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THE EFFECT OF DEFECTS AND DAMAGES IN REINFORCED CONCRETE LOAD-BEARING STRUCTURES ON FURTHER OPERATING CONDITIONS

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Abstract

This article examines in detail the influence of various types of defects in reinforced concrete structures on the residual bearing capacity.
The purpose of this study is to inspect a specific student dormitory with subsequent assessment of the technical condition category of reinforced concrete structures based on the results of identified defects and damage.

The objectives of the work are visual inspection of the building with the identification of all defects, assessment of the suitability of the building for further operation, development of recommendations for strengthening reinforced concrete structures, and safe operation of the building.

Based on the results of the inspection of reinforced concrete structures, the strength properties of concrete in the structures were determined, the most critical defects in the load-bearing elements were identified and recommendations for their strengthening were given.

The relevance of this study for the construction industry is due to the following: 1) such studies are rarely conducted; 2) the issue of strengthening reinforced concrete structures is very relevant when inspecting buildings; 3) defects in reinforced concrete structures can significantly affect their bearing capacity and the assignment of a technical condition category to these load-bearing elements.

Keywords: Collapse, Corrosion of reinforcement, Cracks in concrete, Defects in reinforced concrete elements, Inspection of buildings and structures, Protective layer of concrete, Strengthening of structures, Waterproofing.

I. Introduction

Practical experience in inspecting reinforced concrete structures shows that during operation, defects and damage of various types accumulate in them for various reasons. To optimally resolve the issue of the possibility of further safe operation of the entire building being inspected, it is necessary to be able to assess the technical condition of both individual structures and the entire building as a whole, taking into account the existing defects and damage [IV-V, XVII-XVIII, XXII, XXVI, IX]. Calculation of residual strength includes consideration of various types of damage and defects with an assessment of the maximum loads for each case. This paper considers a very common case from practice when it is necessary to very quickly, while at the inspection site, assess the technical condition of structures and give immediate recommendations on the safe presence of people in this building; it is not possible to perform a verification calculation in such a situation very quickly and accurately [III, XVI-XXI].

The main defects [XIV] that affect the residual strength of load-bearing structures made of reinforced concrete are:

1) corrosion of steel reinforcement, especially a high percentage of corrosion (Fig. 1);
2) damage to the protective layer of concrete (Fig. 2);
3) punching of holes in floor slabs for laying communications (Fig. 3);
4) non-compliance of reinforcement with design documentation;
5) poor quality execution of support units of horizontal load-bearing structures (beams, slabs, trusses).

Fig. 1. Corrosion of the reinforcement bars of the floor slab

Fig. 2. The absence of a protective layer of concrete in the floor slab

Fig. 3. Punching a hole in the floor slab for laying communications

As mentioned earlier, only the most significant defects that can be visually detected during the inspection of buildings and structures were listed above. In the next section, we will consider why these defects and damages in structures are the most important and consider other defects and damages to structures that will have little effect on reducing the bearing capacity of structures.

II. Materials and methods

To assess the impact of defects on further operating conditions, the building of a student dormitory in Moscow is considered as the object of examination in this work (Fig. 4). The building has a mixed load-bearing structural system consisting of a frame [XI] and load-bearing walls (Fig. 5).

Fig 4. The object of the survey

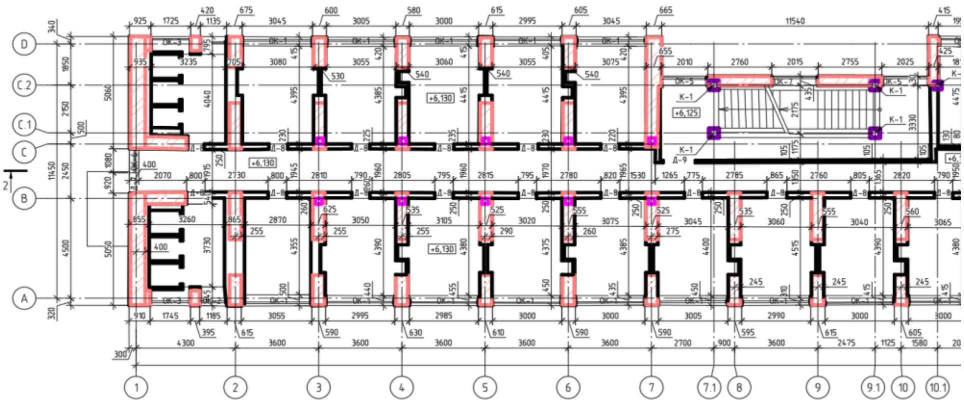

Fig 5. The part of the 3rd floor's plan in axes 1-10.1/A-D

Defects and damages of reinforced concrete structures at this facility can be divided into several groups [XVI, XVIII, XXX – XXXII, IX]:

- defects in floor slabs (coatings);
- defects in floor beams (coatings);
- defects in columns;
- defects in foundations.

The strength of concrete in load-bearing structures is determined according to [II, VI, XXI]. The most frequent and serious damages encountered in floor and roof slabs are:

- Intensive soaking.
- Multiple punched holes for laying communications are made by cutting out the working reinforcement without a frame.
- Crack formation areas.
- Damage to the protective layer of concrete.
- Corrosion of reinforcement with a loss of cross-section up to 50%.
- Use of gravel and large pebbles as coarse aggregate, settling of coarse aggregate on the lower plane of the slab (uneven vibration) (Fig. 6).

The causes of the above defects are long-term exposure to temperatures and humidity [XII], untimely routine repairs, poor quality installation work on the installation of beams to reinforce the floor slab, and work carried out without design documentation. Recommendations for eliminating defects in the monolithic floor slab are as follows: due to multiple defects in the monolithic floor slab, it is recommended to dismantle it and then install a new floor on metal beams (Fig. 7).

During the inspection of monolithic columns, the following defects and damages were identified (Fig. 8, Fig. 9):

- Insufficient size of the protective layer of concrete.
- Corrosion of reinforcing bars of columns with a loss of section up to 20%.
- The destruction of the protective layer of columns near the column base device for a length of up to 2 m (because of which the stability of the reinforcing bars may be lost, including due to the lack of adhesion of the reinforcement to concrete).
- The use of gravel and large pebbles of different fractions as a coarse aggregate. Areas of local accumulation of large aggregate and its uneven distribution over the concrete body were found, which leads to large variability in strength indicators.

Fig 6. Monolithic floor slab (showdown)

Fig 7. Monolithic floor slab on steel beams

The causes of these defects are prolonged temperature and humidity exposure, violation of the technology of concrete work, and untimely carrying out of current repairs [VIII, XII].

Recommendations for eliminating these defects will be to strengthen the columns using a steel frame made of rolled elements. Reinforcement bars must be cleaned of corrosion and treated with corrosion inhibitors. The protective layer of concrete of the columns must be restored with a repair compound to the standard value.

Fig 8. Monolithic column

Fig 9. Monolithic column (enlarged view of the reinforcing bar)

The foundations of the columns of the building are columnar, made of monolithic reinforced concrete (Fig.11). The foundations of the longitudinal exterior walls of the building are ribbon, made of monolithic reinforced concrete (Fig.10).

During the examination of the foundations, the following defects and damages were identified:

- Lack of waterproofing of the foundations, which is contrary to regulatory requirements. As a result of the lack of vertical and horizontal waterproofing of the surface of concrete and rubble foundations, when exposed to surface water, the foundation body becomes moistened, which over time leads to a decrease in the operational suitability and accelerated wear of concrete and rubble foundations, erosion of the masonry mortar and loosening of the masonry (formation of cavities, peeling and falling out of stones [XV].
- In places where water is discharged from the roof through drainpipes onto the building's blind area, external pits are dug. Near the spillway zones, localized areas of destruction of the masonry mortar to a depth of up to 20 mm were found. Areas of leaky connections of the blind area with the external walls were discovered, which led to systematic moistening of the foundation and its destruction.

Fig 10. The foundation for the external wall

To restore the technical condition of the foundations and increase their operational suitability, the following is recommended:

- Due to the long-term operation of foundations without waterproofing, local areas of destruction of the mortar of masonry joints, as well as to increase durability and operational suitability, it is recommended to fix the rubble masonry of foundations by installing a concrete protective cage, for example, by shotcrete (or an alternative method).
- Perform waterproofing of monolithic and rubble foundations, as well as brick walls located below the ground surface and in contact with the backfill soil.
- Seale the joint between the blind area and the external walls to reduce the negative impact of surface water on the rubble masonry of the foundations.
- Develop measures for the installation of drainage (for example, the installation of a storm drainage sewer along the perimeter of the building).

Fig 11. The foundation for the central column

III. Results and Discussions

The concrete strength of the supporting structures was determined using specialized equipment using both destructive and non-destructive testing methods. The survey results are presented in Tables 1 and 2. The tests were conducted in January 2022.

Table 1 presents the results of the physical and mechanical characteristics of concrete using non-destructive testing methods using ultrasound.

Table 2 shows the results of determining the strength of concrete using the destructive testing method - the method of tearing with chipping was used.

Following the design documentation for the building being surveyed, the controlled class of concrete for all monolithic structures should be C20 (MPa).

Table 1: The results of determining the strength characteristics of reinforced concrete elements by ultrasonic method

Controlled design/ Date of the tests- January 2022		Values of the ultrasound velocity in the area V, m/s					The average value of the ultrasound velocity at the site V, m/s	Endurance, MPa
The name and coordinates of the controlled areas in the axes	**The nearest strength class**	**1**	**2**	**3**	**4**	**5**		**average in the test area**
R/C monolithic column of the 1st floor in the axes 13/D	**C20**	3475	3283	3582	3590	3367	3459	28,05
		3621	3289	3555	3422	3282		
R/C monolithic column of the 1st floor in the axes 14/D	**C20**	3319	3307	3587	3641	3361	3443	27,79
		3482	3643	3335	3564	3458		
R/C monolithic column of the 1st floor in the axes 13/C	**C20**	3356	3400	3557	3340	3343	3399	27,09
		3296	3383	3394	3339	3511		
R/C monolithic slab of the 1st floor in the axes 1-2/A-B	**C15**	3240	2988	3251	3122	3001	3120	22,62
		3042	3056	2960	2890	3149		
R/C monolithic slab of the 1st floor in the axes 1-2/C-D	**C15**	2979	2952	3114	3197	3148	3078	21,95
		2891	3105	3167	3259	3139		

Controlled design/ Date of the tests- January 2022		**Values of the ultrasound velocity in the area V, m/s**					**The average value of the ultrasound velocity at the site V, m/s**	**Endurance, MPa**
The name and coordinates of the controlled areas in the axes	**The nearest strength class**	**1**	**2**	**3**	**4**	**5**		**average in the test area**
R/C monolithic slab of the 1st floor in the axes 23-24/A-B	**C15**	3007	3042	3072	3252	2976	3070	21,82
		3248	3099	3010	2962	3223		
R/C monolithic beam of the 1st floor in the axes 10.1/B-C	**C15**	3133	2951	3236	2908	3113	3068	21,79
		3043	2944	3029	3235	2974		
R/C monolithic beam of the 1st floor in the axes 11-12/C	**C10**	2569	2592	2517	2538	2619	2567	13,77
		2679	2540	2617	2668	2546		
R/C monolithic beam of the 1st floor in the axes 12-13/C	**C10**	2488	2628	2599	2662	2540	2583	14,03
		2668	2548	2513	2493	2653		
		3010	3086	2884	2998	3217		
Foundation in axes 17.1/C.2	**C20**	3536	3289	3624	3636	3456	3508	28,83
		3456	3410	3486	3347	3292		
Foundation in axes 14/C	**C20**	3332	3312	3406	3296	3502	3370	26,61
		3553	3486	3383	3481	3490		

Table 2: The results of strength measurements by the method of separation with chipping

Installation location of the anchor device (axis/row)	Working dimensions of the anchor device, cm		Pull-out force, kN	Slippage, mm	Pull-out force considering slippage	Endurance, R_m		The actual concrete class	The nearest concrete strength class
	Diam.	Height				MPa	kgf/cm²		
Foundation in axes 17.1/C.2	2,4	4,8	31,96	0,0	31,96	28,76	282,14	C23,01	**C20**
Foundation in axes 14/C	2,4	4,8	27,78	0,0	27,78	25,00	245,25	C20	**C20**
R/C monolithic column of the 1st floor in the axes 17.1/C.2	2,4	4,8	30,99	0,0	30,99	27,89	273,60	C22,31	**C20**
R/C monolithic column of the 1st floor in the axes 14/C	2,4	4,8	32,49	0,0	32,49	29,24	286,84	C23,39	**C20**
R/C monolithic slab of the 2nd floor in the axes 1-2/A-B	2,4	4,8	20,90	1,0	21,80	19,62	192,47	C15,7	**C15**
R/C monolithic slab of the 3rd floor in the axes 1-2/A-B	2,4	4,8	26,80	0,0	26,80	24,12	236,62	C19,3	**C15**

Based on the results of the defects and damages found, a map of defects and damages was made for all floors and facades of the building to visually display all existing defects with damaged volumes. A fragment of this map is shown in Figure 12.

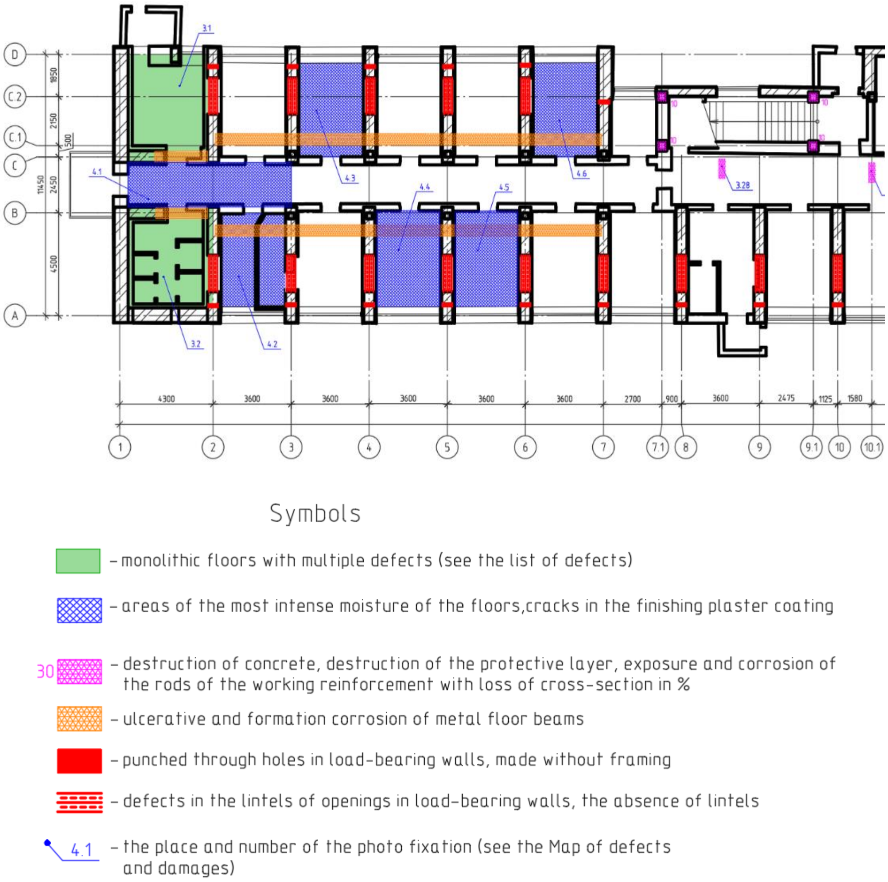

Fig 12. Map of defects of the 1st-floor fragment in axes 1-10.1/A-D with damaged symbols

Based on the results of the inspection of building structures, when assigning a technical condition category for structures [X, XIII, XXVII-XXIX, XXXIII], it is advisable to be guided by the following principles:

1) taking into account important structural defects is necessary when calculating the structural elements of the building, otherwise you can get inaccurate values of the residual load-bearing capacity of structures and offer incorrect recommendations for strengthening building structures;

2) it is not always possible to take into account defects and damage to building structures directly by entering the data obtained from the inspection (Tabl. 1 and Tabl. 2) into calculation programs that allow you to predict the value of the residual load-bearing capacity of building structures [XI], sometimes it is necessary to offer methods for indirectly accounting for damage to structures;

3) from all the damage, it is necessary to select the most significant ones that reduce the strength of the structures as much as possible.

As a result of the inspection of the reinforced concrete structures of the building, defects, and damage were identified that significantly affect the load-bearing capacity of the structures and the building. Based on these defects, the structures were assigned the category: of emergency technical condition [I, XIV, XXIII-XXV].

Therefore, for heavily damaged structures, even without performing a verification calculation, it can be argued that this structure belongs to the technical condition category: emergency or limited-operable.

Having analyzed the results of determining the concrete strength, presented in tables 1 and 2, it can be concluded that the concrete of the compressed elements of the building frame did not lose its strength, even though significant defects and damage to the monolithic columns of the 1st floor and foundations were recorded. The strength of the concrete of the monolithic bending elements of the 1st floor significantly decreased: floor slabs by 25% (concrete class C15), and floor beams - by 25 and 50% (concrete class C15 and C10).

V. Conclusion

Based on the conducted study to assess the residual bearing capacity of the student dormitory, the following conclusions can be made:

I. During the period of operation of the building, the concrete strength of the compressed elements of the building frame did not change, despite the presence of defects and damage. The strength of the concrete of the monolithic columns and foundations was sufficient and corresponded to the design strength (concrete class C20).

II. The strength of the concrete of the monolithic floors of the 1st floor of the building decreased during the operation of the building: floor slabs by 25%, floor beams - by 25-50%.

III. Serious damage and defects of the reinforced concrete structures of the building were identified, and a defect map was compiled (Fig. 12). Based on the presence and nature of the damage, the degree of operational suitability of the building is classified as emergency.

IV. To ensure safety and prevent the collapse of building structures, it is necessary to develop a building reconstruction project.

This study is important for the construction industry due to the following: similar studies are rarely conducted; the issue of strengthening reinforced concrete structures is very relevant when inspecting buildings, especially unique ones; defects in reinforced concrete structures can significantly affect their bearing capacity and the assignment of a technical condition category to these load-bearing elements and the entire building as a whole.

Conflict of Interest:

The authors declare no conflicts of interest.

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