

Cracks in monolithic concrete constructions, their correlation with capacity and durability forecast

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Abstract. The article describes the analysis of authors' experience in the field of the inspection of buildings' technical condition.

The results of the study were obtained at different times for a large selection of constructions. The researched objects were of various life cycles or erection stages, used for different purposes. The aim of such an analysis is a probabilistic estimation of the following facts:

- the influence of different origin cracks in monolithic reinforced concrete buildings and structures on degradation of their properties, load bearing capacity and durability
- the origin and causes of cracks in monolithic reinforced concrete constructions in connection with violations of building process
- concrete shrinkage cracks and load cracks, their interdependence
- the danger degree of crack formation and growth process in correspondence with durability forecast.

The majority of all cracks identified in monolithic reinforced constructions are of the shrinkage origin. The width of cracks opening in general was within the permissible limits according to SP 63.13330.2012 Concrete and reinforced concrete constructions. The verification estimate of constructions determined the convergence of theory and experimental results for crack formation. The shrinkage cracks practically do not influence operational suitability for structures under the static load. But the cyclic dynamic loading upon the open constructions together with the action of the environment is more dangerous for the durability forecast.

1. Introduction

Techniques of monolithic building construction are becoming ubiquitous in Russia [1], and the quality of construction has always been the main factor for evaluation of reliability and safety of buildings. In any kind of reinforced concrete buildings there is always a number of defects or other type of damage, in particular, cracks that appear on all surfaces of monolithic construction both immediately after concrete stripping as well as under bending stress.

According to [2], appendix E state standard on technical inspection of buildings, there is a classification of defects and damage in reinforced concrete buildings where, depending on the type of a defect, possible causes and its potential influence on lowering of building's constructive element operation should be noted. Analysis of this kind of document shows that 16 types of considered defects point out cracks 7 times (1,2,5,7,8,9,16 table E.1), that is, 44% out of all mentioned defects. From these cracks, 70% are estimated as leading to significant lowering of bearing capability or an emergency state of the construction, figure 1.





Figure 1. 44% - number of cracks among all possible defects
70%- number of dangerous cracks in constructions

The documents of the DBV (German Union of Concrete Producers) present a classification of cracks depending on their causes and time of formation in the concrete. A significant number of these cracks is defined as shrinkage cracks that appear within the first 1-2 hours after laying the concrete until the material still preserves its plasticity, or within the first few days or weeks after laying the concrete.

In cases when serious defects are discovered in buildings, there is a necessity to fix them or cut out the defective part fully and pour the concrete again. These labour-consuming tasks do not guarantee that cracks will not reappear. Therefore, the main issue is to find out a more precise definition of the causes and, what is the most important, to estimate the degree of danger of a particular crack. This task requires professional qualification and a broad experience of observations necessary to receive a statistically significant defect sample in observed constructions.

Article [3] presents an analysis of the degree of influence that normal cracks in a stretched zone and horizontal cracks in the compressed concrete zone of bent elements have on their bearing capability. The results obtained by the authors of the experiments follow the logic of reinforced concrete behaviour under stress. Experiments with beams of rectangular cross-section with the length of 1.5 metres built from concrete of different types with similar-type reinforcement showed that the bearing capability is reduced from 5% to 20% for beams with cracks compared to beams without any defects.

The influence of shrinkage cracks in concrete on the decrease of bearing capability of construction has been researched thoroughly. In particular, article [4] describes buildings, where in beams and plates of the ceiling cracks have been discovered with the load being constant and incomplete. The research has been carried out and the causes of their appearance have been singled out – the result of shrinkage.

The authors carried out computer modelling of the development process of shrinkage deformation in given conditions. The results showed that the singled out defects do not have any significant influence on the bearing capability and operational suitability of the building.

The appearance of shrinkage cracks is connected with the lowering of cement gel in the hardening process, the loss of water during the drying process of concrete surfaces and continuing hydration. It is known that the less cement and the lower is water-cement ratio on one unit of concrete, as well as the larger and less porous is the filler, then the less is the shrinkage. However, in this case such a concrete is not very convenient to pour and it can lead to problems with a homogenous concrete structure and appearance of lacunas in reinforced concrete. This way, avoiding shrinkage at the erection state can lead to a more dangerous set of concreting defects. Following all the requirements of the chosen technique of the construction process continues to be of most essential importance.

Insufficient care for the hardening construction, violation of temperature and humidity regime, insufficient moistening of its surfaces, an incorrect concrete composition, lack of shrinkage junctures

and other similar problems lead to conditions that result in stretching loads on concrete surface and appearance of shrinkage cracks.

2. Materials and methods

The present article contains analysis of research results carried out by the authors, spanning several years and focusing on construction objects of different purposes, operational periods and erection stages. The goal of this analysis is statistical evaluation of:

- the influence of different-origin cracks on bearing capability, operational qualities and durability of reinforced concrete buildings;
- causes that made cracks appear in monolithic reinforced concrete buildings, their correlation with violations of the building process;
- interconnection and mutual influence of shrinkage and load cracks in reinforced concrete;
- the degree of danger resulting from crack formation and development when estimating reliability and durability of reinforced concrete constructions.
- To solve the aforementioned tasks the results of a technical inspection of two large construction objects were used:
 - a mall building in Moscow at its erection stage [5];
 - a multi-level car parking in Odintsovo town of the Moscow region that has been in use for several years [6].

At the time of the inspection the building of the mall was a monolithic reinforced concrete frame three floors high with partial wall filling.

In accordance with the technical task, the impact of defects appearing in constructions on their bearing capability needed to be estimated as well as the category of the technical state of the building overall.

The frame consisted of the columns, inter-floor ceilings using the beam scheme, elements providing spatial rigidity of the frame diaphragm plate, elevator shaft walls and staircases.

The building, complex according to its plan, had a considerable length (around 1.5 km) and consisted of 6 sections divided by deformation seams. The overall number of defects mentioned in the statement included in the Technical report [5] was more than 300, and the survey processes had more photos like the ones presented below. Therefore, it can be concluded that the amount of information for statistical processing was sufficiently large. Figure 2 presents fragments of building construction in their mutual arrangement.

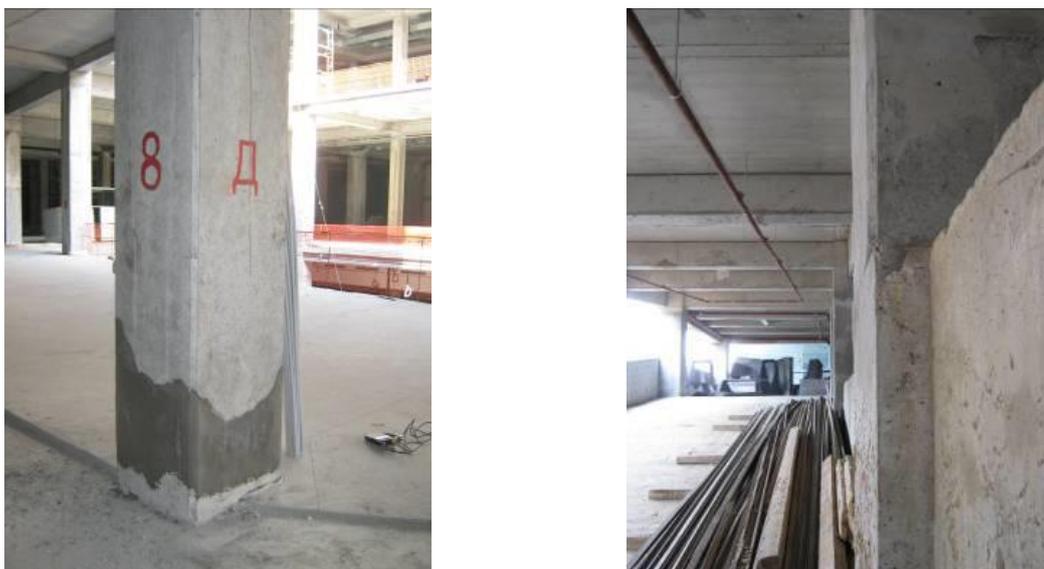


Figure 2. Fragments of building construction in mutual arrangement

The quality of concrete construction was evaluated according to recommendations [7] using an ultra-sonic surface test using Pulsar-1.1. Prior to this, in order to determine universal calibrating dependence of «ultrasonic speed - concrete strength» by mechanical nondestructive pull out method according to [8], [9] using «ONIKS-OS». Actual concrete class is determined by the following formula, mentioned in paragraph 7.5 in the rules of concrete durability estimation [10]:

$$B_{\phi} = 0.8 \cdot B_m \quad (1)$$

The number and location of controlled parts was determined from the technical tasks and in accordance with paragraph 5.8 [10]. In accordance with the methodology of ultrasonic investigation, each part was measured at least 2 times in terms of ultrasonic speed in each of two mutually perpendicular directions.

The analysis of the materials obtained as a result of the study showed that among discovered concrete and frame defects there also existed surface sinks and lacunas in the body of the construction as well as in concrete seams: chips and numerous multi-directional cracks in the protective layers of the concrete.

Among the defects discovered in bearing constructions of bent elements of the monolithic frame, cracks were the most common, spreading through the surface layer in blocks and ceiling beams that appeared right after stripping. The majority of these cracks (90%) was of the shrinkage origin considering that their depth was relatively small. The width 0.1 mm of the most of these multi-directional vertical, lateral and skewed cracks did not exceed the norm [11].

The next object for analysis was the multi-level car parking in Odintsovo town in the Moscow region.

The building had an alternating height from 4 to 7 floors [6], the overall height 19.7 metres and dimensions according to the plan - 164.95 x 25.8m. The operation of the object started in 2013 and its technical inspection was carried out after several years of operation, in 2016. Figure 3 shows the general view of the car park from two positions: from the entrance and from the side of the four-floor part. Fragments of ceiling plan at +16.67 metres and at +19.45 metres showing defects can be seen on figure 4.



Figure 3. A general view from the entrance and from the four-floor part

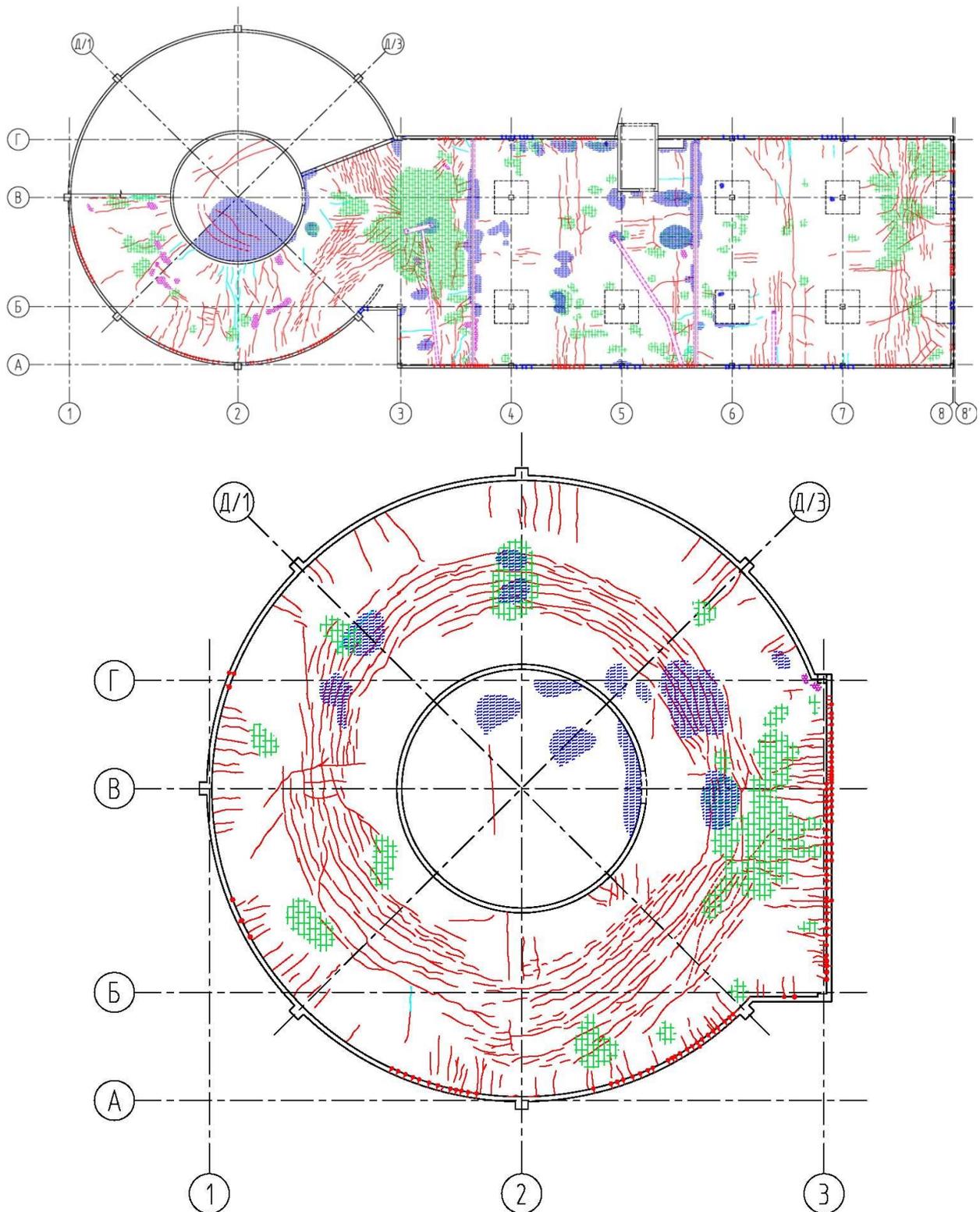


Figure 4. Fragments of ceiling plan at +16.67 metres and at +19.45 metres

The monolithic reinforced concrete building of the car park with a bearing frame and ceilings, built according to the beam-less scheme consisted of three blocks separated by temperature and deformation junctures. Floor slabs are 8.2 metres in span in one direction, 4.35 and 8.2 metres in

transverse direction and have the thickness of 220 mm with capitals near the columns of 250 mm and were reinforced by strapped beams with a cross-section of 200x470(h) mm around the block's contour.

The spiral entrance ramp, according to the project, was to have the width of 250mm but the inspection revealed that its actual width was 230mm. The reinforced concrete ramp had strapped beams around its contour and the beam wall of alternating height from 200x1100mm up to 200x3900mm.

A check of geometrical parameters of the construction was carried out for this object and defects and damage were added to the plan. The floors and the roof were opened in order to specify the exact load and characteristics of used materials.

To check the strength of concrete in monolithic reinforced concrete constructions the ultra-sonic method was used, specified in the state standard [12], using PULSAR-1.1. Prior to that particular gradual calibrating dependency was created, which extended the universal calibrating dependency. This was done by mechanical nondestructive pull out method according to [8], [9]. The concrete class in terms of its durability was defined according to [10] based on the formula (1) and [13].

Prior to experiments with concrete durability each part was to be analysed for reinforcing bars location by non-destructive magnetic method using Profoscope PS01. Checking parameters of reinforced concrete elements of the inspected building was carried out by the means of a complex method in accordance with [14], scanning the controlled surface using Profoscope PS01 and control opening.

The parts that were used for the opening of the construction were determined by the cracks and deformations present in it.

Verification calculations for the ceiling and coating constructions were carried out in terms of actual loads, taking into account all parameters, determined by the study. Estimates were carried out using software LIRA-SAPR PRO, 2014 version.

3. Results and analysis

The primary reason for the appearance of cracks in the car park as well as in the previously discussed building were deformations resulting from temperature changes and shrinkage, which in turn appeared as a result of violations in the building process. However, further development of certain cracks in the process of operation was due to the load factor.

As seen in the previous example, the defects observed in bearing ceiling constructions, floor slabs and spiral ramp included cracks in slabs and strapped beams. In general, the width of the said cracks was no more than 0.2mm and did not exceed the accepted norm [11] - 0.3mm (the calculated width of cracks under the influence of the operational constant and short-term load was 0.25 mm).

The basis for such a conclusion was the data presented in Table 1 for cracks discovered as a result of the study of constructions of the car park and the histogram of statistical distributions, presented on figure 5. The majority of the cracks primarily spread depth-wise without exceeding the protective layer of concrete. The width of all observed cracks was between 0.05mm and 0.3mm, which means that it did not exceed the norm [11].

Table 1.

Crack length, m	The number of cracks of certain width				
	Crack width in ceiling and coating blocks of the car park				
	0.05 mm	0.1 mm	0.2 mm	0.3 mm	All cracks between 0.05 mm and 0.3 mm

1	11	20	7	5	43	403
2	60	60	31	12	163	
3	57	83	47	10	197	
4	34	48	27	9	118	436
5	18	34	32	9	93	
6	16	22	26	6	70	
7	7	21	21	2	51	
8	4	18	17	3	42	
9	2	10	14	1	27	
10	4	18	13	0	35	
Average length of spread, m	3.7	4.3	5.5	3.7	4.3	
Percentage of cracks with more than 3m length	39.9%	51.9%	63.8%	52.6%	52.0%	
Overall number of cracks	213	334	235	57	839	
Percentage of all cracks	25.4%	39.8%	28%	6.8%	100%	

The statistical data adduced above shows:

- cracks with the largest allowed width of 0.3m constitute only 6.8%;
- the biggest number of cracks has the width of 0.1mm;
- the most frequent are the cracks with the length between 2 and 3 metres;
- the biggest number of long cracks has the width of 0.2mm which is less than the largest allowed width of 0.3mm and the estimated width of 0.25mm;
- the number of long cracks with the increasing width between 0.05mm and 0.2mm is growing which conforms with the logic of reinforced concrete;
- as the width nears 0.2mm and gets closer to the estimated width, the length of cracks significantly decreases which might mean that there is a local increase of deformations in the construction and that the crack in question is caused by load pressure.

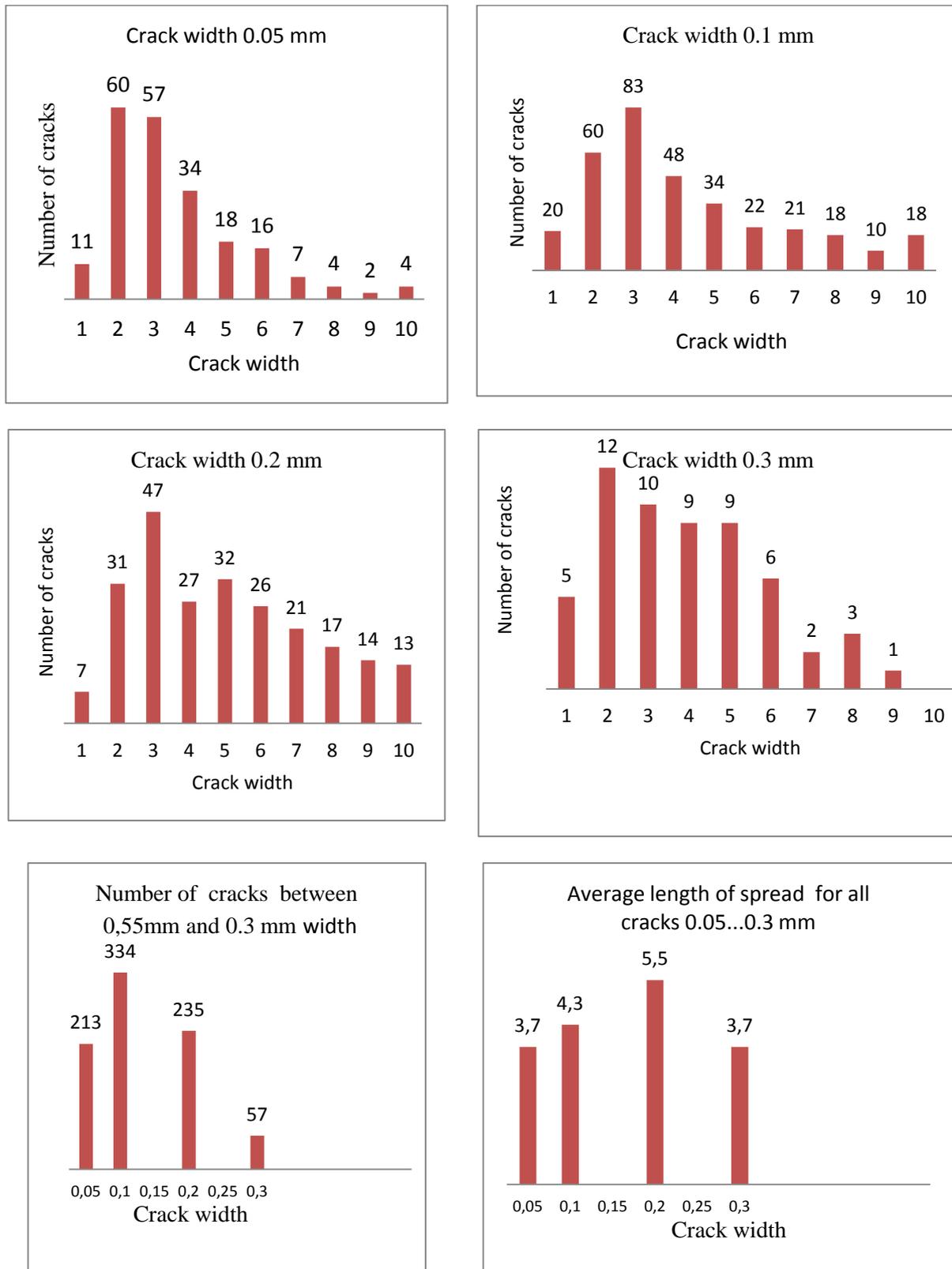


Figure 5. Frequency of appearance of cracks of different length and width determined for cracks in ceiling and floorslabs

4. Conclusions

1. Information obtained in the process of the current inspection of the technical state of both objects [4,6] was sufficiently large for statistical evaluation of frequency and degree of danger for different types of defects and damage. Defects and damage appear both at the erection stage of monolithic reinforced concrete constructions and in the process of operation over the course of several years. The issues of crack formation in reinforced concrete elements bending and working on beams and slabs of ceilings were most thoroughly studied.
2. As a result of the analysis it was determined that the majority of the observed cracks in the concrete of monolithic constructions was of shrinking nature. The width of cracks did not exceed the norm according to [11].
3. Verification estimates were used to determine a good convergence of theoretical and experimental parameters of cracks. It also confirmed that shrinkage cracks do not significantly influence operational suitability of buildings in the conditions of static load on constructions, protected from direct atmospheric influence, temperature changes, precipitation and other aggressive effects.
4. For constructions under aggressive impact from the environment, under dynamic load, especially with a cyclic character of its application, appearance of shrinkage in the form of cracks transforms them into pressure concentrators, leads to quick development and decrease of bearing capability and durability of the building overall. Factors that lead to lower operational suitability and durability of buildings come as a result of violations in the building process and the concreting technology which causes appearance of shrinkage cracks.

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