UDC 624

PROPOSED METHOD OF PLANNED TESTING RANDOMISATION FOR HEALTH MONITORING OF STRUCTURES

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Problem Statement:

In the diagnosis and monitoring of the integrity of building structures one of the main objectives could be the reduction of the number of in-situ tests on structural elements. However, it is of vital importance to obtain information on parameters affecting the integrity of the structure with emphasis on the probability of failure.

Purpose of the study:

To develop a planned testing method of randomised structural elements of buildings / structures within the context of structural health monitoring and assessment of buildings. This will result in reducing the number of in-situ tests on the structural elements but at the same time producing reliable required data for analysis.

Terminology and Definitions:

General Population – unlimited possible test numbers that could be performed on an object (structural or an element of a structure) under investigation.

Sample – defined number of tests performed on the object under investigation from the *Population.*

Homogeneous group of structures, elements and corresponding areas – same type of structural and their elements (e.g. columns, beams, floors, crane girders, foundations, precast elements of deck, etc.). The *areas* refer to concrete surfaces of the structural elements, their sizes, reinforcement types, connection details and similar attributes.

Control – the measurement, analysis, testing and calibration of one or several parameters of an item, and comparison of the obtained results with established requirements – Standard ISO 8402.

Increased control - complete control of the general population.

Standard control - statistical random control.

Randomisation / random test method (Monte-Carlo method) - formation of a sample by random law under a set distribution.

Line structure - building (structure) where one size prevails over another two, e.g. the length in comparison with the sizes of cross section (e.g. channel).

Flatworks (structure) - building (structure) where two sizes are prevailed in comparison with thickness (e.g. cast-in-place walls).

Three-dimensional structure - structure with developed surface of regular, e.g. curved, shape.

General statements:

The developed method is used to form a sample for use in the diagnostic testing of the structural condition of buildings. By having complete control rather than selective control, the amount of testing required is reduced whilst still obtaining reliable information.

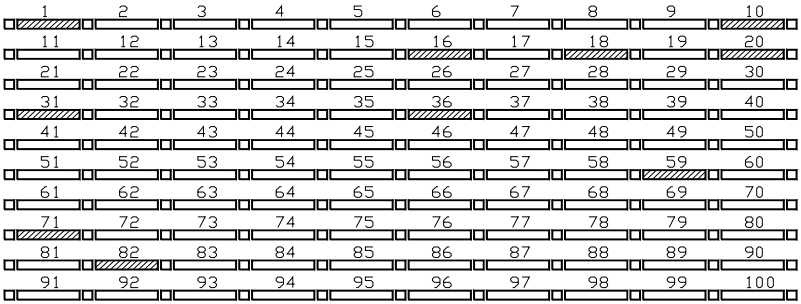
The method is used only for the homogeneous general population of the structures, their elements and areas.

Method refers to standard control, which means that out of the whole number of elements of the general population "N" there shall be selected, randomly, a number of elements n<N, by the results of instrumental control of which there shall be made a conclusion on a monitored parameter of the whole general population.

Randomisation shall be performed in such a way that each structure, element and area of the structure has an equal probability of selection.

Testing plan for the randomisation of same type structures

Problem statement: The sample will be established from the floor beams of ten structures (ten beams per structure: a total of 100 floor beams) for the General Population (Fig. 1). At the first stage the numeration of the structures making up the general population shall be performed (Fig. 1). In order that every structure has an equal probability of selection, random number generator software (e.g. MathCAD Professional) shall be used. The results of calculations are given in Table 1.



Symbols:

- 1
- 2

1 – beams under control;
2 – not controlled beams

Fig. 1. Arrangement of the floor beams and sample for the quality indices control

Testing plan for the randomisation of unique structures

For unique extended line structures (e.g. reinforced concrete discharge channels) or structures with large surface areas (NPP protective containment, cast-in-place walls, etc.), the developed standards of acceptance control oriented for mass same type structures are unacceptable. Taking into account the specificity of the said structures, the problem of sample scope determination at the control of quality indices is reduced to determination of the number of zones under control and the number of determinations in each zone.

Table 1

-Sample for the control of beam quality indices

№ of the test	1	2	3	4	5	6	7	8	9	10
№ of the structure	1	20	59	36	82	18	71	31	10	16

The number of control zones to be utilised will be based on such work execution features as the concreting sector, for example, or the specified dimensions of the sections under control.

Recommendations [1] state that the dimensions of the sectors under control in the course of the concrete strength evaluation shall be taken as follows (not less than): one section per 4 m of length for the line structures; one section per 4 m^2 of area for the floors; and one section per 8 m^2 of area for other cast-in-place structures. These recommendations refer to increased level of quality control.

To determine the number of sections under control according to the present method the statistical testing based approach shall be used.

Testing plan for the randomisation of line buildings (structures)

At the first stage, the whole building (structure) shall be divided into zones along the length, taking into account the recommendations on setting the length of one controlled section. At the second stage, the building (structure) sections making up the general population shall be consecutively numbered. At the third stage, the random number generator software will establish the random sample of the sections. In order to ensure that each section of the building (structure) is equally probable to be selected, the uniformly distributed number generator will be used.

Testing plan for the randomisation of flatworks

The element of the structure is the rectangular shape area. For such a structure, the establishment of a uniformly distributed sample shall be performed as follows. At the first stage, the area of the whole structure shall be divided into equal sections (close to the square) taking into account the recommendations on setting the area of one controlled section. For this purpose the dimensions of the section sides shall be established. At the second stage, the intervals of coordinate changes shall be specified. At the third stage, the sampled population of side coordinates of a specified number of the elements in the sample (separately along each coordinate) shall be established by the uniformly distributed number generator. At obtained coordinates intersection there are the sections that are the uniformly distributed sample.

Below is an example of application of the method.

Problem statement. It is necessary to establish the uniformly distributed sample from 5, 10 and 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. The number of sections to be monitored is determined by the variability of monitored parameters (for example, a coefficient of variation of concrete).

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

MathCAD Professional software was used to solve this problem.

XY(1)=runif(n,1,nx) shall establish the vector from n numbers, uniformly distributed in the interval from 1 to nx; XY(2)=runif(n,1,ny) shall establish the vector from n numbers, uniformly distributed in the interval from 1 to ny; and XYi,k=round (XYi,k,0) shall establish the matrix from columns i rows and k. The numbers of the matrix are rounded off to integers, the first column is vector XY(1) and the second is vector XY(2) – values of the matrix XY, where i=1…n; k=1…2.

Results of the solution are given in Table 2 and at Fig.2.

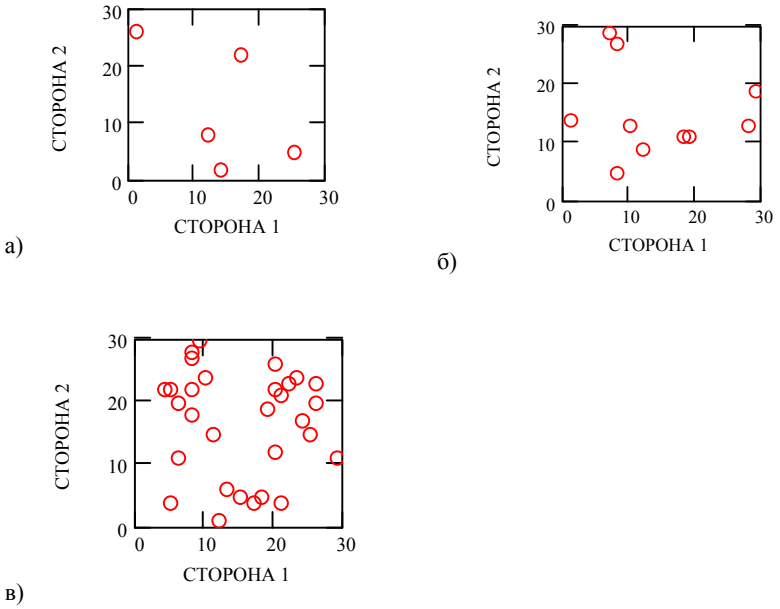


Fig. 2. Arrangement of uniformly distributed sections in the sample from the elements, pcs. а - 5; б - 10; в - 30

Table 2

Uniformly distributed sample for the flatworks

№ of the test	Number of the sections at the sample, pcs					
	5		10		30	
	Side					
	1	2	1	2	1	2
	№ of the element					
1	14	2	7	29	5	22
2	12	8	10	13	4	22
3	17	22	19	11	21	21
4	25	5	29	19	15	5
5	1	26	12	9	20	12
6			8	27	20	26
7			18	11	25	15
8			1	14	26	20
9			28	13	29	11
10			8	5	22	23
11					12	1
12					26	23
13					23	24
14					8	22
15					24	17
16					17	4
17					5	4
18					13	6
19					6	20
20					8	27
21					8	18
22					21	4
23					20	22
24					11	15
25					10	24
26					6	11
27					9	30
28					8	28
29					19	19
30					18	5

Randomisation of testing plan of three-dimensional structures, the surfaces of which have been described by the spherical coordinates

The example of the surface with the spherical coordinates is the dome of NPP reactor building protective containment.

For the surface with the spherical coordinates, determination of the zones and

number of the sections shall be performed in the following way. At the first stage, the polar coordinates shall be specified as: radius of the sphere (r) and boundary values of two angles $\alpha 1$ and $\alpha 2$, where $\alpha 1$ is the angle of radius projected at the horizontal plane and $\alpha 2$ is the inclination of the radius to the horizontal plane.

At the second stage, the surface shall be divided into equal sections, taking into account the recommendations [1], and the total number of the sections shall be determined. The sampled population separately from the values of the first and the second angles at the designated number of the elements within the population shall be established with the uniformly distributed number generator. The coordinates obtained will describe the location of the uniformly distributed sample sections.

The coordinates of the sections under control may be determined also as follows:

a) by the length of two arcs in compliance with the two previously defined angles $\alpha 1$ and $\alpha 2$ which will be determined by the following formulae:

$$l_1 = \frac{\pi \cdot r \cdot \alpha_1}{180} \quad (1)$$

$$l_2 = \frac{\pi \cdot r \cdot \alpha_2}{180} \quad (2)$$

b) by orthogonal coordinates X, Y and Z:

$$X = r \cdot \sin\alpha_2 \cdot \cos\alpha_1 \quad (3)$$

$$Y = r \cdot \sin\alpha_2 \cdot \sin\alpha_1 \quad (4)$$

$$Z = r \cdot \cos\alpha_2 \quad (5)$$

Problem statement. It is required to establish the uniformly distributed sample from the sections presenting the general population of the surface on the hemisphere surface.

Initial data: n – number of the sections in the sample (n=10); N1 – boundary value of the first coordinate of the sections arrangement – angle $\alpha 1$ (N1=3600); N2 - boundary value of the second coordinate of the section arrangement – angle $\alpha 2$ (N2=900); r – radius of the sphere (r=10 m).

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

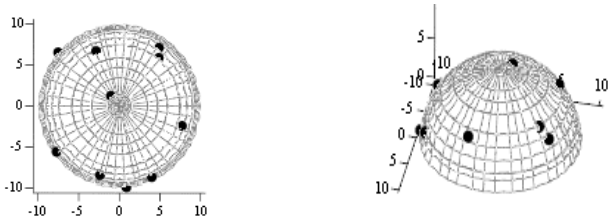
$\alpha 1$=runif (n,1,N1) shall establish the vector of the values of the first coordinate arrangement of the sections from n numbers, uniformly distributed in the interval from 1 to N1; $\alpha 2$=runif (n,1,N2) shall establish the vector of the values of the second coordinate arrangement of the sections from n numbers, uniformly distributed in the interval from 1 to N2.

Results of the solution are given in Table 3 and Fig. 3.

Table 3

Uniformly distributed sample for the fragment of the structure as the hemisphere at the number of the sections in the sample equal 10 pcs

№ of the test	Value of the angle α1, o	Value of the angle α2, o
1	216,056	14,129
2	264,866	13,602
3	206,491	62,666
4	55,409	38,963
5	153,634	87,028
6	186,646	14,640
7	270,802	74,129
8	61,670	18,030
9	177,586	73,729
10	252,211	14,845



а) б)

Fig. 3. Arrangement of uniformly distributed sections in the sample from 10 elements: а – top view of the hemisphere surface; б – side view of the hemisphere surface

GENERAL CONCLUSIONS

1. The presented method, which significantly reduces the amount of diagnostic in-situ testing, is reported. The method provides a reduction in the amount of testing by changing the complete control to a set of selectives.

2. To obtain reliable information, the monitored parameter method of randomisation (random sampling) is used. Randomisation was carried out in such a way that each structure, element and structural area had an equal chance (probability) of being selected. Based on the information obtained, a decision can be made about the properties and integrity of all structures present within the general population.

LIST OF APPLIED SOURCES

1. Recommendations on statistical method of control and estimation of the concrete strength in view of its non-uniformity acc. to GOST 18105-86 / Orgenergostroy – NIIJB. – M.: Stroizdat, 1989. – 63 p.
2. Gnedenko B.V. (1967) Theory of Probability, Chelsea, New York.
3. Joint Committee on Structural Safety (1976) Common unified rules for different types of constructions and materials. CEB Bull. d'Info., 116 E.