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## Selection of rational technical solutions for the repair of residential buildings

The unsatisfactory technical condition of the majority of apartment buildings is explained by the fact that most of them were constructed during the period of rapid housing development (from the early 1960s to the late 1970s of the 20th century), the main objective of which was to erect buildings in the shortest possible time with minimal financial and material resources. This inevitably affected the quality of buildings, since inexpensive, low-quality, and short-lived materials were used in their construction. Moreover, the wide range of normative (design) service lives of the main structures, elements, and systems implies the need for their almost continuous repair or replacement. At present, virtually all apartment buildings erected during the period of mass industrial housing construction are included in regional programmes for the capital repair of common property in apartment buildings. In this context, the selection of technical solutions for capital repairs is of critical importance, particularly those that involve the use of materials and products with design service lives corresponding to the residual service lives of non-replaceable elements. The paper presents a methodology developed by the authors for determining the residual resource (residual service life) of structures, elements, and systems of residential buildings.

**Keywords:** *normative service life, residual resource, gamma-percent residual resource, capital repair, apartment buildings*

One of the key factors determining the unsatisfactory technical condition of a significant part of the housing stock in the Russian Federation is the heterogeneity of structural reliability, caused by the different normative service lives of individual structures, elements, and engineering systems that together form a building as an integrated object. During operation, these components are subjected to unequal loads and environmental impacts, which leads to uneven wear and premature deterioration of the performance characteristics of certain parts of the building.

Current regulatory and technical documents establish design (normative) service lives for the main structural elements and engineering systems of residential buildings. At the same time, the values of normative durability vary significantly depending on the functional purpose of the elements, the materials used, and operating conditions. The discrepancy between the actual service lives of individual systems and their normative values often necessitates repair works of varying levels of complexity.

Information on the normative service lives of structures, elements, and engineering systems of residential buildings, as regulated by current standards, is partially presented in Table [1–3].

In practice, the established normative service lives often differ significantly from the actual service lives [4]. This is due to the fact that normative durability indicators are usually determined under laboratory conditions during the development and preparation of new materials and products for industrial production. In the course of such tests, real operating conditions of buildings are not always fully taken into account, including the effects of climatic factors, operational loads, installation specifics, and the level of technical maintenance. This leads to discrepancies between design and actual durability indicators. As a rule, these values are

obtained using accelerated aging methods. In this case, testing is carried out under ideal conditions in climatic chambers, excluding the influence of external factors characteristic of real operation, where the actual service lives of the same material or product may differ even within a single building [5].

Such a variation in the normative service lives of structures, elements, and systems is explained by two main factors: the intention to reduce construction costs during the period of mass housing development and the lack of technological capabilities at domestic construction industry enterprises to

### *Normative (Design) Service Lives of Selected Structures, Elements, and Systems of Residential Buildings of Capital Group II*

Name of the structure (element, system)	Normative (Design) Service Life, years
Precast and cast-in-place reinforced concrete foundations	200
Reinforced concrete exterior walls	125
Precast reinforced concrete interstory floors	150
Floors:	
• parquet;	50
• linoleum	10...15
Roofs:	
• roll roofing made of roofing felt;	10...12
• roofing steel (carbon steel);	20
• galvanized roofing steel	50
Heating systems (piping and heating devices)	40
Water supply systems (excluding shut-off and mixing valves)	15
Ceramic sanitary fixtures	20
Interior plaster	40

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▶ produce high-quality and durable materials and products [6]. At the same time, it is well known that the main direction for improving technical solutions is the minimization of the dispersion of normative service lives of individual structures, elements, and systems, that is, when:

$$\sigma_{sl} = \sqrt{\sum_i (S_i - T_{sl})^2 d_i} \rightarrow \min, \quad (1)$$

where  $S_i$  — is the normative averaged service life of the  $i$ -th element (structure or system);  $T_{sl}$  — is the average service life of the element (structure or system) based on statistical observation data;  $d_i$  — the share of the replacement cost of the  $i$ -th element (structure or system) in the total replacement cost of the building [7]:

$$T_{sl} = \sum_i S_i d_i. \quad (2)$$

Apartment buildings included in the current regional programmes for the capital repair of common property, with a total area estimated at approximately 2 billion m<sup>2</sup>, were in the vast majority of cases constructed without taking into account modern requirements for the durability of structures and the coordination of service lives of individual elements and engineering systems [8]. During the period of their construction, priority was generally given to reducing construction time and costs, which subsequently led to accelerated wear of certain structural and engineering components and the need for capital repairs.

However, when carrying out capital repairs, materials, elements, and structures are used whose range today is virtually unlimited, often without due consideration of the requirement for equal durability and without mandatory accounting for the residual resource of elements, structures, and systems that are not replaced during capital repair. It is evident that when elements (structures or systems) with a normative service life shorter than the residual resource (service life) of non-replaceable elements are used (which usually occurs in order to reduce repair costs), the effectiveness of the repair is significantly reduced. Conversely, the use of elements (structures or systems) with normative service lives exceeding the residual resource of non-replaceable elements leads to unproductive expenditures that unjustifiably increase the estimated cost of repairs.

This circumstance acquires particular significance in the context of implementing state policy in the field of capital repairs, since the overwhelming majority of regional programmes for the capital repair of common property in apartment buildings were developed and approved without proper consideration of the actual technical condition of the buildings included in these programmes. Such an approach initially reduces the validity of the planned repair measures and does not allow full consideration of the real needs of the housing stock for restoration and modernization.

It should be noted that current legislation on capital repairs provides for mandatory monitoring of the technical condition of apartment buildings, the results of which are intended to serve as the basis for the formation, revision, and updating of regional programmes. However, in practice, this mechanism is largely declarative in nature and does not ensure the acquisition of objective and reliable information regarding the actual condition of structural elements and engineering systems of buildings.

According to data from the Internet portal "Housing and Utilities Reform", in 2014 — at the time when most regional capital repair programmes began to be implemented — comprehensive technical monitoring of apartment buildings was carried out in full in only 56

constituent entities of the Russian Federation. In most regions, however, reporting on monitoring activities was based not on comprehensive technical inspections of the actual condition of buildings, but on data from technical inventory authorities. Such information, as a rule, does not reflect the real level of physical deterioration of structures and engineering systems and therefore cannot be considered a reliable basis for managerial decision-making.

As a result, regional programmes for the capital repair of common property in apartment buildings developed in the absence of state technical accounting data and instrumental inspections inherently contain a high risk of inefficient use of budgetary and extra-budgetary funds allocated for capital repairs. This manifests itself both in the performance of excessive works not justified by the actual condition of buildings and in the underestimation of the need for timely repair of certain structural and engineering elements.

It should be emphasized that only three regional programmes — those of Perm Krai, Belgorod Region, and Chelyabinsk Region — explicitly state that the lists of works (services) for the capital repair of common property in apartment buildings must be determined based on the results of comprehensive inspections of the housing stock, with defect reports prepared for each individual building. In our view, this approach is the most justified and consistent with the objectives of ensuring the reliability and durability of buildings.

Thus, it follows that one of the key conditions for improving the effectiveness of regional capital repair programmes is an orientation toward the normative (design) service lives of structures, elements, engineering systems, and equipment of apartment buildings subject to capital repair, with mandatory consideration of their actual and residual service life. Only by adhering to this approach can rational allocation of capital repair funds and achievement of the required level of reliability of the housing stock be ensured.

The authors propose a methodology for selecting technical solutions for the capital repair of buildings that takes into account the residual resource of structures, elements, and systems that are not replaced during repair and construction works [9].

The residual resource of a building element (structure or engineering system) is understood as the portion of its operational life corresponding to the period from the moment of operation time  $\tau$  to the transition to a limit state under normative operating conditions [10, 11]. This indicator reflects the potential duration of further reliable operation of the element after a certain period of use.

If the total operating time of an element (structure or system) from the start of operation to failure or transition to a limit state is denoted by  $\xi$ , then the value of the residual resource  $\xi_\tau$  after an operating time  $\tau$  can be determined as the difference between the total operating time and the actual time in service:  $\xi_\tau = \xi - \tau$ , provided that  $\xi \geq \tau$ .

For the quantitative assessment of the residual resource of building elements, special probabilistic indicators are used in reliability theory. In particular, it is recommended to apply the indicator of the mean residual resource  $T(\tau)$ , which represents the mathematical expectation of the residual resource value of an element after its operation for a time period  $\tau^1$  [12]. This indicator makes it possible to estimate the expected duration of further failure-free operation of the element.

<sup>1</sup> On determining the requirements for the procedure for determining the residual resource (service life) of the object of examination : Letter of Rostekhnadzor dated December 23, 2021 No. 11-00-15/15945. URL: [https://www.consultant.ru/document/cons\\_doc\\_LAW\\_405324](https://www.consultant.ru/document/cons_doc_LAW_405324) (rus.).

Along with this, the indicator of the  $\gamma$ -percent residual resource  $T_\gamma(\tau)$  is used. It is defined as the time interval counted from the moment  $\tau$  during which an element that has operated without failure up to time  $\tau$  retains its operable condition with probability  $\gamma$  [13]. The value of the  $\gamma$ -percent residual resource is determined from the following relationship:

$$\frac{P[\tau + T_\gamma(\tau)]}{P(\tau)} = \gamma, \quad (3)$$

where  $P(\tau)$  is the probability of failure-free operation up to time  $\tau$ .

If it is assumed that  $P_\tau(t) = P(\tau + t)/P_\tau$  is the probability of failure-free operation of an element (structure or system) within the time interval  $[\tau, \tau + t]$ , then the mean residual resource can be expressed as:

$$T(\tau) = \int_0^\infty P_\tau(t) dt \quad \text{or} \quad T(\tau) = \frac{1}{P_\tau(\tau)} \int_0^\infty P_\tau(t) dt, \quad (4)$$

and the residual resource is determined as the root of the equation  $P_\tau(t) = \gamma$  with respect to  $t$  (i.e.,  $t = T_\gamma(\tau)$ ) for a predetermined value of  $\gamma$ , which corresponds to the normative (design) service life.

The value of the mean residual resource of an element (structure or system) in this case is determined using the following expression, taking into account the reliability function  $P(t) = e^{-2\sqrt{t}}$ :

$$T(\tau) = e^{-2\sqrt{\tau}} \int_0^\infty e^{-2\sqrt{t}} dt. \quad (5)$$

Since:

$$\int_0^\infty e^{-2\sqrt{t}} dt = \frac{1}{2} e^{-2\sqrt{\tau}} (1 + 2\sqrt{\tau}), \quad (6)$$

then

$$T(\tau) = \frac{1}{2} (1 + 2\sqrt{\tau}). \quad (7)$$

The procedure for determining the  $\gamma$ -percent residual resource can be illustrated by the following example. Let us assume that  $\gamma = 90\%$  after a certain period of normative operation of a waterproofing layer made of asphalt mastic on a flat roof with a reinforced concrete base, that is, the value of the reliability function of the waterproofing layer is  $\gamma = 0.9$ . The normative (design) service life of the waterproofing layer is approximately 7 years (2,500 days).

In this case, the failure-free operating time of the coating is determined from the expression:

$$P_\tau(t) \equiv e^{-\sqrt{\tau+1} - \sqrt{t}} = 0.9.$$

It follows that for a given normative (design) service life of the waterproofing layer and a given reliability level  $\sqrt{\tau+1} - \sqrt{t} = 0.10536$ , solving the equation with respect to  $t$  yields the value  $T_{90}(t) = 11.5$ .

Thus, the residual resource and the  $\gamma$ -percent residual resource can be determined using the following relationships:

$$T(\tau) \geq \frac{T - \tau}{P_\tau}; \quad (8)$$

$$T_\gamma(\tau) \geq T_\gamma - \tau. \quad (9)$$

After determining the residual resource of all elements, structures, and systems that are not replaced during capital repair, materials and products are selected for replacement such that their normative (design) service life does not exceed the residual resource of the non-replaceable elements, structures, and systems, while ensuring a guaranteed reliability level of the renovated building<sup>3</sup>.

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<sup>2</sup> GOST R 27.002–2009. National Standard of the Russian Federation. Dependability in Engineering. Terms and Definitions. URL: National Standard of the Russian Federation (rus.).

<sup>3</sup> GOST R 54257–2010. National Standard of the Russian Federation. Reliability of Building Structures and Foundations. Basic Provisions and Requirements. URL: <https://docs.cntd.ru/document/1200083899> (rus.).

## Выбор рациональных технических решений при ремонте жилых зданий

Неудовлетворительное техническое состояние большинства многоквартирных домов объясняется тем, что большая их часть была построена в период скоростного жилищного строительства (начало 60-х – конец 70-х гг. XX в.), основными задачами которого было возводить здания в кратчайшие сроки с минимальными затратами финансовых и материально-технических ресурсов. Это не могло не сказаться на качестве зданий, поскольку для их возведения использовались дешевые, низкокачественные и недолговечные материалы, а разброс значений нормативных (расчетных) сроков службы основных конструкций, элементов и систем настолько велик, что предполагает практически постоянный их ремонт или замену. В настоящее время практически все многоквартирные дома, возведенные в период массового индустриального жилищного строительства, включены в региональные программы капитального ремонта общего имущества в многоквартирных домах, и принципиальное значение имеет выбор при проведении капитального ремонта таких технических решений, которые предусматривали бы применение материалов и изделий с расчетными сроками службы, адекватными остаточным срокам службы несменяемых элементов. В статье излагается разработанная авторами методика определения остаточного ресурса (остаточного срока службы) конструкций, элементов и систем жилых зданий.

**Ключевые слова:** нормативный срок службы, остаточный ресурс, гамма-процентный остаточный ресурс, капитальный ремонт, многоквартирные дома

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