Quality control the technical condition of the building structures by randomization

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Abstract. Reinforced concrete structures are currently the most common construction and have a long history of application. In addition to loads, structures are exposed to external aggressive environments. As a result of this, structures are often damaged. For repair planning, diagnostics and assessment of the technical condition of structures are necessary. The regulatory literature does not contain data on the required sample size and designation of zones and places of control of structures. Known studies are devoted mainly to the substantiation of the methods of instrumental control of the parameters of building structures. The building structures are divided into two types: same type structures and unique ones which are characterized by a large surface area. Therefore, various approaches to diagnosing the technical condition of such structures are necessary. We have developed a methodology for control of structures using the randomization method. The technique allows, with a given degree of confidence, to reasonably designate the sample size of structures, a place or a control zone. This allows you to replace the complete control selective and significantly reduce the amount of testing.

1. Introduction
According to current design standards in reinforced concrete structures damage of materials is not allowed. However, there is a large amount of structures that have received damage at the operation stage. Therefore, at the stage of operation of structures, tasks often arise to assess their technical condition for planning repair activities.

Building diagnostics is the process of determining the causes and solutions to problems in buildings [1, 2]. The most typical cases in which there is a need for diagnosis and assessment of the technical condition of reinforced concrete structures:

a) acceptance control of prefabricated reinforced concrete structures of factory manufacture;
b) instrumental acceptance control of the technical condition of the constructed, overhaul or reconstructed objects;
c) technical inspection during the renovation of construction in progress;
d) instrumental control of the technical condition of the facility during scheduled or extraordinary inspections (monitoring, preventive control);
e) technical inspection for the design of capital repairs and reconstruction;
f) technical inspection (examination) in case of structural damage and accidents during operation.
These problems are solved by the “technical diagnostics” of the general theory of reliability [3]. Four groups of recognition methods used in technical diagnostics are noted: 1) probabilistic methods of statistical solutions; 2) separation methods in the space of signs; 3) metric methods; 4) logical methods.

Its specific tasks are associated with methods, devices and equipment for detecting defects and structural damage, determining the causes of damage, measuring the actual parameters of structures, identifying the resource, optimizing the process of maintenance and repair, determining the necessary restoration measures, etc.

Some aspects of the noted problems for buildings and structures made of reinforced concrete were solved in the works [4-6].

The disadvantages of existing regulatory and reference documents are the lack of clear quantitative assessments of the category of technical condition; assessment of the condition mainly by visual inspection; inclusion in the assessment of organizational safety requirements.

Currently, there is no statistically sound methodology governing the selection of parameters, locations, zones and the number of tests.

We have developed the system of diagnostics, assessment of quality and technical condition, of erected or operated building structures, mainly bearing reinforced concrete, guarantees the receipt of quality and technical condition estimates with a given security. The system allows you to reasonably reduce the volume of control structures and their parameters.

In the system of diagnostics, assessing the quality and technical condition of erected or operated building structures the parametric method is adopted. It lies in the fact that when assessing the quality and technical condition, individual parameters (characteristics) of structures are controlled, which affect the functional properties and allow the calculation method to determine the reliability of structures.

When examining and evaluating the technical condition of building structures the problem arises of choosing structures to be controlled. Such a choice may be based on an assessment of the degree of responsibility of structures and their technical condition.

In the case of sample control, structures in the general population should be selected with the same degree of probability. This condition can be fulfilled using the Monte Carlo method or random tests. The number of designs should depend on the degree of variation of the controlled property of the structure, approved design security of the controlled characteristics, permissible error in the estimation of the functional property of the structure.

2. The choice of designs according to their degree of responsibility

Buildings and structures belong to large systems, which are a combination of a significant number of interconnected components of varying complexity, subject to variable changing loads and external influences.

Failure hazard designs are divided into:
- a) structures related to the most critical elements (foundations, columns, beams, etc.) the failure of which leads to a complete failure of the entire structure;
- b) structures related to less critical structural elements (self-supporting walls, etc.).

Designs by type of failure are divided into:
- a) enclosing elements, finishing structures, the failure of which occurs according to operational functions;
- b) elements of statically indeterminable systems whose failure does not entail sudden destruction;
- c) bearing elements with gradual failures;
- d) designs with sudden failures.

Constructions are classified according to the consequences of failure:
- a) life-threatening;
- b) great economic damage;
- c) minor economic damage.

To develop a strategy and plan for the control of structures and increase the efficiency of diagnostic methods and tools, it is necessary to use formalization of control operations and their further automation.
As a methodological basis for field surveys and assessment of functional properties (strength and deformation indicators, fracture toughness indicators) of structures, a model of logical forecasting of building behavior under the influence of external loads can be adopted taking into account the quality of structural parameters.

3. Determination of structures to be controlled by their technical condition

The most characteristic defects and damage to structures to be identified during the examination include:

- defects associated with design - inconsistency of the design scheme with the actual working conditions, deviations from design standards, etc.;
- manufacturing defects - deviations from the design geometric dimensions, reduced strength and excess permeability of concrete compared with the design, violation of reinforcement and displacement of embedded parts, insufficient thickness of the protective layer, the presence of shells, cavities, cracks in the welds of welded joints, etc.;
- defects in installation and erection of structures - displacement from the design position, insufficient bearing area, inaccurate fitting of the interface units, poor quality of mounting joints and their subsequent termination, lack or poor performance of corrosion protection, linings, screens, waterproofing, etc.;
- mechanical damage from violation of the operating rules - punching holes, openings with exposure and cutting reinforcement in reinforced concrete structures, exposure of reinforcement for securing communications and equipment, concrete chips and cracks from shocks during cargo movement and during equipment operation, etc.;
- damage from static and dynamic force impacts not foreseen by the project - the development of excessive deformations (deflections), cracks (normal and inclined) in bent, eccentrically compressed, eccentrically extended, stretched elements, cracks (normal and longitudinal) in compressed and eccentrically compressed reinforced concrete elements etc.;
- damage from external aggressive influences - corrosion destruction of concrete, formation of corrosion cracks, origin along reinforcing bars, exposure of reinforcement and its corrosion, frosty destruction of concrete, local bulging and peeling of the paint layer, development of foci of metal corrosion under the paint film corrosion of elements of metal assemblies.

The first stage of field surveys is a visual inspection of the structures. The results of the visual inspection are recorded in the form of a map of defects plotted on plans, sections, facades of buildings, development structures or in the form of sheets of defects. Based on preliminary surveys, an initial assessment of the technical condition of structures is carried out.

Preliminary assessment of the technical condition of structures is carried out in accordance with the following categories:
- serviceable,
- workable,
- partially workable,
- non-workable,
- emergency.

Multistage control comprises three stages:
- establishment of a number of structures to be tested;
- localization and establishment of a number of testing areas of the structure subject to control;
- establishment of a number of tests at each area.

In terms of method of control, the structures are divided into two types: same type structures and unique ones.

In accordance with [7] there have been established three levels of quality control for the same type structures: increased, standard and reduced ones.

Increased control is testing of all elements of the general population. It shall be carried out for objects or structures, on which no design and as-built documents are available, or there are signs of stricture damages, characterizing the condition of the structure as "non-serviceable" or "dangerous"
Standard control means that out of the whole number of elements of the general population $N$ there shall be selected, randomly, a number of the elements $n < N$ by the results of instrumental control of which there shall be made a conclusion on a controlled parameter of the whole general population.

Under reduced control, the number of elements of the general population does not depend upon statistical characteristics of quality indices.

According to recommendations [8], under reduced control, the number of elements of the general population subject to instrumental control depends upon degree of aggressiveness of environment, to be identified according to [9] (table 1).

Table 1. The number of elements of the general population subject to instrumental control depends upon degree of aggressiveness of environment.

| Aggressiveness degree | Number of elements |
|-----------------------|--------------------|
|                       | %                  | pcs., not less than |
| Not aggressive        | 10                 | 3                  |
| Low-aggressive        | 10                 | 3                  |
| Mean-aggressive       | 15                 | 4                  |
| High-aggressive       | 20                 | 6                  |

It is admitted to carry out reduced control if "a priori" it is known that the elements (structures) had been constructed by the same technique with known quality indices and their statistical characteristics, which had been subject to statistical control by verified methods (i.e. under availability of QC system at the stage of construction).

Localization of testing areas may be performed proceeding from static behavior of the structure optimal area or admissible area.

Establishment of a sample or of admissible areas shall be performed by randomization of statistical tests (Monte-Carlo) [10]. To generate a random sample of designs, a random number generator built into modern software packages, such as MathCAD Professional 2000 or the Random Number Generator v1.2 is used. Randomization is carried out in such a way that each structure, elements, zones of structures had the same probability of being selected.

The number of tests of structures and their parameters is determined on the basis of the regulation of the estimation of the mathematical expectation of the functions of the properties of structures or their parameters, the permissible error in estimation, the statistical characteristics of the functions of the properties of structures or their parameters.

The test rate ($n$), which characterizes the number of structures, areas of control, is calculated by the formula [11]:

$$n = \left( \frac{t \times V}{d} \right)^2$$

where: $t = 1.64$ on the basis of the approved design security of the controlled characteristics (strength of materials), equal to 95%; $V$ - coefficient of variation of the controlled property of the structure (concrete strength) is accepted a priori equal to 0.05 - 0.20 and is refined after conducting surveys and probabilistic calculations. $d = 5\text{-}15\%$ - the maximum permissible error in the estimation of the average value of the functional property of the structure.
4. Example of flatworks testing plan

4.1. Problem statement

It is required to establish the uniformly distributed sample from 5, 10, 30 sections presenting the general population from 900 elements on the surface of the fragment of the square-form structure containing 30 elements on each side.

Initial data:
- \( nx \) is the number of the elements in horizontal direction (\( nx = 30 \));
- \( ny \) is the number of the elements in vertical direction (\( ny = 30 \));
- \( n \) is number of the elements at the sample.

4.2. Solution of the problem

In the course of the solving the problem the software MathCAD Professional 2000 was used.

\[ XY^{(1)} = \text{runif}(n, 1, n_x) \] – shall be established the vector from \( n \) numbers, uniformly distributed in the interval from 1 to \( n_x \);

\[ XY^{(2)} = \text{runif}(n, 1, n_y) \] – shall be established the vector from \( n \) numbers, uniformly distributed in the interval from 1 to \( n_y \);

\[ XY_{i,k} = \text{round} (XY_{i,k}, 0) \] – shall be established the matrix from \( i \) rows and \( k \) columns, The numbers of the matrix rounded off to integers and the first column is vector \( XY^{(1)} \), and second is vector \( XY^{(2)} \) – values of the matrix \( XY \), where \( i=1…n; \ k=1…2 \).

Results of the solution are given in Figure 1 and Table 2.

![Figure 1](image-url)

**Figure 1.** Arrangement of uniformly distributed sections in the sample from the elements, pcs. (a) - 5; (b) - 10; (c) - 30.
Table 2. Uniformly distributed sample for the flatworks.

| № of the test | 5 | 10 | 30 |
|---------------|---|----|----|
|               | Side |    |    |
| 1             | 1 | 2 | 1 |
| 2             | 1 | 2 | 1 |
| 3             | 1 | 2 | 1 |
| 4             | 1 | 2 | 1 |
| 5             | 1 | 2 | 1 |
| 6             | 1 | 2 | 1 |
| 7             | 1 | 2 | 1 |
| 8             | 1 | 2 | 1 |
| 9             | 1 | 2 | 1 |
| 10            | 1 | 2 | 1 |
| 11            | 1 | 2 | 1 |
| 12            | 1 | 2 | 1 |
| 13            | 1 | 2 | 1 |
| 14            | 1 | 2 | 1 |
| 15            | 1 | 2 | 1 |
| 16            | 1 | 2 | 1 |
| 17            | 1 | 2 | 1 |
| 18            | 1 | 2 | 1 |
| 19            | 1 | 2 | 1 |
| 20            | 1 | 2 | 1 |
| 21            | 1 | 2 | 1 |
| 22            | 1 | 2 | 1 |
| 23            | 1 | 2 | 1 |
| 24            | 1 | 2 | 1 |
| 25            | 1 | 2 | 1 |
| 26            | 1 | 2 | 1 |
| 27            | 1 | 2 | 1 |
| 28            | 1 | 2 | 1 |
| 29            | 1 | 2 | 1 |

5. An example of a randomization of a test plan for mass-type structures

5.1. Problem statement
It is necessary to form a sample of 10 structures for the general population of beams (Figure 2).

5.2. Solution of the problem
MathCAD Professional 2000 software package was used for the solution.
The results of the calculations are given in Figure 2 and Table 3.

![Figure 2.](image)

**Table 3.** Sampling for quality control of beams

| Test number | Design number |
|-------------|---------------|
| 1           | 120           |
| 2           | 59            |
| 3           | 36            |
| 4           | 82            |
| 5           | 18            |
| 6           | 71            |
| 7           | 31            |
| 8           | 10            |
| 9           | 16            |
| 10          | 20            |

- 1 – beams under control;
- 2 – not controlled beams

**Figure 2.** Arrangement of the floor beams and sample for the quality indices control.

6. Conclusions

1. At the stage of operation a large number of building structures receive damage caused by exposure to loads and external influences. The disadvantages of existing regulatory and reference documents are the lack of clear quantitative assessments of the category of technical condition, performing assessment of the condition of the building structures mainly by visual inspection. Presently, there is no statistically sound methodology governing the selection of parameters, locations, zones and the number of required tests. Therefore, it is necessary to develop scientific research on the methodology of technical diagnostics and quality control of the technical condition of building structures.

2. A statistically substantiated diagnostic technique for load-bearing building elements based on the use of selective control was proposed. The developed technique allows, with a given degree of confidence, to reasonably designate the sample size of structural elements, a place or a control zone. This allows to replace total control by selective control and to significantly reduce the quantity of necessary tests. The number of structural elements, areas of control depend on the approved design confidence of the controlled characteristics of materials or structures, variability of the controlled property of the structure, the maximum permissible error in the estimation of the average value of the functional property of the structure.

3. Determination of the sample size of structural elements, control locations or control areas shall be performed by randomization using statistical functions (Monte-Carlo). Randomization allows to have any structural element, locations of structures to be selected with the same degree of probability. To generate a random sample of structural elements, a random number generator built into modern software packages can be used. Examples of practical application of the technique are given for designating of the controlled locations for structures with large area and for typical structural elements.

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