Comparative solutions for the rehabilitation of damaged structural elements of reinforced concrete

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Abstract: In the context of an old locative fund, the structural rehabilitation is a high priority current issue. The rehabilitation solutions designed must ensure the restoration of the loading capacity of the damaged structural elements, using simple technology, easily performed and economically efficient.
In the present work there are, technically and economically, presented and analyzed two practical rehabilitation solutions, by establishing the level of recovery of the loading capacity of short consoles of reinforced concrete of the structural pillars that have acquired certain degradation on their use.

Key-Words: - Short console, Reinforced concrete, Inflexible metal box, Reinforced concrete cover.

1. Introduction

1.1 General aspects

The study on the resistance capacity of reinforced concrete elements, which have acquired a certain state of degradation as a result of destructive actions, is a concern for many experts in the field.

This because most of the industrial structures of reinforced concrete (especially in our country) are old and the costs of demolition and replacement with the same or different type of structure are large, often irregular or more exceeding the financial possibilities of the units.

The experimental study includes two practical solutions to rehabilitate the damaged short consoles by placing a reinforced concrete cover on them or covering them in rigid metal boxes.

1.2 Description of initial experimental elements

The short consoles made for the experimental study are made of reinforced concrete with longitudinal reinforcement under the form of bars and the transversal one under the form of stirrup.

The preparing the concrete the additive fluidizing type BV 3, manufactured in Germany was used.

For determining the geometric dimensions and of the area of transversal and longitudinal fixture an operating load of 20 tf was taken on the console.
The characteristic strength and of computation for concrete and fixture used in the dimension computation are as follows:

- **For concrete class Bc 20 (C16/20)**
  
  \[
  R_c = 12.5 \text{ N/mm}^2 \\
  \frac{R_c}{1.75} = 21.88 \text{ N/mm}^2 \\
  f_{ck} = 16 \text{ N/mm}^2 \\
  f_{cd} = \frac{f_{ck}}{1.5} = 10.67 \text{ N/mm}^2
  \]

- **For fixture**
  
  OB 37 (transversal fixture stirrup)
  
  \[
  R_a = 210 \text{ N/mm}^2 \\
  \frac{R_a}{1.35} = 283.5 \text{ N/mm}^2
  \]

  PC 52 (longitudinal fixture)
  
  \[
  R_a = 300 \text{ N/mm}^2 \\
  \frac{R_a}{1.35} = 405 \text{ N/mm}^2
  \]

  The geometrical dimensions of the consoles were established based on the general structure rules, including the console carried out in the category of short consoles [1]:

  \[
  0.4h_c \leq a_c \leq h_c 
  \]

  The sizing of the longitudinal fixture was made at maximum moment in the section of fixing the console in the pole:

  \[
  M_{max} = P.a_c 
  \]

  And for the transversal fixture the calculations and the specific conditions of constructing structure have been applied.

  The same result was reached also after sizing the longitudinal fixture like the Eurocode 2 [1], through "the process of models of bars".

  Having determined the effective area of longitudinal fixture and the geometric dimensions of the console, it was determined the width of compressed diagonal "d" with the formula (3), obtaining for this value, \(d = 76\) mm. By the value obtained it was verified the condition of limiting the compression efforts within the compressed diagonal with the formula (4). Following the calculations performed, it resulted that this condition is fulfilled:

  \[
  \sigma = 10.56 \text{ N/mm}^2 < f'_{cd} = 10.67 \text{ N/mm}^2 \\
  \frac{d}{\omega} = \sqrt{(\omega \cdot h)^2 + a^2} \\
  \sigma < f'_{cd}
  \]

  The form, geometrical dimensions, and fixing the experimental elements are presented in Fig.1.

2. Behaviour of experimental consoles on vertical loads

**Working stage no. 1.**

Testing all the experimental models, of which 3 elements (CS 1-1; CS 1-2; CS 1-3) up to breakage and 6 elements (CS 2-1; CS 2-2; CS 2-3; CS 3-1; CS 3-2; CS 3-3) up to a load of 30 tf;

**Working stage no. 2.**

Reinforcement of the 6 tested elements up to 30 tf in the first stage, by replacing to a reinforced concrete cover (CS 2-1; CS 2-2; CS 2-3) respectively into a rigid metal box (CS 3-1; CS 3-2; CS 3-3)

**Working stage no. 3.**

Testing up to breakage of the experimental models reinforced in the stage no. 2.

After the preliminary preparation of the testing stand, applied to the console, all experimental elements have been subjected to the vertical load.

An overview of an experimental element ready for testing is shown in Fig.2.
Testing the experimental models was conducted in the laboratory of reinforced and pre-combined concrete and Building of the Faculty of Technical University of Cluj-Napoca.

2.1 Behaviour at vertical loads tested at breakage

For the consoles CS 1-1, CS 1-2, CS 1-3 (tested on breakage), their yield occurred at a load of 48 tf for the consoles CS 1-2, CS 1-3 and 50 tf for the console CS 1-1.

The table of generating and developing the cracks (Fig.3) shows that they are of two to three, which then ramified into new cracks of a lower length and opening.

![Fig.3 Statement on cracks](image)

The first crack ◊ appears at a vertical load of 15 tf for CS 1-1 and of 20 tf for the consoles CS 1-2; CS 1-3, in the area of fixing the console into the pole.

The second ◌ and the third crack ◍ are observed at a load value of 30 tf, inclined forming an angle of $45^\circ$, set out under/or next to the supporting metal board and reaching the area of the lower corner of connection between the console and the pole.

The yield of the consoles was generated by the strong opening of the cracks ◊, ◌, ◍, opening and becoming frequent the ramifications formed from the existing cracks crushed the concrete next to the lower corner for the connection of the console with the pole.

2.2 Behaviour at vertical loads tested at 30 tf

For the consoles carried out in the second series (CS 2-1; CS 2-2; CS2-3) and the third casting (CS 3-1; CS 3-2; CS 3-3), the maximum load was limited to 30 tf, being noticed also in this testing method, the emergence sideways of the consoles, of one, two or three cracks.

The table on the formation, development and opening of the cracks on the consoles, is presented in Fig.4.

![Fig.4 Statement on cracks](image)

After discharge of tubes it was noticed for all the tested consoles the diminishing of all the opening of cracks in some areas being completely closed.

Following the diagram of opening cracks, the following aspects are ascertained:

- the maximum opening of cracks ($\alpha_{f,\text{max}}$) reaches the value of 0,2 mm, at the value of the vertical opening of 20 tf, except for the consoles CS 3-2 (where $\alpha_{f,\text{max}} = 0,38$ mm for $P = 20$ tf;
- up to the values of the vertical load of 35 tf there are no accentuated increases (from one degree to another) of the maximum opening of the cracks;
- for the consoles tested up to breakage, the maximum opening of the cracks ($\alpha_{f,\text{max}}$), reaches the value of 3,67 mm.

2.3 Behaviour on vertical loads of the rehabilitated consoles by placing a reinforced concrete cover

The experimental models, for which the testing load was limited to 30 tf, were subsequently reinforced in order to restore the strength capacity. Three of them, respectively CS 3-1; CS 3-2; CS 3-3, have been reinforced by covering.

The cover of reinforced concrete covers both the console and the portion of the pole of which this is attached.

Of the condition to assure the minimum thickness of the concrete covering layer of the fittings and of favourable
conditions of adhesion between them and the concrete, it resulted for the cover achieved the thickness of 8 cm.

For reinforcement concrete from class Bc 20 (C16/20) was used, having the compression of 7 cm, prepared with river aggregates (0-16) mm, cement type II AM/32, 5R and additive type BV 3 German manufacturing.

To achieve the fitting carcass the same brand of steel was used and the same fittings diameters as for the initial elements, Fig. 5.

Fig.5 Experimental elements – view, sections

After exceeding a period of 28 days of reinforcement, the experimental elements have been tested up to breakage, using the same device as for the initial elements.

The consoles breakage occurred at a vertical load of 69 tf for CS 3-2 and of 70 tf CS for 3-1, CS 3-3, by opening and ramification of major cracks and crushing the concrete of the supporting pole of the console from the concrete poles supporting the console.

Following the table of the emergence and development of cracks, it is noticed sideways the consoles, a number of 4 (four) up to 5 (five) major cracks, Fig. 6.

Fig.6 Statement on console cracks after reinforcement

### 2.4 Behaviour on vertical loads of the rehabilitated consoles by using rigid metal coverings

The consolidation consists of covering the experimental consoles tested up to 30 tf in a rigid metal cover, carried out in accordance with technical requirements in the industry. [2], [3], [4]

An overview of the experimental element prepared for testing is shown in Fig.7 and details of design in Fig.8.

Fig.7 Overview of the experimental element using a metal box

Fig.8 Design elements of the experimental model using the rigid metal covering
a – sideways view   b – section
The remaining free space between the interior walls of the metal box and lateral surfaces of the reinforced element was filled with cement mortar by injection.

The experimental plant is identical with the first stage of testing the samples, since the weight of the elements after strengthening using this method, was not changed.

The yielding of the consolidated elements using metal, occurred at the value of the vertical load of 70 tf, for CS 2-1, 72 tf for CS 2-2 şi 74 tf for CS 2-3, by:

- wide opening of the crack Ω in the connection area of the horizontal side of the console with the pole, (Fig.9);
- opening, growing longer and ramifying of crack no. Ω (Fig.9);
- increased distortion of the upper side of the back wall of the metal box (back side of the pole) and yielding in this area the welding line.

![Fig.9 Statement on cracks on the horizontal side of the consoles](image)

**a** – console CS 2-1; **b** – console CS 2-2; **c** – console CS 2-3

### 3. Comparative analysis of the proposed reinforcing methods

The main objective of the study was to evaluate the restorative capacity of the loading capacity of the restored consoles using the two variants and the mechanism of their yield, under vertical loads.

The results obtained from the experimental study conducted on the unconsolidated and consolidated elements using the method "rigid cover of reinforced concrete", tested up to breakage, revealed the following aspects:

- the number of major cracks occurred and developed on the sideways of the consoles is higher (4 – 5 cracks/console side) for the reinforced elements as compared to the non-consolidated elements (2 – 3 cracks/ console side);
- medium opening of the major cracks is much more slim for the consolidated elements as compared to that of the non-consolidated, both for the common loading degrees and on reaching the breakage force;
- the first crack appears in all cases in the area connecting the console – pole;
- the sequence of occurring the cracks is on the area of console-pole settling, towards its end;
- for the non-reinforced elements, the first crack is developed on about all the console height, being joined in front of the lower corner of the console-pole connection, with the leaning crack or cracks.

The aspects presented on the mechanism of yielding of consoles, highlights the role played by the concrete cover in the development of cross-diagonal distortions of the compressed diagonal.

This is due to the effect of confinement that this produces on the damaged item, the newly created concrete cover, preventing the opening of cracks while ensuring an increase of the ductility of the rehabilitated console.

In case of the metal method of consolidation, it could not be noticed on the sideways of the console, the cracks occurred in the first stage of testing or of forming and development of new cracks. But the statement on the occurrence and development of cracks on the top side of the console (not covered by the metal cover), confirms in this case as well the tri-axial compression state created by the metal cover on the old concrete core.

Following the distribution of capable load (Fig.10) on the experimental non-consolidated and consolidated (both)
consoles, tested up to breakage, results the following:

- **capable load**, determined by series of elements has similar values, between (48 – 50) tf for initial consoles, between (69 – 70) tf for the reinforced ones using the method „reinforced concrete cover”, respectively between (70 – 74) tf for the consoles covered by rigid metal boxes”;
- **reinforcing solutions**, using the methods „rigid cover of reinforced concrete” or „metal”, approached within the present work, lead to very close values of the **capable load**;
- **the degree of rugosity of the concrete surface** (before the consolidation), does not exercises a significant influence on the strength capacity of the consolidated element.

![Fig.10 Capable load on consoles](image)

### 4. Conclusions

Regarding the restoration level of the loading capacity (noted with „\( n_{RCP} \)”) of the damaged consoles damaged taken into account using the two methods, have resulted the following values:

- **the reinforcing method „rigid cover of reinforced concrete”**

\[
\begin{align*}
n_{RCP} &= \frac{\text{Capable load reinforced elements}}{\text{Capable load non - reinforced elements}} \\
\end{align*}
\]

\[
\begin{align*}
n_{RCP} &= \frac{69.7 \text{ tf}}{49.3 \text{ tf}} \approx 1.41 \\
\end{align*}
\]

- **the reinforcing method „rigid metal box”**

\[
\begin{align*}
n_{RCP} &= \frac{\text{Capable load reinforced elements}}{\text{Capable load non - reinforced elements}} \\
\end{align*}
\]

\[
\begin{align*}
n_{RCP} &= \frac{72 \text{ tf}}{49.3 \text{ tf}} \approx 1.46 \\
\end{align*}
\]

The values obtained indicate that the levels of recovery for the loading capacity for the two types of consolidation are very close and may be considered practically equal.

Following the economic calculation, it results that the type of consolidation through ”rigid metal box” leads to a cost price / console higher than approx 40% than the type ”rigid reinforced concrete cover”.

The comparative analysis of results indicates that the type of consolidation ”rigid reinforced concrete cover”, is more economical than the ”rigid metal box” and provides the same level of recovery as the loading capacity of the latter.

The high level of recovery of the loading capacity, the ductile yield character of the elements recommends the consolidation methods approached within the paper as being competitive, both in technical-economic and technological.

### References:


