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Statistical methods for quality control of building materials and components

Méthodes statistiques de contrôle de la qualité des matériaux et éléments de construction

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 12491 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 2, *Reliability of structures*.

Annex A of this International Standard is for information only.

Introduction

Quality control of building materials and components is, according to ISO 2394, 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 quality requirements in building. It appears that properly employed statistical methods can provide efficient, economic and effective means of quality control, particularly when expensive and destructive tests are to be performed. The purpose of this International Standard is to provide general techniques for quality control of building materials and components used in building or other civil engineering works.

Described techniques consist predominantly of classical statistical methods of common interest for all the participants in the building process. For other more sophisticated techniques and specific problems, existing statistical standards listed in annex A should be applied.

Statistical methods for quality control of building materials and components

1 Scope

This International Standard gives general principles for the application of statistical methods in the quality control of building materials and components in compliance with the safety and serviceability requirements of ISO 2394.

This International Standard is applicable to all buildings and other civil engineering work, existing or under construction, whatever the nature or combination of the materials used, for example concrete, steel, wood, bricks.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 2394:—[1], *General principles on reliability for structures.*

ISO 3534-1:1993, *Statistics — Vocabulary and symbols — Part 1: Probability and general statistical terms.*

ISO 3534-2:1993, *Statistics — Vocabulary and symbols — Part 2: Statistical quality control.*

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 3534-1 and ISO 3534-2, and the following definitions, apply.

NOTE - The terms and their definitions are listed in the order corresponding to their appearance in the main text. An alphabetic list of these terms with numerical references to subclauses where the terms appear is given in the index.

3.1 quality control: Operational techniques and activities that are used to fulfill requirements for quality.

3.2 statistical quality control: That part of quality control in which statistical methods are used (such as estimation and tests of parameters and sampling inspection).

[1] To be published. (Revision of ISO 2394:1986)

3.3 unit: Defined quantity of building material, component or element of a building or other civil engineering work that can be individually considered and separately tested.

3.4 population: Totality of units under consideration.

3.5 (random) variable, X: A variable which may take any of the values of a specified set of values and with which is associated a probability distribution.

NOTE - A random variable that may take only isolated values is said to be "discrete". A random variable which may take any value within a finite of infinite interval is said to be "continuous".

3.6 (probability) distribution: A 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).

3.7 distribution function, $\Pi(x)$: A function giving, for every value of x, the probability that the variable X is less than or equal to x:

$$\Pi(x) = P_r (X \leq x)$$

3.8 (probability) density function, $f(x)$: The derivative (when it exists) of the distribution function:

$$f(x) = \frac{\mathrm{d}\,\Pi(x)}{\mathrm{d}x}$$

3.9 (population) parameter: Quantity used in describing the distribution of a random variable in a population.

3.10 fractile, x_p: If X is a continuous variable and p is a real number between 0 and 1, the p-fractile is the value of the variable X for which the distribution function equals p. Thus x_p is a p-fractile if

$$P_r (X \leq x_p) = p$$

3.11 (population) mean, μ: For a continuous variable X having the probability density $f(x)$, the mean, if it exists, is given by

$$\mu = \int x\, f(x)\,\mathrm{d}x$$

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

3.12 (population) variance, σ^2: For a continuous variable X having the probability density function $f(x)$, the variance, if it exists, is given by

$$\sigma^2 = \int (x - \mu)^2 f(x)\,\mathrm{d}x$$

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

3.13 (population) standard deviation, σ: Positive square root of the population variance σ^2.

3.14 standardized variable: A random variable, the mean of which equals zero and the standard deviation of which equals 1. If the variable X has a mean equal to μ and a standard deviation equal to σ, the corresponding standardized variable is given as

$$(X - \mu)/\sigma$$

NOTE - The distribution of the standardized variable is called "standardized distribution".

3.15 normal distribution: Probability distribution of a continuous variable X, the probability density function of which is

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

3.16 log-normal distribution: Probability distribution of a continuous variable X which can take any value from x_0 to $+\infty$, or from $-\infty$ to x_0.

In the former, more frequent, case the probability density function is given as

$$f(x) = \frac{1}{(x-x_0)\sigma_Y\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln(x-x_0)-\mu_Y}{\sigma_Y}\right)^2\right]$$

where

$x \geq x_0$

μ_Y and σ_Y are, respectively, the mean and the standard deviation of the new variable;

$$Y = \ln(X - x_0)$$

In the latter, less frequent, case the sign of the brackets $(X - x_0)$ and $(x - x_0)$ is to be changed. Note that the variable Y has a normal distribution.

3.17 (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.

3.18 (sample) size, n: Number of sampling units in the sample.

3.19 sample mean, $\bar{x}$: Sum of n values x_i of sampling units divided by the sample size n:

$$\bar{x} = \frac{1}{n}\sum x_i$$

3.20 sample variance, s^2: Sum of n squared deviations from the sample mean $\bar{x}$ divided by the sample size n minus 1:

$$s^2 = \frac{1}{n-1}\sum(x_i - \bar{x})^2$$

3.21 sample standard deviation, s**:** Positive square root of the sample variance s^2.

3.22 estimation: Operation of assigning, from observations on a sample, numerical values to the parameters of a distribution chosen as the statistical model of the population from which this sample was taken.

3.23 estimator: Function of a set of the sample random variables used to estimate a population parameter.

3.24 estimate: Value of an estimator obtained as a result of an estimation.

3.25 confidence level, γ : Given value of the probability associated with a confidence interval.

NOTE - In ISO 3534-1, it is designated $(1-\alpha)$.

3.26 two-sided confidence interval: When T_1 and T_2 are two functions of the observed values such that, θ being a parameter to be estimated, the probability P_r $(T_1 \leq \theta \leq T_2)$ is at least equal to the confidence level γ (where γ is a fixed number, positive and less than 1), the interval between T_1 and T_2 is a two-sided γ confidence interval for θ.

3.27 one-sided confidence interval: When T is a function of the observed values such that, θ being a population parameter to be estimated, the probability P_r $(T \geq \theta)$ or the probability P_r $(T \leq \theta)$ is at least equal to the confidence level γ (where γ is a fixed number, positive and less than 1), the interval from the smallest possible value of θ up to T (or the interval from the T up to the largest possible value of θ) is a one-sided γ confidence interval for θ.

3.28 outliers: Observations in a sample, so far separated in value from the remainder as to suggest that they may be from a different population.

3.29 (statistical) test: Statistical procedure to decide whether a hypothesis about the distribution of one or more populations should be accepted or rejected.

3.30 (statistical) hypothesis: Hypothesis, concerning the population, which is to be accepted or rejected as the outcome of the test using sample observations.

3.31 significance level, α: Given value, which is the upper limit of the probability of a statistical hypothesis being rejected when this hypothesis is true.

3.32 number of degrees of freedom, ν : In general, the number of terms in a sum minus the number of constraints on the terms of the sum.

3.33 χ^2-distribution: Probability distribution of a continuous variable χ^2 which can take any value from 0 to ∞ , the probability density function of which is

$$f(\chi^2;\nu) = \frac{(\chi^2)^{(\nu/2)-1}}{2^{(\nu/2)}\,\Gamma(\nu/2)} \exp\left(-\frac{\chi^2}{2}\right)$$

where

$\chi^2 \geq 0$ with a parameter (number of degrees of freedom) $\nu = 1, 2, 3,\ldots$;

Γ is the gamma function.

3.34 *t*-distribution: Probability distribution of a continuous variable t which can take any value from $-\infty$ to $+\infty$, the probability density function of which is

$$f(t;\nu) = \frac{1}{\sqrt{\pi\nu}} \frac{\Gamma[(\nu+1)/2]}{\Gamma(\nu/2)} \frac{1}{(1+t^2/\nu)^{(\nu+1)/2}}$$

where

$-\infty < t < +\infty$ with a parameter (number of degrees of freedom) $\nu = 1, 2, 3,\ldots$;

Γ is the gamma function.

3.35 noncentral *t*-distribution: Probability distribution of a continuous variable t which can take any value from $-\infty$ to $+\infty$, the probability density function of which is

$$f(t;\nu,\delta) = \frac{1}{\sqrt{\pi\nu}} \frac{1}{2^{(\nu-1)/2}\,\Gamma(\nu/2)} \frac{1}{(1+t^2/\nu)^{(\nu+1)/2}} \times$$

$$\times \exp\left(-\frac{\nu\delta^2}{2(\nu+t^2)}\right) \int_0^\infty z^\nu \exp\left(-\frac{1}{2}\left(z-\frac{\delta t}{\sqrt{\nu+t^2}}\right)^2\right) dz$$

where

$-\infty < t < +\infty$ with two parameters; i.e. number of degrees of freedom ν and noncentrality parameter δ.

3.36 *F*-distribution: Probability distribution of a continuous variable F which can take any value from 0 to $+\infty$, the probability density function of which is

$$f(F;\nu_1,\nu_2) = \frac{\Gamma[(\nu_1+\nu_2)/2]}{\Gamma(\nu_1/2)\,\Gamma(\nu_2/2)} (\nu_1)^{\nu_1/2} (\nu_2)^{\nu_2/2} \frac{F^{(\nu_1/2)-1}}{(\nu_1 F+\nu_2)^{(\nu_1+\nu_2)/2}}$$

where

$F \geq 0$ with parameters (numbers of degrees of freedom) $\nu_1, \nu_2 = 1, 2, 3,...$;

Γ is the gamma function.

3.37 lot: Definite quantity of units, manufactured or produced under conditions which are presumed uniform.

NOTE - In statistical quality control in building, a lot is usually equivalent to a "batch" and is considered as a "population".

3.38 isolated lot: A 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.

NOTE - In statistical quality control in building, lots are usually considered as "isolated lots".

3.39 conforming unit: Unit which satisfies all the specified requirements.

3.40 nonconforming unit: Unit containing at least one nonconformity which causes the unit not to satisfy specified requirements.

3.41 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.

3.42 sampling inspection by variables: Method of sampling inspection which consists of measuring a quantitative variable X for each unit of a sample.

3.43 sampling inspection by attributes: Method of sampling inspection which consists of distinguishing between conforming and nonconforming units of a sample.

3.44 sampling plan: A plan according to 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.

NOTE - It includes the sample size n and the acceptance constants k_σ, k_s (in sampling inspection by variables), or the sample size n and the acceptance number Ac (in sampling inspection by attributes).

3.45 operating characteristic curve (OC curve): Curve showing, for a given sampling plan, the probability that an acceptance criterion is satisfied, as a function of the lot quality level.

3.46 producer: Any participant of the building process supplying a lot for further procedure or use.

3.47 consumer: Any participant of the building process purchasing a lot for further procedure or use.

3.48 producer's risk point (PRP): A point on the operating characteristic curve corresponding to a predetermined and usually low probability of non-acceptance.

NOTE - This probability is the producer's risk (PR) when an isolated lot is considered.

3.49 consumer's risk point (CRP): A point on the operating characteristic curve corresponding to a predetermined and usually low probability of acceptance.

NOTE - This probability is the consumer´s risk (CR) when an isolated lot is considered.

3.50 producer's risk (PR): For a given sampling plan, the probability of non-acceptance of a lot when the lot quality has a value stated by the plan as acceptable.

NOTE - This quality is the producer's risk quality (PRQ) when an isolated lot is considered.

3.51 consumer's risk (CR): For a given sampling plan, the probability of acceptance of a lot when the lot quality has a value stated by the plan as unsatisfactory.

NOTE - This quality is the consumer's risk quality (CRQ) when an isolated lot is considered.

3.52 producer's risk quality (PRQ): A lot quality level which, in the sampling plan for an isolated lot, corresponds to a specified producer's risk (PR).

NOTE - When a continuing series of lots is considered, the acceptable quality level AQL is used instead of PRQ.

3.53 consumer's risk quality (CRQ): A lot quality level which, in the sampling plan for an isolated lot, corresponds to a specified consumer's risk (CR).

NOTE - When a continuing series of lots is considered, the limiting quality level LQL is used instead of CRQ.

3.54 acceptance constants, k_σ , k_s : In sampling inspection by variables, constants used in the criteria for accepting the lot, as given in the sampling plan.

NOTE 1 Both these constants are also used as coefficients in estimation of population fractiles.

NOTE 2 In ISO 3534-2, the acceptance constant is designated k.

3.55 acceptance number (Ac): In sampling inspection by attributes, the largest number of nonconforming units found in the sample that permits acceptance of the lot, as given in the sampling plan.

3.56 lower specification limit, L: Specified value of the observed variable X giving the lower boundary of the permissible value.

3.57 upper specification limit, U: Specified value of the observed variable X giving the upper boundary of the permissible value.

3.58 number of nonconforming units, z: Actual number of nonconforming units found in a sample.

4 Population and sample

4.1 General

Mechanical properties and dimensions of building materials and components are described by random variables (called variables in this International Standard) with a certain type of probability distribution. The popular normal distribution (Laplace-Gauss distribution) may be used to approximate many actual symmetrical distributions. When a remarkable asymmetry is observed, then another type of distribution reflecting this asymmetry shall be considered. Often, three-parametric log-normal distribution is used (see 4.3).

To simplify calculation procedures, standardized variables (see 3.14) are used, whose means are equal to zero and whose variances are equal to one, and which have standardized distributions for which numerical tables are available.

As a rule, only a limited number of observations constituting a random sample x_1, x_2, x_3,..., x_n of size n taken from a population (lot) is available. The aim of statistical methods for quality control is to make a decision concerning the required quality of a population using the information derived from one or more random samples.

4.2 Normal distribution

The well-known normal distribution of a continuous variable, X, is a fundamental type of symmetrical distribution defined on an unlimited interval, which is fully described by two parameters: the mean μ and the variance σ^2. Any normal variable may be easily transformed to a standardized variable $U = (X - \mu)/\sigma$, for which tables of probability density and distribution function are commonly available.

In quality control of building materials and components, the fractiles u_p are frequently used, where the following values for the probability p are most often applied: p = 0,95; 0,975; 0,99; 0,995. The corresponding values of the fractiles u_p are given in table 1. It is to be noted that for high ratios σ/μ there is a non-negligible probability of the occurrence of negative values of the variable X. If X must be positive (which may follow from some physical reasons), then other theoretical models for the probability distribution may be more suitable.

All the information derived from a given random sample x_1, x_2,...,x_n of the size n, taken from a normal population, is completely described by two sample characteristics only: the sample mean $\bar{x}$ and the sample variance s^2. These characteristics are specific values of the corresponding estimators of the population mean and variance, denoted by $\bar{X}$ and S^2 . The mean estimator $\bar{X}$ is a random variable described by the normal distribution having the same mean μ as the population and the variance equal to σ^2/n. The variance estimator S^2 is a random variable described by transformed χ^2-distribution with $\nu = (n-1)$ degrees of freedom as

$$S^2 = \sigma^2\chi^2/(n-1)$$

This transformation allows any fractile of S^2 to be determined from the corresponding fractile of χ^2. As the χ^2-distribution is asymmetrical, the lower fractiles χ^2_{p1} as well as the upper fractiles χ^2_{p2} are given in table 2. The recommended probabilities to be used in building are as follows: p_1 = 0,05; 0,025; 0,01; 0,005 and p_2 =0,95; 0,975; 0,99; 0,995.