LABORATORY TESTS OF OLD REINFORCED CONCRETE PRECAST BRIDGE BEAMS

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Abstract
Every year all over the world many concrete structures are being disassembled for various reasons. The idea of reuse of whole structural members from disassembled or renovated structures is not a new problem but still it is not well recognized. In Department of Structural Engineering of Silesian University of Technology a wide research program was undertaken concerning acquisition and reuse of steel members [1], RC and PC members [2], [3], [4] and timber ones [5], [6]. Especially reinforced concrete precast members seems to be appropriate to be subjected the procedure of reuse [7]. The paper presents the tests and investigations focused on precast elements typical for bridge structures. These are reinforced concrete I-shaped beams, obtained from the demolition of road viaduct on the route from Gliwice to Mikolów. The elements have been in service for more than 40 years. The laboratory tests consisted of the mechanical part and chemical part. The overarching goal of conducted analyses is to work out the method of usefulness evaluation of structural elements and to provide the guidelines for required tests preceding their reuse.

Keywords: Bridge beams; Laboratory testing; Precast elements; Reuse; Sustainable construction.

1. INTRODUCTION

The idea of reuse of whole structural elements has become more and more popular all over the world. For both environmental and economic reasons the necessity of such actions has arisen since nowadays many concrete structures are being disassembled. It seems to be particularly significant the common reuse of precast elements, RC and PC alike. Such elements are relatively easy to dismantle and to take away for next use. The procedure of reuse of whole structural elements will also help to limit the landfill disposal of materials that can be reused, thereby to reduce contamination of the environment which is essential for the
Sustainable development of the construction industry including the environmental aspects. Sustainable development in the construction industry should cover the entire life cycle of the building, from design through whole period of utilization until its demolition. In each of these periods, the impact of buildings on the environment should be minimized (by minimizing the energy demand) and the use of building materials should be optimized (including the possibility of their future reuse).

In Poland, the precast structural systems have been in common use since early 1960s, therefore, the great number of structures 30 to 50 years old have to be disassembled nowadays, mainly due to changes in functional demands [4]. Unfortunately, there are no practical guidelines what procedure of testing and assessment should be used to qualify and categorize the members for reuse. It often happens that these elements are fully useful from technical point of view, but for functional reasons they ceased to fulfil their original function [3]. This was the main reason to initiate the research program with general target to prepare such guidelines for the most popular precast elements used in the past [7].

2. DESCRIPTION OF LABORATORY TESTS

2.1. Object of the researches and preparation of elements for testing

The subject of the researches were three I-shaped reinforced concrete beams on the basalt aggregate, with the total cross-sectional dimensions 0.36 m by 0.80 m and a length of 6.0 m (two elements) and 7.0 m (one element). The beams were obtained from the demolition of the road viaduct on the route from Gliwice to Mikołów, after a few decades of operation. During the inspection of the beams, there were found some minor damages to the concrete cover on the front surfaces (Fig. 1). They probably formed during the dismantling works and did not affect the preparation of the beams for research.

Preparation of beams for laboratory testing required only cleaning and painting white the side surfaces for the observation and recording of cracks. Front view and cross-section of the beam are shown in Figure 2.

2.2. Carbonation of concrete test

Alkalinity tests of concrete were made for investigated reinforced concrete beams. These tests were the basis for determining the approximate thickness of the carbonated concrete layer. Alkalinity of concrete evaluation (pH value) is very important to assess the degree of reinforcing steel protection against corrosion. It is assumed that in reinforced concrete structures the reinforcing steel is enough protected against corrosion when concrete keeps a sufficiently high pH value (>10).

In this case, the pH of concrete was determined with the use of phenolphthalein and indicator paper to a depth of approximately 20 mm. As a result of using a phenolphthalein test, it was found that the thickness of the concrete layer completely carbonated (pH ≤ 8) is 2 to 3 mm. Such a thickness of completely carbonated concrete with dense structure does not threaten the reinforcing steel at the correct depth of concrete cover. At a depth of about 10 mm concrete becomes
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strongly alkaline with a pH of 11.5 to 12, which means that the steel is not threatened by corrosion even in the presence of chlorides \([\text{Cl}^-]\), where in such a situation it would be required that the concrete had alkaline pH > 11. Summing up the carbonation test it can be concluded that concrete in these particular beams presents a vestigial degree of carbonation and provides sufficient protection against corrosion of reinforcing bars.

2.3. Inventory of reinforcement

Before the testing, an inventory of reinforcement with the use of non-destructive method was done. As a result of the investigation, it was noted the occurrence of the four reinforcing bars of diameter 12 mm at the upper and lower surfaces of the beams. Using the reinforcement detector, the reinforcing bars of diameter 12 mm were also found in the folds of the lateral surface of the beam. Average concrete cover of the bars was approximately 35 mm. The diameter of bars was confirmed by performing a local outcrop. On the basis of bars ribbing, the steel grade as A-IIIN was determined. Similarly the transverse reinforcement was defined. This reinforcement is made of ribbed bars of diameter 6 mm (steel grade A-III) at a spacing of about 0.2 m on the entire length of the beam.

2.4. Quality and homogeneity of concrete in sclerometer tests

The Schmidt sclerometer of N type was used for the measurements. The actual number of repulse (checked immediately prior to the measurements on the Schmidt anvil of hardness HB = 500) was equal of \(L_k = 79\) – the same as the nominal value. Researches were carried out at different positions of sclerometer, therefore the calculation of correction factors were introduced. Because of the age of concrete – around 40 years (which is more than 1000 days) the reduction factor 0.6 was implemented in calculations.

Detailed results and research logs of Schmidt sclerometer tests are not included in this paper. Only the final results of the estimated average strength and minimum strength (taking into account the age of the concrete) and criteria for compliance with the relevant classes of concrete were provided.

Classification of the tested concrete to the appropriate strength classes was done with the use of the compliance criteria given in section 8 and Annex B of the PN-EN 206-1:2003 standard [8] and Annex A2: 2006 to the same standard. According to these criteria, the concrete can be classified to the appropriate strength class when inequalities (1) and (2) are fulfilled:

\[
\begin{align*}
  f_{cm} &\geq f_{ck} + 4 \quad (1) \\
  f_{ci} &\geq f_{ck} - 4 \quad (2)
\end{align*}
\]

where:

- \(f_{cm}\) – the average of the “n” results of concrete compressive strength,
- \(f_{ci}\) – any single test result on the compressive strength of concrete,
- \(f_{ck}\) – characteristic concrete compressive strength.

Strength of concrete in the structure was calculated using the hypothetical regression function specified in ITB Instruction [9]. For the strength of cylindrical samples, this function takes the form:

\[
\overline{R_{\phi16}} = \overline{L} \cdot \left[ 0.0356 \cdot \overline{L} \cdot \left( \nu_L^2 + 1 \right) - 0.795 + 6.4 \right] \quad (3)
\]

where:

- \(\overline{R_{\phi16}}\) – average strength of concrete at the age of from 28 to 100 days.

Compliance criteria were developed according to PN-EN 206-1 standard [8], assuming:
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The correspondence with the concrete strength class C30/37 (old class B37) according to [8] was confirmed (6) and (7). Assuming \( f_{ck} = 30 \text{MPa} \) and substituting to the formulas (1) and (2):

\[
\bar{R}_{d\phi} = f_{cm} = 38.06 \quad (4) \\
R_{\min d\phi} = f_{\phi} = 32.65 \quad (5)
\]

38.06 MPa \( \geq 30 + 4 = 34 \) MPa – inequality satisfied, (6)

32.65 MPa \( \geq 30 - 4 = 26 \) MPa – inequality satisfied. (7)

Based on the sclerometer tests and the assessment of the compliance criteria of the existing concrete in the tested beams, it was found that the concrete meets the requirements of the concrete class C30/37 (old strength class B37).

2.5. Laboratory stand and description of the testing

As it was mentioned above, two beams with a length of 6.0 m and one with a length of 7.0 m were used for testing. Therefore, the distance between supports was respectively 5.70 m and 6.70 m.

Scheme of the testing as well as the laboratory stand are shown in Fig. 4 and Fig. 5 respectively. Force, deflection and concrete deformation on the lower, upper and side surface of the beam were measured during the short-term strength tests. On a selected reinforcing bar of the main reinforcement, steel strain was also measured. Electro-resistive extensometers were glued on the reinforcing steel and on concrete in the middle of the beam span.

Deflection measurement was carried out for the bottom surface of the beam. Inductive sensors were distributed along the beam length, in supports place, in place of applied forces and in the middle of the beam span (Fig. 6). Measurement of deflections during the testing does not take into account the deflection caused by the beam deadweight, which was less than 1mm.

3. SUMMARY OF LABORATORY TESTS

3.1. Results of testing

Destructive force and size of the deflection were measured during the testing. Due to the different lengths of the tested beams, and therefore the different lengths between the supports, Fig. 7 shows the graph dependence of the bending moment and deflection of beams. The size of the bending moment shown in the graph is determined on the basis of the driven force and it does not include the size of the bending moment of the beam deadweight. The size of the bending moment from the beam deadweight, for 6.0m long beams equals 21.8 kNm, and for 7.0 m long beam equals 30.2 kNm. These values should be added to the real size of the bending moment obtained in testing. Appearance of perpendicular cracks was catalogued during the testing. Oblique cracks did not occur. The first cracks with a very small (immeasurable) wide opening appeared already at the value of bending moment (including the weight of the beam) equalled 145 kNm for beams with supports spacing of 5.7 m and 123 kNm for beam with supports spacing of 6.7 m.

3.2. Verifying calculations

In order to verify and compare laboratory tests to the requirements of load bearing capacity, verifying calculations according to PN-B-03264/2002 standard [10] were carried out.

For the calculations it was assumed a real cross section of I-beam beam of concrete C30/37, reinforced with the use of steel A-IIIN and rods diameter \( \varnothing = 12 \text{mm} \) arranged as shown in Fig. 9. Concrete cover equaled 35 mm and was assumed according to the measurements.
As a result of calculations, the load bearing capacity of the beam cross-section (excluding the crack width) was determined to $M_{Rd} = 251.54$ kNm, which is smaller than the real load bearing capacity obtained in destructive tests.

In case of taking into account the allowable cracks aperture of 0.3 mm (which is unacceptable for bridge beams, but acceptable in other structural elements) for the method of loading and static scheme adopted in tests, the maximum bending moment corresponding to the cracking of 0.3 mm was equal 175 kNm. During the testing, the cracks width of 0.3 mm was observed when the size of the bending moment was equal 240 kNm, which is much greater than the value obtained in calculations.
4. CONCLUSIONS

4.1. Conclusion of testing

The necessity of rebuilding of the traffic system caused that some reinforced concrete bridge beams had to be dismantled. Instead of crushing the beams, it was possible to gain three of them for laboratory tests. As a result of non-destructive testing and small local exposures reaching the reinforcement, it was possible to determine the strength class of the concrete as well as the parameters of the reinforcing steel. In second part of the researches some destructive tests were done. Due to these tests, the load bearing capacity was defined and the value of the bending moment during cracks occurrence was observed. The laboratory tests of full-scale beams confirmed that the technical condition of the beams was good. Despite of decades of usage, the bridge beams are able to fulfill their original function or they can be successfully reused in other structure.

4.2. Proposed method of cataloguing and sharing of information

At present day, in accordance with the Polish law, after obtaining a demolition permit the property developer has no obligation or motivation to recover materials or structural elements. Such legal status means that in most cases the materials from the demolition are disposed to the landfills, and they are processed only in a few cases. On a larger scale, recycling and reuse of whole structural members, basically does not exist in Poland. This is due to both the lack of legal conditions favourable to this practise as well as the ignorance of potential property developer (both those who perform the demolition works and those who could use these materials). One of the factors that could have a positive impact on the more common reuse of whole structural elements is to change the legal requirements or at least to create several legal facilitates in recycled elements certification, so it was not necessary to perform expertise in each case. Another equally important factor is to provide information about the possible acquisition of structural elements. To facilitate the exchange of information between the property developer carrying out demolition and a potential buyer interested in reusing of elements from demolition at another structure, it should be prepared a widely available special database, where at the level of the province or country, there will be possibility to enter information about the potential to acquire whole structural members ready for reuse, or available in the near future. With this database, it also should be possible to include information about the demand for specific types of structural elements (material, cross section, dimensions etc.).

Such a database should allow sharing at least some basic technical information allowing the unique identification of structural members such as:
- name of the elements,
- the material they are made of,
- basic dimensions,
- the number of available units,
- material data and strength properties (if known),
- general technical condition,
- location of (a possible date of acquiring), etc.,
- photographs.

In a broader approach, it is also possible to include more detailed information about the technical data of the elements for reuse, such as:
- regarding design documentation of the elements or objects,
- the conditions of use,
- the history of repairs, modernization, maintenance operations,
- available documentation of the elements or objects,
- inventory documentation of the elements or objects,
- the date of dismantling works and the storage conditions,
- about technical investigations or lack of the thereof,
- the proposal to use, etc.

Nowadays, reporting of demolition of buildings is done in relevant Departments of Architecture and Building Construction of authorized offices of municipalities, cities and communes. The permission for the demolition of the buildings is issued on the basis of documents which, among others, should include the demolition project. At this stage it could be possible to gather and share information about the planned demolition and thus possible to obtain the elements of the structures.
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