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Estimation of the residual resource of several buildings and structures as a single object

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Abstract. In this article, the author raises the problem of assessing the residual resource of an object, which consists of several buildings and structures. Four different approaches to solving this problem are presented. The advantages and disadvantages of these approaches are presented. The areas of their application are indicated. Within the framework of these approaches, one can use the direct enumeration method, the combinatorial method, the algebra of logic, the general logical-probabilistic method. The author has developed two possible options for calculating the residual resource of these objects using the general logicalprobabilistic method. It is proposed to develop a Methodology for calculating the residual life of such objects before the survey. The author indicates the main points that must be prescribed in the developed Methodology. An example of calculating an object consisting of five buildings is given. The scheme of functional integrity is constructed according to the general logical-probabilistic method. In the program complex "Arbiter" the static and probabilistictime calculation of the given scheme is performed. Then the calculation of the object as a whole was carried out according to the "2 of 5" system. As a result, the value of the probability of failure-free operation and the residual resource of the object as a whole is shown.

1. Introduction

In practice, a situation may arise when it is necessary to calculate the residual resource of an object as a whole, which consists of several buildings and structures. To date, there is no method for calculating the residual life of such objects.

The problem of calculating such objects is much more complicated than one building, since in this case the failure of even one or several buildings may not lead to the failure of the entire object as a whole.

In fact, this task is reduced to solving the problem of calculating the reliability of a system of the "m out of n" type. Since the number of objects (buildings and structures) can be unlimited in theory, and besides, the buildings or structures themselves can be complex systems with many elements that may not yet be equivalent in terms of reliability, it is not possible to obtain an exact solution.

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Nevertheless, it is possible to obtain the lower and upper bounds for the probability of no-failure operation of the entire facility as a whole, as well as its operating time.

To solve this problem, it is necessary to involve the apparatus of logical-probabilistic modeling.

It can be applied in several ways, which will be described in detail below.

Before we start considering each of these methods separately, it is necessary to talk about how the functional integrity diagram (FIS) is built.

The scheme must be built according to the top-down principle. This is convenient in the sense that the resulting SFC will be divided into levels (sublevels) during the construction process. What does it mean. This means that at first the entire object as a whole is accepted as a fictitious vertex. Then they are built as vertices as one element of a building or structure as a whole and are connected to a fictitious vertex (our objects as a whole) by the "or" connection. Then the systems and elements of each building are already built, which can be organized into several levels. Why is it convenient to build a SFC in this order? This is convenient because "going down" to a lower level, you can exclude further construction of any branch, because there are many elements connected by the "or" link (see Figure 1).



Figure 1. Diagram of the structural organization of the object.

How can you calculate the residual life of such objects? To answer this question, it is necessary to ask a criterion (condition) for the selection of systems and elements. When setting such a criterion, it is important that it allows one to unambiguously select those elements and systems that directly affect the performance of such an object as a whole and whose failure will lead to the failure of the object as a whole.

There is one peculiarity here. It is important to set only one criterion for the selection of systems and elements. It is possible to set more than one criterion, but in this case it is necessary to formulate the criteria so that they do not contradict each other and do not create a situation when not all elements important for the safety of the facility will be taken into account.

Let's consider a specific example. Let there be given two conditions (criteria) for selecting elements for calculating an object (building). The first criterion, an object failure will occur if an element failure will cause the object to be inoperable, i.e. the building will be in disrepair. The second criterion, the failure of an element leads to a threat to the safety and health of people. According to the condition of the task, both criteria must be fulfilled simultaneously. If at least one condition is not met, then the element cannot be included in the calculation. Consider two elements important to safety: a sealed radionuclide source and building structures. Let's start with building structures. If there is a failure of building structures, then the object will go into an emergency state (condition no. 1 will be met) and there will be a threat to the safety and life of people (condition no. 2 will be met). Thus, this element can be included in the calculation. Now let's consider a sealed radionuclide source. In case of his

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refusal (de-germitization), a threat to human life is created (condition no. 2 will be met). However, the object itself will not go into an inoperative state (condition No. 1 will not be met). Thus, an element important for safety (sealed radionuclide source) is not included in the calculation, although it is necessary to take it into account for the further safe operation of the facility.

2. Methods

After the selection criterion is set and the elements are selected, a specific approach is selected for calculating the residual resource.

The choice of a specific approach depends on the number of buildings or structures that make up the object, as well as on the impact of each specific structure or building on the object.

The **first approach** is based on the application of <u>logic circuits using the algebra of logic</u> (<u>Boolean algebra</u>). The application of this method is reduced to compiling a logic algebra formula for the object, which determines the condition of the system's operability. In this case, for each element and system as a whole, two opposite events are considered - failure and preservation of performance. You can use two methods to create a logic diagram: *minimum paths* and *minimum sections* $[1\div15]$.

The *minimum path* is called a sequential set of workable elements of the system, which ensures its operability, and the failure of any of them leads to its failure. The minimum path method gives an exact value only for relatively simple systems with a small number of elements. For more complex systems, the calculation result is the lower bound for the probability of no-failure operation $[1\div15]$.

The method of minimum sections is used to calculate the upper bound for the probability of failurefree operation of the system. The *minimum section* is a set of inoperable elements, the failure of which leads to a system failure, and the restoration of the operability of any of them - to the restoration of the system operability. There can be several minimum sections. A system with a parallel connection of elements has only one minimum cross-section, including all its elements (restoration of any will restore the system to work). In a system with a series connection of elements, the number of minimum paths coincides with the number of elements, and each section includes one of them $[1\div15]$.

A distinctive feature of this approach is the use of monotone logical functions of Boolean algebra, which involve finding a system of only two logical operations "AND" and "OR". They do not allow to calculate or simulate, for example, multiple (more than two) states of the system operability, its failure, accident, or specific causes (factors) of damage to individual or groups of elements, etc.

The **second approach** is to apply the *general logical-probabilistic method (GLPM)*. This method allows solving problems of monotonic and non-monotonic logical functions, since it uses the full basis of logical operations "AND", "OR" and "NOT" [1÷15].

This approach is the most convenient, since a universal graphic-analytical method (UGM) has been developed, and the corresponding algorithm and program for constructing all types of monotonic and non-monotonic logical functions of operability (FRS) of systems. This allows using GLPM to solve both all traditional problems of analyzing the reliability of systems of classical monotonic PCs, and a fundamentally new class of problems of non-monotonic logical-probabilistic modeling and calculation of indicators of survivability, safety and risk of functioning of structurally complex system objects and processes for various purposes [1÷15].

3. Results and discussion

In this work, the author will consider only the second approach. This will be due to the fact that, according to the conditions of our study, in order to calculate the residual resource of the entire object as a whole, we will need to first construct a diagram of the functional integrity of each building (structure) separately, followed by their integration into a system of the type "m of n".

What options are possible using this approach.

The **first possible option** is to implement a two-stage residual life calculation.

In this case, the calculation sequence will be as follows.

1. First, for each building or structure, its own SFC is built.

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2. Then the residual life of each selected element is calculated according to the appropriate calculation methods.

3. Then the obtained values of the residual resource and the probability of failure-free operation are entered into the software complex, on which the GLPM is implemented, where the SFC is built for each building or structure. The calculation of the residual life and the probability of failure-free operation of each building or structure as a whole.

4. After that, the SFC of the object as a whole is built in the form of a system "m of n" (see Fig. 2).





5. The calculation of this SFC is carried out on the basis of the calculated data obtained for each building or structure according to the results of the calculation of their SFC.

6. Processing and analysis of the obtained values is carried out. The final value of the residual resource of the object as a whole is assigned, for each building separately and for each element separately. Also, restrictions and conditions for further operation are established, if necessary.

The second option is to build a complete scheme of the organization of the object as a whole.

In this case, the calculation sequence will be as follows.

1. The SFC of the object as a whole is constructed in the form of a system "m of n", where all elements of all buildings and structures are depicted.

2. Then the residual life of each selected element is calculated according to the appropriate calculation methods.

3. Then the obtained values of the residual resource and the probability of failure-free operation are entered into the software package, on which the GLPM is implemented, where the SFC of the object as a whole is built.

4. The calculation of this SFC is carried out on the basis of the calculated data obtained for each building or structure according to the results of the calculation of their SFC.

5. Processing and analysis of the obtained values is carried out. The final value of the residual resource of the object as a whole is assigned, for each building separately and for each element separately. Also, restrictions and conditions for further operation are established, if necessary.

Which option when to use? It all depends on the tasks set and the number of elements built by the SFC. If the task is to find out the effect on the object as a whole of a particular building or structure without indicating which element of this building or structure makes the greatest contribution to the probability of failure of the entire object as a whole, i.e. to assess the impact of a particular element on the object as a whole, then in this case it is necessary to apply the first option. If the task is to consider in detail the influence of each element on the object as a whole, then in this case it is necessary to use the second option.

Let's give an example of calculation. Let there be five identical buildings with engineering support systems connected in a certain functional way to each other. In the program complex "Arbiter", a diagram of the functional integrity (see Figure 3) of such a building is built, which shows the interconnections of the elements and their influence on the functioning of the building as a whole. The

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calculation was carried out for a fictitious top 21, which is an object as a whole. Based on the results of the object survey, the probabilities of failure-free operation of each element included in the SFC are assigned. In the software package "Arbiter" static and probabilistic-time calculations are performed.

The results are shown in Tables 1 and 2. Let us set the condition that the operability of this complex of buildings will be ensured under the condition of "2 of 5" operation.

The probability of failure-free operation of the "2 of 5" system will be equal to:

$$P = 10p^2 - 20p^3 + 15p^4 - 4p^5 \tag{1}$$

The probability of failure-free operation of the building as a whole is P = 0.671 (for a static calculation) and 0.598 (for a probabilistic-temporal one, see Figure 4).

The smallest value has been substituted into the formula. According to the calculation results, the probability of failure-free operation of the facility as a whole was 0.911. Residual resource will be approximately 14 years.

N⁰ element	Element uptime probability	Element significance	Negative contribution	Positive contribution
1	0.9	0.09949	0.089541	0.009949
2	0.9	0.09949	0.089541	0.009949
3	0.9	0.09949	0.089541	0.009949
4	0.9	0.09949	0.089541	0.009949
5	0.9	0.22232	0.20008	0.022232
6	0.9	0.22232	0.20008	0.022232
11	0.945	0.067506	0.063794	0.0037129
12	0.9	0.037129	0.033416	0.0037129
14	0.955	0.70299	0.67135	0.031634
15	0.955	0.70299	0.67135	0.031634
16	0.955	0.0013596	0.0012984	6.1183E-5
17	0.955	0.0013596	0.0012984	6.1183E-5
18	0.955	0.0013596	0.0012984	6.1183E-5
22	0.9	0.067813	0.061032	0.0067813
23	0.9	0.067813	0.061032	0.0067813
25	0.8	0.83919	0.67135	0.16784

Table 1. Results of the static calculation of the building.

Table 2. Results of the probabilistic-temporal calculation of the building.

N⁰ element	Element uptime probability	Element significance	Negative contribution	Positive contribution
1	0.818730753	0.13217	0.10822	0.023959
2	0.818730753	0.13217	0.10822	0.023959
3	0.818730753	0.13217	0.10822	0.023959
4	0.818730753	0.13217	0.10822	0.023959
5	0.818730753	0.32936	0.26965	0.059702
6	0.818730753	0.32936	0.26965	0.059702
11	0.925961079	0.038745	0.035877	0.0028687
12	0.935506985	0.04448	0.041611	0.0028687
14	0.951229425	0.62855	0.5979	0.030655
15	0.951229425	0.62855	0.5979	0.030655
16	0.951229425	0.0014223	0.0013529	6.9367E-5

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17	0.951229425	0.0014223	0.0013529	6.9367E-5
18	0.951229425	0.0014223	0.0013529	6.9367E-5
22	0.904837418	0.057417	0.051953	0.005464
23	0.904837418	0.057417	0.051953	0.005464
25	0.818730753	0.73027	0.5979	0.13238



Figure 3. An example of a diagram of the functional integrity of a conventional building (structure).



Figure 4. Chart of positive contributions of elements and duration of operation.

4. Summary

In order to better understand how to calculate a specific object, it is necessary to develop a Methodology for calculating the residual resource for a specific object. Initially, the Methodology is developed before the comprehensive survey and can subsequently be adjusted, if necessary, after the comprehensive survey. In this Method it is necessary to prescribe:

1. What kind of object, i.e. give a description of this object as a whole, a description of all systems and elements included in this object.

- 2. Establish criteria for the selection of systems and elements for the SFC.
- 3. Determine which option will be used to calculate the residual resource of the object as a whole.

4. Build the SFC. If the calculation is carried out according to the first option, then a general SFC is built for the entire object, as well as an SFC for each building (structure) separately. If according to the second option, then one FSC for the entire object as a whole. If the constructed SFC contains many

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elements, it is allowed to show the SFC buildings (structures) in separate drawings, as well as, if necessary, a separate system. In this case, the equivalent peaks should be shown. If there are several such vertices on any SPC, then it is necessary to sign each subsequent drawing of the subsystem, including the number of the equivalent vertex.

If the calculation is carried out according to the third option, then it is necessary to stipulate that the relationship of various elements and their influence on the object as a whole are not determined.

5. Write what methodological approach is used to calculate the residual resource.

6. Write what methods of calculating the residual resource are applied for each element or group of elements.

7. If for an element or a group of elements the calculation of the residual resource is carried out using several methods, then show how the analysis and assessment of the obtained values will be performed, and also write how the final value of the residual resource of the element or group of elements will be assigned.

8. Give a short description of the OLVM used to calculate the residual life of this object.

9. Write how the residual resource of the object as a whole, systems and elements separately will be assigned.

10. Set limits if necessary.

In conclusion, I would like to note that at present, very little experience has been accumulated in the calculation of such objects, which include many buildings and structures and, in fact, are a kind of unified association, which is connected by technological, regulatory, historical or other ties.

Therefore, the development of a unified methodology for calculating such objects, its elaboration and accumulation of experience in calculating such objects will be a very important task in the near future.

5. References

- Payan C, Abraham O and Garnier V 2018 Ultrasonic Methods Non-Destructive Testing and [1] Evaluation of Civil Engineering Structures (Elsevier Inc.). doi: 10.1016/B978-1-78548-229-8.50002-9
- Vu Q A, Garnier V, Chaix J F, Payan C, Lott M and Eiras J N 2016 Concrete cover [2] characterisation using dynamic acousto-elastic testing and Rayleigh waves Const. and Build. Mat. 114 87–97. doi: 10.1016/j.conbuildmat.2016.03.116
- Hassan A M T and Jones S W 2012 Non-destructive testing of ultra high performance fibre [3] reinforced concrete (UHPFRC): A feasibility study for using ultrasonic and resonant frequency testing techniques Const. and Buil. Mat. 35 361-367. doi: 10.1016/j.conbuildmat.2012.04.047
- [4] Garnier V, Piwakowski B, Abraham O, Villain G, Payan C and Chaix J F 2013 Acoustic techniques for concrete evaluation: Improvements, comparisons and consistency Const. and Build. Mat. 43 598-613 doi: 10.1016/j.conbuildmat.2013.01.035
- Planès T and Larose E 2013 A review of ultrasonic Coda Wave Interferometry in concrete, [5] Cem. and Concr. Res. 53 248-255 doi: 10.1016/j.cemconres.2013.07.009
- Schabowicz K 2014 Ultrasonic tomography The latest nondestructive technique for testing [6] concrete members - Description, test methodology, application example Arch. of Civ. and Mech. Eng. 14 295-303 doi: 10.1016/j.acme.2013.10.006
- Moradi-Marani F, Rivard P, Lamarche C P and Kodjo S A 2014 Evaluating the damage in [7] reinforced concrete slabs under bending test with the energy of ultrasonic waves, Const. and Build. Mat. 73 663-673 doi: 10.1016/j.conbuildmat.2014.09.050
- [8] Xu Y and Jin R 2018 Measurement of reinforcement corrosion in concrete adopting ultrasonic tests and artificial neural network Const. and Build. Mat. 177 125-133 doi: 10.1016/j.conbuildmat.2018.05.124
- [9] Wolf J, Pirskawetz S and Zang A 2005 Detection of crack propagation in concrete with embedded ultrasonic 146 sensors Eng. Frac. Mech. 161–171 doi:

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1926 (2021) 012040 doi:10.1088/1742-6596/1926/1/012040

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10.1016/j.engfracmech.2015.07.058

- [10] Choi H, Popovics J S 2015 NDE application of ultrasonic tomography to a full-scale concrete structure *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 62 1076–1085 doi: 10.1109/TUFFC.2014.006962
- [11] Tsioulou O, Lampropoulos A and Paschalis S 2017 Combined Non-Destructive Testing (NDT) method for the evaluation of the mechanical characteristics of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) Const. and Buil. Mat. 131 66–77 doi: 10.1016/j.conbuildmat.2016.11.068
- [12] Karaiskos G, Deraemaeker A, Aggelis D G and Van Hemelrijck D 2015 Monitoring of concrete structures using the ultrasonic pulse velocity method *Smart Mat. and Str.* 24 doi: 10.1088/0964-1726/24/11/113001
- [13] Karaiskos G, Tsangouri E, Aggelis D G, Van Tittelboom K, De Belie N and Van Hemelrijck D 2016 Performance monitoring of large-scale autonomously healed concrete beams under four-point bending through multiple non-destructive testing methods *Smart Mat. and Str.* 25 doi: 10.1088/0964-1726/25/5/055003
- [14] Kozhomberdieva G I and Burakov D P 2020 J. Phys.: Conf. Ser. **1703** 012042 doi:10.1088/1742-6596/1703/1/012042
- [15] Wei Wei et al 2009 J. Stat. Mech. 02010 doi:10.1088/1742-5468/2009/02/P02010.