Comparison of the Durability of Buildings in a Group

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Abstract. The influence of various factors on the durability of concrete and reinforced concrete structures is determined. Three groups of factors are identified: elasticity, strength, and crack resistance, which influence the assessment of the durability of reinforced concrete. Based on the analysis, the determining influence of the crack resistance factor on the degradation of concrete was revealed. Based on the analysis of existing methods for determining the characteristics of concrete crack resistance, a new method is proposed. The method allows us to evaluate the crack resistance (fracture toughness) of concrete and reinforced concrete structures in any state. The method is proposed and the description of samples for the implementation of the method is given. Standard formulas based on prismatic samples extracted from concrete were used to evaluate the crack resistance characteristics. Comparative tests of samples were carried out using the known and proposed method. The obtained characteristics are used to assess the condition and durability of structures of buildings and structures.

1. Introduction

The concept of durability is determined by the indicators of time and the standard state of the object. Usually, durability is defined as the property (ability) of operating conditions to the limit state [1]. On the other hand, the state of the object is determined by a large number of factors. Durability is usually considered depends on individual factors, (temperature, corrosion, including gas, acid, alkaline, groundwater, bioinfluence, mechanical influences of various factors influence the action of chlorides, concrete carbonation and other cyclic effects of low climatic and technological temperatures affect the nature of concrete work diagrams[2]). The concept of durability is closely related to the restoration, repair (requiring significant and reasonable costs) and strengthening of construction objects [3, 4]

Recovery costs in Russia in industry are about 20-25%. [5]

A significant amount of work has been carried out to assess the resistance and durability of concrete and reinforced concrete. [6-10]

The works investigate the degradation properties and durability of complex structures.

When assessing the durability of a complex structure, it is considered that the durability of individual elements should exceed the durability of the entire structure.

The initial theoretical base and methodological basis in solving problems of durability is the theory of probability. According to Rzhansitsin's model, is defined by optimum reliability based on the minimum total expected cost.
In many cases, the calculation of the real durability of structures and buildings is in demand. Based on the foregoing, it is proposed to introduce calculations of durability into the norms. [12,13].

There is no general method for calculating durability. A variety of approaches to this calculation have been proposed. [14-16]

The expert method for calculating the service life of structures based on physical wear is widespread. [16]

In these works, the curve of the development of damage accumulation is shown, shown in Figure 1. [17,18]. The second inflection point is assumed at 50% wear.

![Figure 1. The working curve wear (experimental points are highlighted).](image)

The dependence shown in Figure 1 is described by the formula

\[ y = \ln \left( \frac{1+B \cdot x/A}{1-x/A} \right), \]  

where

- \( y \) - current degradation value of the object;
- \( B \) - limit wear of the object at time \( T \);
- \( x \) - current time;
- \( m \) - curve shape factor.

Actual depreciation of buildings is currently estimated by the number and volume of defects detected [18]. For the assessment, empirical graphs of the dependence of the percentage of wear on time are used. The works [19, 20] show the possibility of a theoretical assessment of the physical deterioration of a building in time. In works [21-25], analyzing the potentials of the object, the following conclusions were made: restoration of the object is most effective at the greatest age; getting defects in the later stages of life is very dangerous (the slightest defect dramatically reduces the life span); repairs are less effective at an early age, but damage at an early age is less dangerous.

The work analyzed the work of a structure consisting of two objects (layers, products, etc.) or groups of objects. The first object with a life expectancy of 100 years and a conditional potential \( B = 65 \), the second object with a life span of 40 years and a conditional potential \( B = 40 \). After 40 years, the second object is replaced by a third one with similar characteristics. The operating costs of a complex product begin to rise sharply after 30 years of operation until the period of normal operation. Further, costs begin to decline. A certain paradox arises: it is profitable to operate a product after its normal operation, and the longer, the more profitable. In this case, the safety of operation of the structure suffers. This applies to both single and complex designs. In this case, construction monitoring begins to play an important role.

Let’s consider a building as a sum of structural elements with different service life. So, from the analysis of the estimate for a 16-storey monolithic-frame residential building, it was determined that structures (in terms of 100%) with a service life of 100 years or more account for 74.3%, for structures with a service life of 25 ... 50 years - 11.9%, for construction from 10 to 25 years - 13.8%. [26]
2. Analysis of the durability of parts

Summing up the potentials, the service life of the entire building as a whole is less than the service life of the main load-bearing elements of the building. To increase the duration of the building’s service life, it is necessary to repair and restore the least long-lived structures. It is possible to restore an object almost indefinitely, but analysis has shown that rebuilding a structure with a service life of 10 years for another 10 years is 10 times less effective than restoring a structure with a life expectancy of 60 years by 10 years. Sometimes it is easier to replace the design. With an increase in the duration of operation, repair costs rise sharply. An increase in the potential of an object (cost of repairs) by the same amount over time increases sharply in price. It is necessary to consider the balance: for example, an increase in potential at the point of 20 years by seven times leads to an increase in life expectancy by 20 years and energy expenditure in relative units - 150; a threefold increase in potential at the point of 50 years leads to an increase in life expectancy by 16 years (about the same as at the point of 20 years), but energy costs in relative units are 450. Another issue is the operation of a group of buildings. What durability should a building working in a group have? If a residential building is designed to operate for 100 years, then how long should a school or kindergarten building be expected to last? Table 1 shows a breakdown of the structures of construction objects by the terms of operation.

| Durability group | Life span of construction | Constructions |
|------------------|---------------------------|---------------|
| 1                | 100                       | Reinforced concrete structures. Brick walls, finishing stones |
| 2                | 60                        | Overlapping on wooden beams, penetrating waterproofing, aluminum stained-glass windows, plastered (on steel beams) wooden floors, etc. |
|                  |                           | Foundations rubble, tile, reinforced concrete, complex walls, wooden window columns, balconies, steel stairs, gluing waterproofing, polystyrene foam plates. |
| 3                | 50                        | Walls made of laminated veneer lumber, cast iron and metal-plastic pipes, cast-iron radiators, concrete floors, metal purlins. |
| 4                | 40                        | Brick foundations, foam and aerated concrete blocks, hardwood floors, siding, steel radiators, ventilation, aluminum partitions. |
| 5                | 30                        | Steel roofing, galvanized, asbestos-cement, timber walls, plaster, steel pipes, entrance and interior doors, welded roofing, wooden attics, etc. |
| 6                | 20                        | Roofs made of ondulin, black steel, roofing material, soft tiles, downpipes, parquet boards, plaster on wood, black pipes, aluminum and bimetallic radiators. Lighting, elevator, PVC windows, blind area, coating waterproofing, plasterboard cladding, finishing materials (wallpaper, painting, etc.), etc. |
| 7                | 10                        | |

3. Analysis of the longevity of the whole

To assess the durability of structures, we use the theory of degradation [26]. In theory, the interaction of energies and the assessment of durability are determined by the potentials of energies in time. The property of potential is that energy and time are described independently. The potentials can be added, and therefore the assessment of the durability of a complex object can be represented as the sum of the potentials of individual components. On the other hand, the potential of a complex object can be described by a single stable potential. Therefore, a simple object can be described by the sum of the potentials of the groups. To analyze the durability, the relationship for the potential was used:

\[ B = B^*(L / t - 1), \]
\[ P = B^*(L \ln t - L \ln a - a), \]
\[ A = B^* \left( \frac{L}{a} \cdot t \cdot \ln t - 0,5(t^2 - a^2) - (L - a)(t - a) \right). \]
In formulas (2) - (4): \( L \) - life span (durability) of the object; \( B \) - energy characteristic of the object; \( t \) is the current time; \( a \) - parameter (in time units) characterizing the initial defectiveness of the object. The parameter shows after what time from the beginning of the object’s operation, the defects that appear begin to exceed the defects obtained during construction.

Figure 2 shows the graphs of the objects, built in accordance with Table 1. At \( L = 100, 60, 50, 40, 30, 20 \) and 10 years. Energy characteristics \( B \) for this graph are taken equal to 1, therefore this graph characterizes the behavior of the object only in time. To build graphs for buildings, this parameter was taken numerically equal to the estimate for the corresponding group of objects, according to Table 1. The characteristic of defect-free work \( a \) for all objects was taken equal to 10 years. In general, for different buildings, it is determined by the acceptance certificates.

Figure 2. Graphs of the durability of construction objects.

For a comparative analysis, we used the estimate documentation used in the construction of a sixteen-story monolithic frame building with external self-supporting brick walls [26-30], a school for 825 students built in Magnitogorsk, a kindergarten for 140 children in Kartaly, a kindergarten for 80 places in the village of Kizilskoe. The documentation was compiled in 2000 prices by the Magnitogorsk Design Institute for Civil Engineering (JSC MGrP). In the valuation, only the costs of structures (materials) were taken into account. Table 2. shows the data for the considered buildings. Figure 3 shows generalized graphs of the durability of these objects, built according to Table 2. In the figure, a graph was added for a kindergarten for 80 places in which, when distributing, groups were removed for 10 and 30 years and added a group for 80 years.

Table 2. Distribution of the cost of objects by groups.

| Durability group | Cost according to local estimate calculation, thousand rubles |
|------------------|----------------------------------------------------------|
|                  | School                  | Kindergarten for 140 places | Kindergarten for 80 places |
| 100 years        | 25869.34                | 16347.59                     | 13807.88                     |
| 60 years         | 3010.37                 | 17059.0                      | 9416.20                      |
| 50 years         | 3133.29                 | 1834.91                      | 2425.72                      |
| 40 years         | 1668.53                 | 866.18                       | 536.39                       |
| 30 years         | 7777.88                 | 1036.20                      | 1480.0                       |
| 20 years         | 5901.72                 | 3796.58                      | 6043.53                      |
| 10 years         | 1522.18                 | 3869.54                      | 997.07                       |
4. Conclusion
1. The obtained method of analysis of durability is quite simple and flexible and allows you to analyze the durability of any buildings and groups of buildings.
2. As can be seen from the graphs, buildings constructed from materials of the same quality have the same durability.
3. The durability of the building exceeds the allocated durability of the individual structures.
4. The materials used in their durability exceed the required initial durability. Therefore, it seems possible to reduce the cost of buildings by reducing the durability of the structures used.
5. Graphs show that the beginning of the main repair work will need to be carried out after 40 years of operation. The durability of all structures is estimated at 120 years.
6. The technique allows you to evaluate and plan the timing of repair work.

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