The degree of physical depreciation of buildings and structures

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Abstract. The influence of an aggressive environment affects the appearance of physico-mechanical and physico-chemical corrosion processes, which in turn affects the depreciation of concrete properties, the redistribution of internal forces in sections and the depreciation of the working conditions of the reinforcement. The article discusses issues related to the degree of influence of environmental aggressiveness on building structures. It was shown that steel corrosion in concrete occurs due to a change in its passivity, which is associated with a decrease in alkalinity to pH <12 during carbonation of concrete. Data on the average rate of destruction of the material (metal and concrete) are given in case of corrosion. Types of solutions to extend the life of buildings and structures are presented. Methods for calculating physical wear are highlighted. The physical depreciation of the building is shown graphically, considering repair work. The definition of physical depreciation of buildings based on the calculation of the physical depreciations of its individual structural elements is given. An example of calculating the physical depreciation of a building is considered. A formula has been developed for determining the degree of damage to structural elements of a building object. The results of calculations of the degree of damage and the degree of physical depreciation of structural elements of the building are presented.

Keywords: Aggressive environment, corrosion, physical depreciation, degree of damage, service life.

1. Introduction

Due to the long life of existing structures, as well as the great uncertainty of various factors affecting their work, there is a need to monitor their condition.

Assessment of the degree of physical depreciation of prefabricated reinforced concrete structures is carried out on the basis of the analysis of the surveys, with the establishment of dependences of the degree of physical depreciation from the service life of structures and operating conditions [1,2,3].

One of the main components to guarantee reliability of durability is the condition of the reinforcement [4,5,6,7]. In concrete, which is free from defects and damage, the reinforcement is practically not exposed to environmental influences for a long time and retains its performance properties. This is due to the fact that the presence of an alkaline medium (pH = 12.5) at the metal surface facilitates the maintenance of a passive state of steel [8].

Corrosion of steel in concrete occurs due to a change in its passivity, which is associated with a decrease in alkalinity to pH <12 during carbonation or corrosion of concrete [9].

The degree of aggressive effect of the environment on building structures (presented in table 1) is characterized by the average annual loss of strength in the corrosion zone, as well as the rate of destruction of the material.
Table 1. The average rate of destruction of materials during corrosion.

| State                        | Non aggressive | Weak aggressive | Medium aggressive | Very aggressive |
|------------------------------|----------------|-----------------|-------------------|-----------------|
| The average rate of destruction of the surface layer of metal, mm/year | 0              | <0.1            | 0.1÷0.5           | >0.5            |
| The average rate of destruction of the surface layer of non-metallic material, mm/year | 0.2            | 0.2÷0.4         | 0.4÷1.2           | >1.2            |
| The decrease in strength in the zone of corrosion of the metal, %  | 0              | <5              | 3÷15              | >15             |
| The decrease in strength in the corrosion zone of non-metallic material, % | 0              | <5              | 5÷20              | >20             |

The average annual rate of destruction of the surface layer and a decrease in its strength in the zone of corrosion of the material is determined according to field surveys over several years (at least three).

2. Methodology

In regulatory documents, for determining the amount of physical wear are based on the ratio of physical depreciation and the cost of the repair restoration. After repair work, there is a decrease in the growth of physical depreciation. The most intense periods of depreciation occur in the first 20 to 30 years and after 90 to 100 years.

In buildings, reinforced concrete coatings and ceilings have a service life of about 100-150 years, and the service life of structures and buildings directly depends on current loads and impacts, operating conditions and aggressiveness of the environment [10,11,12]. To extend the service life of buildings and structures, there are 2 types of solutions:

- usage the materials with increased crack resistance and strength. We can assume that these materials have a long period of elastic work.
- protection of material and building structures from moisture and corrosion.

Physical depreciation is the loss of the initial technical and operational qualities of an object under the influence of natural and climatic factors and human life activity. At the moment three methods can be distinguished for calculating physical depreciation:

- expert (normative);
- cost;
- method for calculating the building life cycle.

The expert method is to collect information for the defective statement, which determines the percentage of physical depreciation of individual structures. This method involves the use of various regulatory instructions at the intersectoral or departmental level. As an example were mentioned in [13], which used the Bureau of Technical Inventory (BTI) to assess the physical depreciation of residential buildings during technical inventory, planning of capital repairs of the housing stock regardless of his departmental affiliation. These rules give a description of the physical depreciation of various structural elements of buildings and their assessment. This method is the most time-consuming of all methods, but its results are the most reliable and accurate.

3. Results and discussion

The increase in physical depreciation depends on such indicators as previously carried out repair work, the period of operation, conditions of detention, structural design and layout of the building (Figure 1).
If we consider physical depreciation at a more detailed level, this is the reason for the loss of operational and technical qualities of structures and the cost of the building as a whole. Over time, the depreciation of structures accumulates, as a result of which it becomes possible to predict the probability of failure of structures [14,15,16]. The main regulatory document for determining physical depreciation is [13], which reflects the necessary tables and graphs, with a full description of defects and damage, as well as the percentage of physical depreciation that correspond to these defects. This document uses the same dependence to describe physical depreciation over time, expressed by a curve of the form (Figure 2.)

Figure 1. Schedule of physical depreciation taking into account repair work.

Figure 2. Physical depreciation of structures (service life 60-125 years).

Figure 3 presents a generalized graph of the depreciation of the structure (a) and the change in the strength of the structure (b) over time.

Figure 3. A generalized graph of the structure depreciation over time (a) and the change in structural strength over time (b). 1 - 3 – depreciational zones, 4 – cracking; 5 – loading moment; 6 – strength increase before loading.
The methodology for determining the physical depreciation of residential buildings is to determine the physical depreciation of all structural elements.

Physical depreciation based on the calculation of the physical depreciation of individual structural elements of a building is given by the formula:

\[
F_k = \sum_{i=1}^{n} F_i \frac{P_i}{P_k}
\]

\[
F_b = \sum_{i=1}^{n} \frac{F_{ki} \cdot L_i}{100}
\]

where:
- \(F_k\), physical depreciation of the structure, %;
- \(F_i\), physical depreciation of i-th section of the construction, %;
- \(P_k\), dimensions of the examined structure (area, length, volume, etc.);
- \(P_i\), dimensions of the damaged i-th section of the construction;
- \(F_{ki}\), physical depreciation of the k-th construction, %;
- \(L_i\), proportion of the cost of the i-th structure in the replacement cost of the building, %;
- \(n\), number of surveyed structural elements.

Proportion of the replacement cost of individual structures, elements and systems in the total replacement cost of a building should be taken according to aggregated indicators of the replacement cost of residential buildings, approved in the established order, and for structures, elements and systems that do not have approved indicators - according to their estimated cost.

Tables have specific physical depreciation intervals for each damage reported. Depreciation of the section is taken according to the results of a visual inspection, considering the found faults, and the technique recommends choosing the upper values, in the presence of all signs of depreciation [13].

By this analogy, physical depreciation is established for all building structures, and specific weights of structures are taken by calculation. Consider an example of calculating the physical depreciation of a building (table 2).

| No. | Structural elements of the building | The proportion of the cost of the structural element in the total cost of the building (L_i) % | Physical depreciation of the structure (F_{ki}) % | Physical depreciation of the building (F_b) % |
|-----|-----------------------------------|---------------------------------------------|--------------------------------|------------------|
| 1   | Foundation                        | 7                                           | 12                           | 0.84             |
| 2   | Walls, partitions                 | 42                                          | 15                           | 6.3              |
| 3   | Overlap                           | 12                                          | 15                           | 1.8              |
| 4   | Floors                            | 6                                           | 20                           | 1.2              |
| 5   | Windows and doors                 | 4                                           | 20                           | 0.8              |
| 6   | Finish                            | 8                                           | 40                           | 3.2              |
| 7   | Roof                              | 3                                           | 30                           | 0.9              |
| 8   | Technical systems                 | 12                                          | 25                           | 3                |
| 9   | Other items                       | 6                                           | 10                           | 0.6              |
|     | Total                             | 100                                         | 20.8 (avg. value)           | 18.64            |

The physical depreciation of the building is 19%.

Thus, when determining the amount of physical depreciation by the appraisers independently, without taking into account materials on the inspection of buildings and structures, it is necessary to very thoroughly describe their technical condition and thereby justify the obtained value.
It is necessary to be very careful about the calculated value of physical depreciation and be sure to take into account the following main indicators (critical values of physical depreciation):

- with a physical depreciation rate of more than 50%, especially for load-bearing structures (foundations, frame, walls, stairs (staircase and elevator unit), this value is critical. Structural elements for the most part simply need to be replaced;
- with a physical depreciation rate of more than 70% (75%) for any buildings and structures and more than 65% for any wooden buildings, it is always necessary to justify the economic feasibility of any repair and construction measures.

This technique allows to consider the degree of damage to the building, structure, their premises and / or structural elements. Determining the degree of damage to a structure or element is carried out by specialists using calculations of specific weights of structural elements of a certain type of object, given in the collections of aggregated indicators of replacement cost or obtained from other sources.

The degree of damage is the loss of the initial qualities of structures, such as strength, reliability, etc., under the influence of various factors, such as aggressive environment, etc.

The degree of damage to the structural elements of the object (D) is determined by the formula:

$$D = P_p + (100 - P_p) \cdot D_f$$  \hspace{1cm} (3)

where $P_p$, part of a damaged and partially destroyed structural element, %;
$D_f$, percentage of physical depreciation of the remaining part of the structural element.

The degree of damage to the structural elements of the object, calculated by the formula (3), is shown in table 3.

**Table 3.** The degree of damage to the structural elements of the object.

| Percentage of physical depreciation of existing parts of a structural element | Part of a damaged and partially destroyed structural element, % |
|---|---|
| 5  | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| 10 | 14.5 | 19 | 23.5 | 28 | 32.5 | 37 | 41.5 | 46 | 50.5 | 55 | 59.5 | 64 | 68.5 | 73 |
| 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 |
| 30 | 33.5 | 37 | 40.5 | 44 | 47.5 | 51 | 54.5 | 58 | 61.5 | 65 | 68.5 | 72 | 75.5 | 79 |
| 40 | 43 | 46 | 49 | 52 | 55 | 58 | 61 | 64 | 67 | 70 | 73 | 76 | 79 | 82 |
| 50 | 52.5 | 55 | 57.5 | 60 | 62.5 | 65 | 67.5 | 70 | 72.5 | 75 | 77.5 | 80 | 82.5 | 85 |
| 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 |
| 70 | 71.5 | 73 | 74.5 | 76 | 77.5 | 79 | 80.5 | 82 | 83.5 | 85 | 86.5 | 88 | 89.5 | 91 |
| 75 | 76.3 | 77.5 | 78.8 | 80 | 81.3 | 82.5 | 83.8 | 85 | 86.3 | 87.5 | 88.8 | 90 | 91.3 | 92.5 |

Table 4 presents the quantitative values of the physical depreciation of structural elements (reinforced concrete columns, panels, floor slabs, beams) depending on their parameters.

**Table 4.** The degree of physical depreciation of the structural elements of the object.

| Name of damage | Percentage of depreciation |
|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| Columns: | | | | | | | | |
| Cracks, mm | 0.1 | 0.25 | 0.35 | 0.5 | 1.25 | 2 | >2 | >2 |
| Curvature | 1/200 | >1/200 |
Reinforced concrete panels:
Cracks, mm
<0.3 0.65 1 2 3 >3
Deflection
<1/200 >1/200
Damage to the area, %
>5 10 20 25 30 >30

Reinforced concrete floor slabs:
Cracks mm
<0.5 0.5 1 2 3 >3
Damage, %
10 20
Deflection
<1/150 1/120 1/100 1/50 >1/50

Prefabricated and monolithic solid slabs
Cracks, mm
<0.5 2 2.2 2 2.5 2.6 2.8 3
Deflection
<1/200 1/150 1/100 >1/100

Reinforced concrete beams of coatings and floors:
Cracks, mm
<0.5 0.5 0.75 1 1.5 2 >2
Reinforcement corrosion
5 7 10 12 >12
Deflection
<1/200 1/200 1/150 >1/150

Based on the data in Table 4, the dependence of the depreciation of residential buildings of various structural systems on the duration of operation was calculated (Figure 4).

**Figure 4.** Dependence of the depreciation of residential buildings on the duration of operation. 1 - large-panel buildings with external multilayer walls; 2 - large-panel with internal load-bearing walls and external single-layer panels of light concrete; 3 - buildings with brick walls and reinforced concrete floors.

**4. Conclusions**
Currently, there is no approved methodology that unambiguously determines the nature of operating conditions and the corresponding standard of service life or coefficients of the rate of change in the accumulation of physical depreciation over time, so there is a need to improve the methodology of technical inspection of buildings taking into account durability and predicting service life.

The paper discusses the existing methods for determining the technical condition and physical deterioration of the building as a whole and its individual structures using precast concrete structures as an example.
When performing maintenance and repair activities at the time, before accelerated depreciation, it is possible to minimize the failure rate in the future operating time of this type of structure. The rationality of major repairs in buildings in disrepair determined by the economic value of the repair and should not exceed 80% of the replacement cost.

5. References

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