength. To be able to demonstrate this, the manufacturer can operate a FPC that includes a statistical evaluation.

The confidence level for a property shall be fixed depending on how important the property is in a building. The higher the confidence level is the lower is the risk that the product does not fulfil the declared values. When dealing with the safety of a building it is necessary to presuppose a minimum confidence level fulfilled by the used products, otherwise the partial safety factors cannot be fixed.

Confidence levels other than 95 % can be used, e.g. the safety system specified in EN 1990 to which the Eurocode for masonry (EN 1996 series) refers to for safety aspects, is based on the assumption that declared values for the used product properties fulfil a confidence level of 75 %.

For characteristics, where a certain minimum confidence level is not fixed in a technical specification or in a contract to be fulfilled, the manufacturer is free to fix the confidence level he will operate with, and the higher the chosen level is the lower the risk that the manufacturer is running that the delivered products do not fulfil the declared values. The risk the manufacturer is running is fixed by a combination of the actual variation in test results over time, the frequencies of checking and testing, the way the FPC system is developed and how close the declared value is to the tested values.

In the product standard the conformity criteria are related to a 'consignment', that is a delivery to a building site. The product standard defines a declared value as a value that the manufacturer is confident in achieving, bearing in mind the precision of the tests and the variability of the production process, and when the declared values are accompanying the product to the building site, they are valid for the delivered consignment. Since it is impractical to test each consignment, the manufacturer should plan the FPC system in such a way that the effect of the variations of product characteristics during the production is taken into account when declaring the characteristics for the consignment. In some production processes products are naturally separated into batches and a consignment is quite often only a part of a batch. If a production is based on a continuous flow a consignment is only a part of the continuous production.

5 Statistical evaluation

5.1 Factory production control

The FPC system can be developed in such a way that the checking procedures are:

— mainly related to the process only (full process control and consequently only a small amount of finished product testing); or

— mainly related to the finished products only (and consequently limited process control); or

— a combination of both.

It can even be so that the amount of process control and finished product testing varies depending on the property to be assessed. If the test for the property is low cost, e.g. a test of dimensions, and if the property is less important in relation to the end use then it might be the right solution to use finished product testing. But if the testing of the property is expensive, e.g. frost resistance tests, then the solution might be to base the assessment on process control using proxy tests.

The manufacturer defines the product groups. A product group consists of products from one manufacturer having common values for one or more characteristics. That means that the products belonging to a product group might differ according to the characteristics in question. If a product group is defined, then the FPC system should ensure that all types of units within a group are controlled and over time also in the finished product testing, if that is part of the FPC.

Depending on the way the FPC system is developed (mainly related to process control only, mainly related to finished product testing only or a combination of both) a selection of these should be considered.

Samples, taken during the process and finished product samples need to be representative for the inspection lot. For that reason the sampling procedure is important and so should be specified. When the frequency of testing is fixing the size of the inspection lot and thereby the manufacturer's risk the frequency should be carefully considered, decided and recorded. If test results and FPC system give evidence of problems then the frequencies can be reconsidered and reduced compared to the ones used.

5.2 Finished product testing

5.2.1 General

When testing the finished product in FPC, it is possible to use alternative test methods if a correlation can be established between the alternative test method and the reference test method or if a safe relationship can be demonstrated when using the alternative method compared to the reference method.

It is also important to notice that a test result of a spot sample (see 5.2.3) is representing an inspection lot (see 5.2.2). If an evaluated test result is not conforming, the whole production since the last test should be looked upon as non-conforming. For that reason it can be recommended that for properties where the reference test is time consuming and might be costly, alternative tests or proxy tests that are less time consuming and costly are used. By doing so the time span between the tests can be shortened and the amount of products covered by a non-conforming test result will be less and thereby reduce the manufacturer's risk.

The amount of products produced between two tests is an inspection lot. The frequency of testing can vary from one property to another and thereby the inspection lot can vary from one property to another.

5.2.2 Inspection lot

The production is divided into inspection lots.

An inspection lot shall consist of units produced under uniform conditions:

- same raw materials;
- same dimensions;
- same production process.

If a certain characteristic is the same for multiple units, where the dimension has no influence, these units can belong to the same product family.

This means that an inspection lot for the characteristic in question can only consist of products belonging to the same product group.

The manufacturer decides on the size of the inspection lot from:

- raw material mixing lots; or
- number/volume of units; or
- number of production days.

Independent of the way the size of the inspection lot is decided, it shall be possible to draw a representative spot sample.

5.2.3 Spot sampling and sample sizes

When the inspection lot has been decided, the sampling procedure for a spot sample shall be fixed in such a way that the spot sample is representative for the inspection lot as shown in the example of Figure 1.

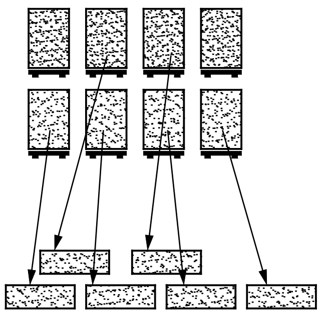

Figure 1 — An example of representative sampling

Sampling procedures for stacks and banded packs are given in the European product standard. It is also possible to sample from the conveyer belt or, in the case of fired units, after the kiln.

The number of units in the spot sample is decided by the manufacturer. If a minimum number of units has been fixed then this should be accepted.

By deciding on the size of the inspection lot the manufacturer is fixing the frequencies of tests to be done. The size of the inspection lot should be decided based on:

- how close the declared value is to the test value;
- the deviation of the test values;
- how much process control is going on.

These decisions allow the manufacturer to manage their own risks.

5.2.4 Production types

A production, which is naturally separated into batches, is named a batch production. In the case of the batch production the properties of the units may change batch by batch. A batch is normally looked upon as a separate inspection lot. If the process control minimizes the changes from one batch to another, an inspection lot can cover more than one batch. An example of a batch production is shown in Figure 2.

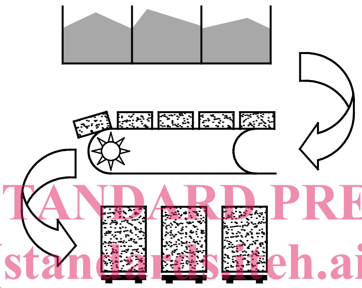

Figure 2 — Example of batch production

A production, which is based on a continuous flow, is named a series production. An example of a series production is given in Figure 3. In the case of series production the properties of the units are the same within a series. A series production usually contains more than one inspection lot.

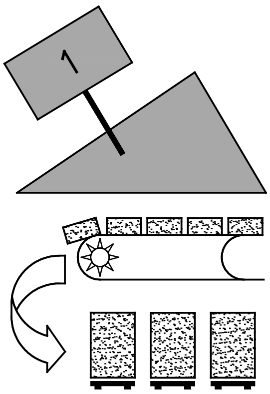

Figure 3 — Example of series production

5.2.5 Control method A: Batch control

When a batch production is in operation, then the FPC system needs to be based on a batch control, which means, that each batch is controlled separately as shown in Figure 4.

When dealing with the evaluation of test results, the acceptance coefficient k_n is given in Tables 1 and 2 (5.2.7). These tables show that there is a great difference in using k_n for three or for six test results and for that reason it is recommended to operate with spot sample sizes of at least six units.

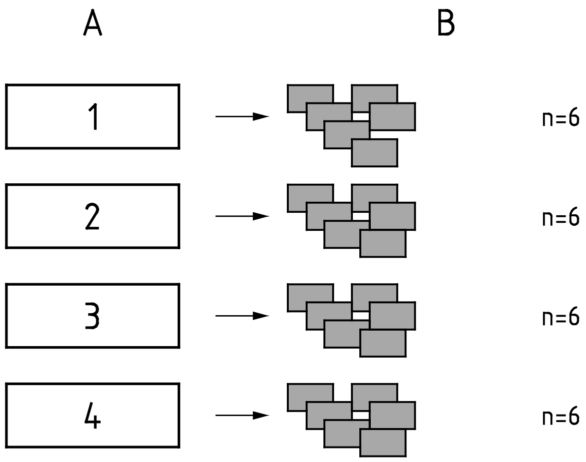

Figure 4 — Example of Method A: Each inspection lot is evaluated individually

5.2.6 Control method B:'Rolling' inspection

In a series production there are a series of inspection lots, which should not exceed a total number of five. In the example in Figure 5 four are used.

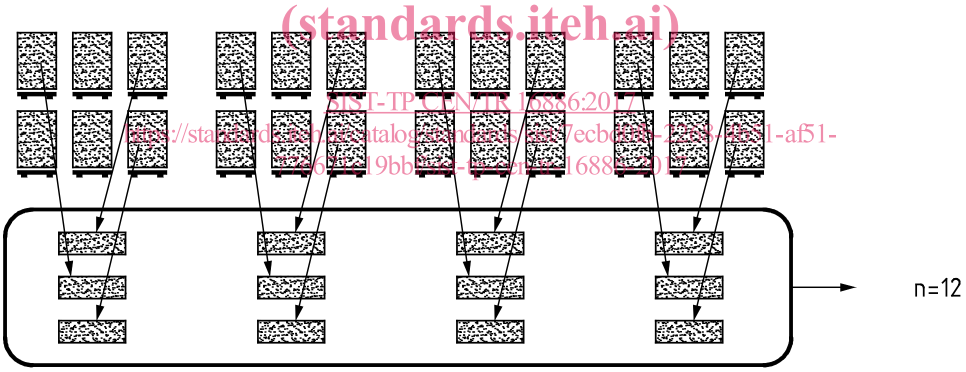

Figure 5 — Example with 4 inspection lots in a series

For the first inspection lot a spot sample size of three is taken and tested. For the second inspection lot three new samples are taken, tested and evaluated together with the ones from the first inspection lot and therefore the spot sample size will be six. For the third inspection lot three new samples are taken, tested and evaluated together with the ones from the first and second inspection lot and therefore the spot sample size will be nine. For the fourth inspection lot three new samples are taken and tested and evaluated together with the ones from the first three inspection lots and therefore the spot sample size will be 12. For the fifth inspection lot three new samples are taken, tested and evaluated together with the ones from the second, third and fourth inspection lots and therefore the spot sample size will be 12. The described rolling system will continue for the following inspection lots. The rolling system is illustrated in Figure 6. When dealing with the evaluation of test results the acceptance coefficient k_n is given in Tables 1 and 2 (5.2.7). These tables show that there is a great difference for 6 and 12 test results, and the number of tests to be done is half compared to the batch control when the size of the inspection lot is the same. Another possibility is to half the size of the inspection lot and therefore to reduce the number of units covered by non-conformity, if that occurs.