

The on-site example of influence of selected factors on the quality of monolithic reinforced concrete elements

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Abstract. The subject of the article is the analysis of the influence of factors related to the course of concreting on the quality of the reinforced concrete element. The problem was discussed on the example of columns with an unusual narrow cross-section (18x80 cm). The characteristics of the surface defects of tested columns are presented and their causes are discussed. The basis of discussion were observations and in-situ tests of concrete mix performed during concreting similar elements in similar conditions. The potential effects of defects in terms of component durability were also considered.

1 Introduction

Evaluation of the quality of concrete during the construction process of the object is usually carried out on the basis of tests of technical features, including in particular compressive strength. The control tests carried out with reference to the samples, both by the concrete supplier and by the contractor, allow to assess the conformity of the characteristics of the delivered concrete with the specification. However, they do not allow for consideration of the impact of the technological operations on the concrete quality, starting from the preparation of the formwork and reinforcement, and ending on the concrete curing. Testing of concrete in construction with non-destructive or semi-non-destructive methods is usually quite expensive, often technically troublesome, and the results of such tests are not easy to interpret.

The first signal indicating irregularities that occurred in the technological process of concreting are often changes, visible on the concrete surface. These problems are not only related to the visual aspect, but can also affect the durability of the structure. The correct analysis of the scale of defects along with the analysis of documentation of the course of deliveries of concrete and works is the initial stage of diagnostics, which can indicate both the causes of the problem and forecast their possible effects, and can be used as an aid in determining the program for further, in-depth diagnostics.

The subject of consideration in this paper are selected reinforced concrete structural elements - columns of a multi-storey residential building. The purpose of the work was to identify potential causes of defects, in the form of very numerous pores and cracks on the

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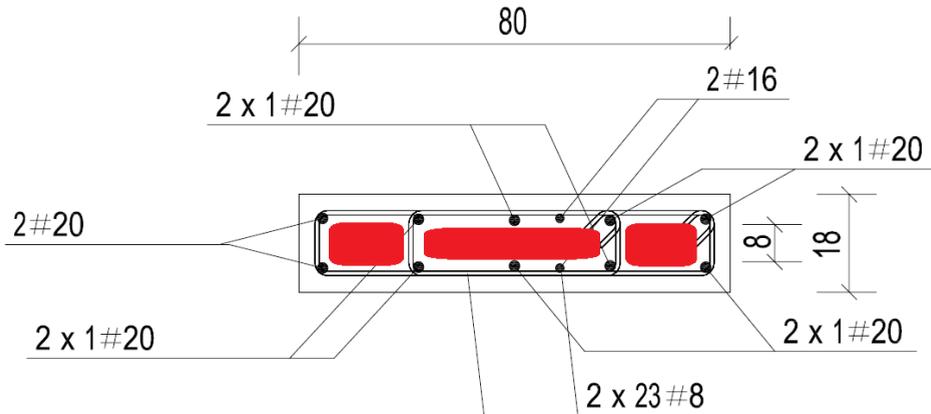


Fig. 2. Cross-section of a reinforced concrete column with space marked by the authors, remaining after taking into account reinforcement, for filling with a concrete mix and compaction.

The material composition of the concrete mix used to make the above-described reinforced concrete columns, given in the technical documentation, is summarized in Table 1.

Table 1. The composition of the concrete mix used to perform the analyzed reinforced concrete columns

No.	Component	Quantity, [kg/m ³]
1	Cement CEM I 42,5 R	355
2	Water	161
3	Aggregate fraction 0/2 mm	590
4	Aggregate fraction 2/16 mm	1180
5	Admixture - high range water reducing	4.97
6	Fly ash (additive type II)	65

The exposure classes adopted in the concrete specifications are: XC4, XD3, XF1, XA1. The assumed class of compressive strength of concrete (C35/45), the amount of cement, water-cement (0.45) and water-binder (0.42 - determined after taking into account fly ash) coefficients meet the requirements formulated in the PN-EN 206 standard [2], with reference to the exposure classes.

According to the recipe, an admixture significantly reducing water (polycarboxylic superplasticizer) was used, in an amount of 1.40% relative to the cement mass, which is in accordance with the manufacturer's recommendations. The technical sheet of the admixture contains a statement that "the product can be used at temperatures down to -15°C". Because there were no lower temperatures during concreting, the admixture could be used. Table 1 shows that aggregate with a $D_{max} = 16$ mm was used to make the mix. This value of aggregate grain diameter, in relation to the cross-section geometry and column reinforcement, could significantly hinder filling of the formwork by the concrete mix (see Fig. 1 and 2).

3 Test methods used

In order to document the irregularities occurring on the concrete surface of the analyzed columns, extensive photographic documentation was made during the visual inspection of the facility. Photographs were taken for columns, on the surfaces of which defects and irregularities of the highest intensity were observed.

As part of the evaluation of the concrete mix used, consistence and air content tests were carried out. The consistence of the concrete mix, taken from the batch to be used for

subsequent reinforced concrete elements, was determined on the basis of the slump test, according to the test procedure described in PN-EN 12350-2 [3]. This method is sensitive to changes in the consistence of the concrete mix, which correspond to the slump between 10 mm and 210 mm.

The consistence of the concrete mix was determined twice. The first test was made immediately after collecting the mixture from a basket feeder filled with a mix from a truck mixer. Due to the long time of unloading and concreting of the elements, in order to check the ability of the concrete mix to maintain the consistence over time, the consistence determination was carried out 20 minutes after the first test. Between the first and the second measurement of consistence, the concrete mix was kept in the container without mixing, which corresponded to the actual situation, i.e. the concrete mix between successive loads of the basket remained in the concrete mixer truck without mixing.

The air content in the concrete mix was determined according to the procedure described in the PN-EN 12350-7 standard [4].

4 Inspection and measurement results and analysis of the causes of defects

4.1 Photographic documentation of reinforced concrete elements

The local inspection were done, including an analysis of the surface state of reinforced concrete columns, in the case of which the most irregularities regarding the concrete surface were found. It should be emphasized that the surface defects described below revealed only on vertical support elements, with the largest changes occurring on elements with a cross-sectional size of 18 x 80 cm and therefore these elements were analyzed. The scale of the issue was high, because the observed defects related to the majority of made columns. In all cases, the presence of very numerous defects on the concrete surface as well as discoloration and cracks at the edges of the columns were found. A large number of open pores and blisters were found, located at the entire height of the columns. The distribution of pores was relatively uniform, there is no reason suggesting the local nature of the cause (Fig. 3). Pore diameters have values ranging from a few to a dozen or so millimeters. Blisters and honeycomb, which are usually the result of leaking water/mortar from formwork in the corners of columns and improper laying and compacting of the concrete mix, occurred less often and their distribution was of a less regular nature. Diameters of blisters had values from a few to several tens of millimeters, and their depth reached even a few millimeters (Fig. 4).

Observed surface texture inside many blisters indicates that these were places where water accumulated during binding and hardening of concrete (so-called bleeding; Fig. 5).

The separation of water from the concrete mix is also confirmed by defects on the edges of the columns. A darker color of edges was observed, suggesting a much greater moisture content of the cement matrix (Fig. 6). The structure of the material within the defect was very porous, and the aggregate was partially exposed (honeycomb effect), which could be the result of washing out a part of the mortar from the mix. The fact that during the dismantling of the columns, water leaks appeared on the floor around them is the confirmation of the mixture segregation and bleeding phenomenon.



Fig. 3. A view of a reinforced concrete column - visible concrete defects: numerous pores and blisters located on the entire surface of the column and crushed and discolored corner (left edge).



Fig. 4. Blisters in concrete at the edge of a reinforced concrete column (located in its lower part).

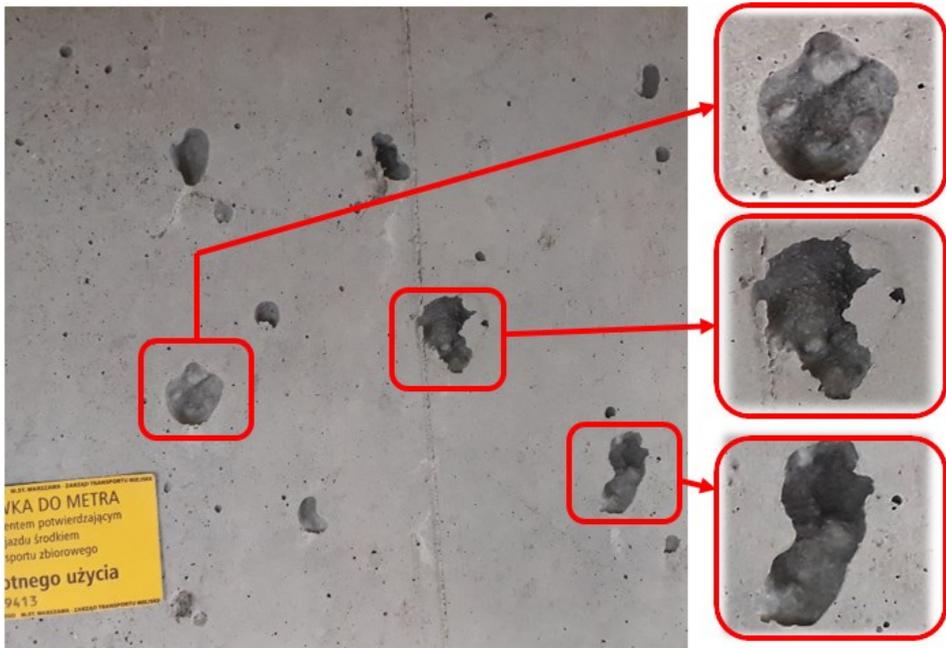


Fig. 5. Blisters on the concrete surface; the scale of their dimensions is indicated by the reference to the dimensions of a typical pass.

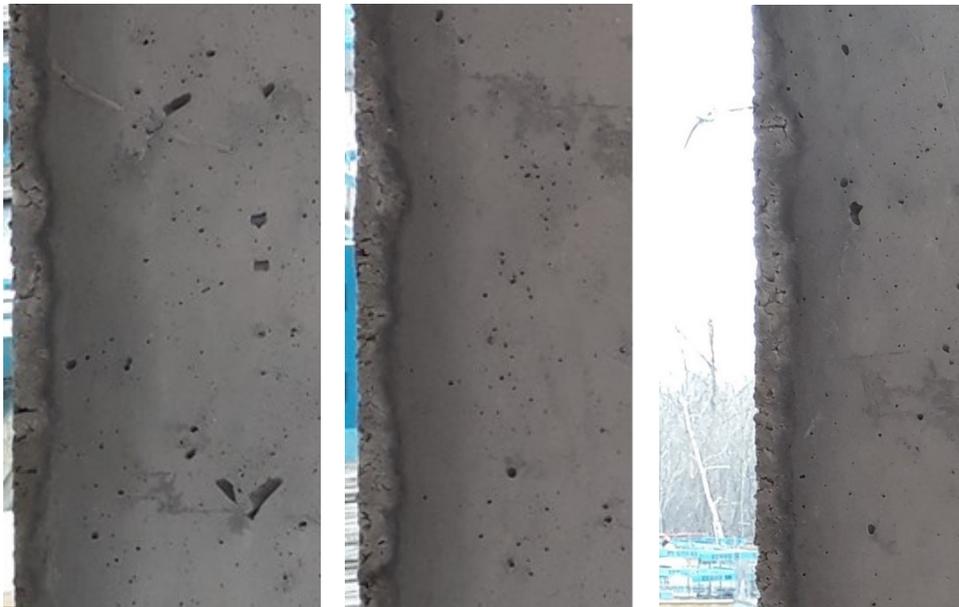


Fig 6. Honeycomb effect and discoloration of concrete at the edges of reinforced concrete columns (occurring at the entire height of the element).

Another defect observed during the inspection was the occurrence of "flakes" resembling fragments of plastic (Fig. 7). They were very brittle and easily destroyed. According to the authors, it could have been a residue of the anti-adhesive agent, which was used for moulds, and which could react with the concrete components. This effect could also come from the outer layer of formwork panels, especially in the case of panels with high degree of use.

Noteworthy is the fact, that the flakes often covered pores and voids, the edges of which correspond to the shape of the flakes (Fig. 8).

As stated, a anti-adhesive agent used to coat the formwork, according to the manufacturer is suitable for various types of formwork. It should be noted that the manufacturer does not provide information on the suitability of the agent for use during the winter in the technical datasheet.



Fig. 7. „Flakes” on the surface of concrete.



Fig. 8. Pores and blisters visible after removing „flakes”.

4.2 Tests for concrete mix

During concreting, on the construction site, key parameters, such as consistence and air content in the concrete mix, were examined according to the authors.

In Table 2 the results of the concrete mix slump test carried out in accordance with the test procedure described in the PN-EN12350-2 standard [3] are summarized. According to the adopted research program, the measurements were carried out in two stages - immediately after taking the concrete mix from the basket feeder and after 20 minutes of holding the mix without mixing. On their basis, the consistence class of the mixture was determined in both cases.

Table 2. The results of the test of the slump and the determination of the consistence class of the concrete mix

No	Description of the state of the concrete mix sample	Test result - slump, [mm]	Consistence class	Range corresponding to the consistence class [mm]
1	Sample taken directly from the basket feeder, mix temperature: 10.6 °C	120	S3	100 - 150
2	Sample after 20 minutes without mixing	75	S2	50 - 90

The research program was based on the concreting technology used on-site. During the local inspection, it was found that the concrete mix, not loaded into the basket container in one stage, was not mixed during its storage in a concrete mixer truck. Mixing occurred only during the unloading of subsequent batches of the mixture. So the consistence measurements were made twice. Leaving the concrete mixture immobile, results in a change in the parameters of the mixture, including a change in the consistence class, which was confirmed by the result of the examination of the cone fall after 20 minutes of storage of the mixture in this state. The value of the fall of the mix slump was then only 75 mm, which corresponds to the consistence class S2. Therefore, during concreting the mix consistence was much less fluid than it was indicated in the specification (S3). The result of too dry consistence were problems during compaction of the mixture with an immersing vibrator - the mixture was so dry that after removing the vibrating tip there was an empty space that practically did not close up sufficiently. The effect of the above-described phenomenon are defects on the surface of the concrete described in the chapter 3.1 of the article. Changing the mix fluidity, due to the lack of mixing, can be considered as an undesirable effect, typical when using a polycarboxylic superplasticizer.

The result of testing the air content in a concrete mix are shown in Table 3. They were carried out in accordance with the test procedure described in the PN-EN12350-7 standard [4], immediately after taking the concrete mixture from the basket feeder.

Table 3. Results of testing air content in a concrete mix.

Lp.	Description of the state of the concrete mix sample	Test result - air content, [%]
1	Sample taken directly from the basket feeder, mix temperature: 10.6 °C	2.55

The obtained value air content in the concrete mix equal to 2.55% is correct, in the case of non-aerated mixtures and indicates a good cooperation of admixture, additive and cement.

4.3 Observations during concreting

During the analyzes, doubts appeared as to the correctness of the course of laying and compacting the concrete mix. As given in Chapter 1 of the paper, the smaller dimension of the column cross-section was 18 cm, and the thickness of the designed concrete cover was 2.5 cm. Taking into account the thickness of the cover and the diameters of the reinforcing bars, very little space remains, i.e. around 80 mm, for introducing the tip of the vibrating tool (see Fig. 2). During the observation of the concreting process of the subsequent elements, it was found that a vibrator with a 60 mm diameter tip was used to compact the concrete mix. The vibrating tip hit the reinforcing rods, which made it impossible to properly compact the mixture in its entire volume. Narrow mixing space in combination with too large, in this case, dimension of the vibrating tip could hinder proper compaction of this mixture. This was important especially in critical places, such as the concrete and reinforcement contact zone, and the cover zone. It could also contribute to the formation of vibrated spaces filled with water at the surface of the concrete. An additional difficulty was, as demonstrated in the work, too dry consistence of the concrete mix.

5 Analysis of the effects of identified defects

The available construction documentation showed that the design requirements for the concrete, including compressive strength, were met. For this reason, the subject of research and analysis presented in this paper were mainly surface defects of concrete. Therefore, the assessment of the effects of the identified defects was carried out in relation to the serviceability of the analyzed columns. Referring to the norm regulating the principles of execution of concrete structures [5], the observed surface changes can be classified into the group of defects related to the visual aspect. Requirements regarding concrete surface defects in [5] were limited only to the situation when "the visual effect is significant". It should be understood that the record refers only to elements made of architectural (facing) concrete. Although in the analyzed case, the specification does not formulate visual requirements, however, the existing defects, in such a large intensity and scale, require consideration in the context of further finishing works and durability of the structure. The effect of defects is the need to perform additional works related to the repair of the concrete surface before it is plastered, which increases the costs of materials and labor. The depth of blisters on the surface of the concrete reaching half the thickness of the cover and the frequency of their occurrence has a direct influence on the effectiveness of this cover as protection of reinforcement against corrosion. In the absence of repair, this can lead to a reduction in the durability of structural components.

6 Summary

Based on the results of the inspection, analysis of documentation and results of testing the concrete mix, a number of conclusions, regarding the causes and effects of defects found on the surfaces of reinforced concrete columns can be formulated.

As the causes of defects, you can indicate:

- cross-section geometry of the column: the vertical support element analyzed with dimensions as for the wall has been designed as a column, which caused major execution complications due to the shape of reinforcement,
- leaving the concrete mix without mixing in a concrete mixer truck, in periods between successive fillings of the concreting container,
- choosing the wrong diameter of the vibrator tip according to the cross-sectional dimension of the element and causing local segregation of the mixture as a result of vibration of the reinforcement,
- use of aggregate with a $D_{\max} = 16$ mm, which significantly complicated concreting and compaction with the designed geometry of the column,
- no assessment of the suitability of the anti-adhesive agent to be used in the winter,
- high use of formwork panels.

It is difficult to indicate one of the above-mentioned causes, while the final effect visible on the surface of columns is probably the result of their synergy. Each of the above-mentioned reasons, occurring independently, probably would not be a significant factor in the occurrence of defects, on such a large scale and intensity. On the other hand, the combination of several reasons led to an intensification of the effects that appeared in the analyzed structure.

The effects of existing defects can be considered in several aspects:

- visual effect, important also when using concrete, for which no aesthetic requirements are applied,
- execution - increased expenses on materials and labor,
- durability - in the case of lack of repair of deep blisters, the protective function of the reinforcement cover may be weakened.

It should be emphasized that the analyzed defects are very often observed on the surfaces of structural elements made of "non-architectural" concrete. The problem is therefore not limited to the individual case. The authors point out that standard documents contain no requirements, both qualitative and quantitative, for the defects such as those analyzed in the paper. Due to the lack of such requirements, it is difficult to formally qualify them as a defect, but as demonstrated in the article, their impact can be significant.

References

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