Operational Problems in Structural Nodes of Reinforced Concrete Constructions

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Abstract. Reinforced concrete structures are frequently designed and executed in such facilities as: halls, warehouses, factories, multi-family buildings, single-family buildings, tanks, silos and many others. For this type of structures, it is particularly relevant to provide an appropriate thickness of concrete lagging, which aims at protecting reinforcement against corrosion, and to design it with appropriate spacing allowing the in-between space to be filled with a concrete mix. A frequent problem met while making reinforced concrete structures is such a density of reinforcing bars, particularly within structural nodes, that there is no possibility of filling the space between them with a concrete mix or it is not possible to vibrate the concrete mix in order to prevent segregation of mixture components. Structural nodes are points where special attention should be paid to careful compaction of concrete mixes and application of measures that prevent concrete from adhering to molds. The case study illustrates two structural nodes connecting a column with a bolt, located in a wall with a column-transom structure. During the modernisation works carried out in the production hall there were exposed two structural nodes completely unfilled with a concrete mix and with visible reinforcing bars that showed little buckling and the onset of corrosion. The columns, due to their location in the general static scheme of the wall, were subjected to compression or locally compressed and affected by bending. Particularly unfavourable was the fact that the columns did not feature the concrete lagging in the compression zone of the element. Removal of concrete lagging in the compression zone always results in decrease in the bearing capacity of a structure. It can be concluded that due to faulty workmanship the columns had a lower load bearing capacity than anticipated in the building permit design. The paper provides software-derived guidelines for repairing reinforced concrete columns so as to obtain the value of load bearing capacity equal or higher than expected in the design and on the assumption that repair works would be carried out on columns subjected to loading.

1. Introduction

When designing framework or skeleton reinforced concrete structures, special attention should be paid to the correct construction of nodes, since they are the most responsible structural elements of frames. The construction of nodes should ensure the entire system monolithism and non-deformability as well as simplicity of execution [1]. Redistribution of working loads is affected by the assembling method of structural elements, in the case of frame structures these are columns and transoms. The most common calculation models of connections are rigid, flexible and articulated joints. For a rigid connection, it is assumed that there are no mutual rotations between the elements joined, and the stiffness of the node is
2. Case study

The construction nodes discussed in the article are located in the frame wall in the production and warehouse hall that has been in use since 2007, in the town near Poznań. The wall is inside the building and acts as a link between the halls constructed at different times. Modernisation works carried out in the hall revealed hidden defects of two reinforced concrete columns. Basic data concerning these columns and transoms were read from archive documentation provided by the owner of the facility. The reinforced concrete columns with a cross-sectional area of 35x35 cm were designed from B25 concrete (according to contemporary designations), currently it is C20/25. Vertical reinforcement was made of 4 Ø20 bars made of A-III steel 34GS grade, double clevises made of Ø8 bars with 20 cm spacing, in the column connector part the spacing was reduced to 10 cm at a height of 73 cm, made of A-I smooth steel St3SX grade. Wall transoms with cross-sectional dimensions of 24x24 cm, located at the outer edge of the column, were designed from B25 concrete (according to contemporary designations), currently C20/25. Horizontal reinforcement was made of 6 Ø12 bars (3 bars at the bottom and 3 bars at the top) made of A-III ribbed steel 34GS grade, single clevises, double clevises made of Ø6 with 25 cm spacing made of A-I smooth steel St3SX grade. Figure 1 shows a fragment of the wall including the elements described above.
Modernisation works consisted in adapting the building to the current user's requirements, i.a. making openings in the walls. For this reason, reinforced concrete transoms were removed in sections intended for new openings. At the contact points of structural nodes, i.e. column – wreathe contact point, it revealed some construction defects. The construction works were carried out on the wall over its length between the axes 6 and F, and consisted in making new openings for the gates. Therefore, it was necessary to remove part of the wall made of cellular concrete blocks (24 cm thick, var. 700, with lime-cement mortar no. 5 [Polish designation]). The reinforced concrete transom located 3 m above the floor was also removed. The steel structure was made to ensure stability and adequate load-bearing capacity of the wall. It consisted of columns and transoms taking over the loads previously affecting the reinforced concrete skeleton frame wall. In addition, there were made marginal reinforced concrete columns, as a support for steel beams. Figure 1 shows a fragment of the wall including the steel support structure.

After the removal of transoms, the buckling length of columns in the system plane did not change, however, the buckling length of columns from the system plane changed. The bearing capacity of existing columns was checked by adopting the correct buckling length. After making verification calculations, it was found that the dimensions of column cross-section and reinforcement were correct despite the change introduced.

Modernisation works revealed workmanship defects in columns in the places of structural nodes. After removing the wall casing and reinforced concrete transoms, two columns exposed places not filled with concrete. They were formed as a result of poor performance of columns. Figure 3 shows the columns in axes 6 and F with visible defects in concrete in the places of the previous column-transom structural node.

The discussed columns were compressed or locally compressed and affected by bending elements. Particularly unfavourable for the columns was the fact that, the element reducing the load capacity of the structure lacked concrete lagging in its compressive zone. It can be concluded that due to faulty workmanship, the columns had a noticeably lower load bearing capacity than anticipated in the building permit design. In total there are 18 columns in the wall, and there is a high probability that similar damage exists in others, too.
Figure 2. Fragment of the wall after modernisation works including the steel support structure and the reinforced concrete column, in which decrements in concrete were revealed due to reconstruction works.

Figure 3. View of the column in axis 6 (left) and axis F (left) with visible decrements in concrete, 3 m above the floor.
3. Results and discussion

The modernised columns should be repaired. Their load bearing capacity after repair cannot be lower than previously assumed. Strengthening works should be carried out on an unloaded element, as carrying out reinforcement on loaded columns affects their bearing capacity. However, it was allowed to perform repairs on loaded elements using the results contained in the work, since in the current situation it would be difficult to relieve the columns [10]. The authors of the publication [10] reported the results of experimental tests carried out on 12 models of columns reinforced with a reinforced concrete corset made of high performance concrete. The tests included both square and circular columns, grouped into pairs. One column was reinforced under load, the other without preload. It was assumed that the compressive strength of the concrete was two or three times higher than the concrete the column was made of, while the initial load on the structure ranged within 44-87% of the boundary load bearing capacity of the columns. The conducted tests showed that the bearing load capacity ratios of pre-loaded and unloaded column pairs fluctuated between 0.98-1.14. This leads to the conclusion that carrying out reinforcing works on a loaded column does not adversely affect its bearing capacity after reinforcement [11]. Thus, it has been proposed to use expansive cement types to repair and fill in decrements in concrete in columns. These cement types do not show shrinkage, but they increase their volume and adhere strongly to old concrete surfaces, i.e. 35 Portland cement (non-metallurgical) as well as sharp sand and gravel with grain diameter up to 10 mm. Alternatively, it is possible to use i.e. assembly mortar for filling decrements in concrete on dolomite aggregate 4/8 mm, with 28 days compression strength of not less than 40 MPa. The surface of contact points between old and new concrete should be properly prepared to reduce the possibility of shrinkage, and thus cracking. Although it does not pose a threat to compression elements, it is recommended to select the right repair product justified by the least possible shrinkage value. The columns in question were designed from B25 class concrete (according to contemporary designations). The increase in long-term compressive strength of concrete occurs over time of use of a given concrete element and it primarily depends on the water-cement ratio and the type of cement used, as well as proper care of concrete and subsequent use of the elements. Figure 4 shows the charts taking into account an increase in compressive strength of concrete over time depending on the assumed water-cement ratio for concretes with Portland cement. The tests were carried out on cubic samples with side dimensions of 150 mm stored in humid conditions. The relative increase in compressive strength was higher with higher water-cement ratios, and it was on average after 20 years approx. 2.3 times more than the 28-day strength. Whereas for Portland metallurgical cements, compressive strength increase was about 3.1 times [12].

![Figure 4. Increase in compressive strength of concrete over 20 years [12](image)]
In view of the fact that the compressive strength of concrete increases with its age, the class of repair concrete should be at least B35 (according to previous designations). According to currently valid designations, it is C30/37 (which would correspond to B37, as well as B35), although the columns were made of B25 concrete (which currently corresponds to C20/25). The rationale for such an assumption is the fact that with proper care of concrete and at the average service temperature of 20°C for the structure, the compressive strength of concrete \( f_{cm} \) aged 10 and more for \( R_w = 25 \text{ MPa} \) concrete might increase, which is in accordance with formula (1) taken from [11]:

\[
f_{cm}(t = 10 \text{ years}) \approx 1.25 \cdot 0.92 \cdot R_w = 1.25 \cdot 0.92 \cdot 25 = 28.27 \text{ MPa}
\]  

(1)

In the calculation given above, the value of coefficient dependent on an increase in the compressive strength of concrete over time \( f_{int}/f_{cm} = 1.25 \) for cement class N (i.e. with standard early compressive strength) was read from the chart in figure 5 [11].

![Figure 5. Increase in compressive strength of concrete over 0-50 years [11]](image)

The characteristic strength of concrete depends on its homogeneity and is subject to a certain standard deviation, the upper limit of which however does not exceed 0.2 \( f_{cm} \). Therefore, concrete class no lower than C30/37 should be used for repair with the characteristic compressive strength \( f_{ck} = 30 \text{ MPa} \). Although the increased compressive strength of concrete given above is an estimate [13, 14], it is based on direct assessment of the quality of concrete in columns, the state of which is considered very good. Thus, it can be accepted as a repair guideline.

### 4. Conclusions

Modernisations, reconstructions, extensions or changes in the way facilities are used often result in the necessity to adapt existing building elements to new desired requirements [15]. This is more difficult when it concerns structural elements. The columns described in the article were subjected to changes due to the extension of the facility. The discovered workmanship defects were revealed accidentally, the User of the building had no knowledge about them. Structural nodes are places particularly sensitive to design and implementation errors, therefore it is necessary to follow the executive regime and supervise the construction works carried out. The discussed columns have been strengthened and currently the hall is used for its intended purpose. However, the question remains whether the other column-transom structural nodes located in the same axis and executed in the same way are also defective and therefore their load capacity is reduced. There are numerous non-destructive approaches to assessing the technical condition of existing building elements, as the occurrence and significance of voids, cavities or cracks in reinforced concrete structures. These include electromagnetic, ultrasound, acoustic emission and eddy current scanning methods [16]. Each would be suitable for examining the remaining construction nodes in the discussed wall, however, since there is no access to the node from the outside – where defects in columns described in the article have appeared – the User performs visual monitoring of nodes at risk.
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