EXPERIMENTAL STUDY ON THE STRENGTHENING PROCEDURES FOR REINFORCED CONCRETE COLUMNS

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Abstract: The paper to be presented here contains the results of an experimental research program focused on the strengthening of the reinforced concrete columns. The aim was to clarify different aspects regarding the ductility of these types of elements and to identify the type of interaction between the strengthening in bending and the strengthening by confinement.
There were performed several test, in various configurations. The goal was to be able to establish an efficient retrofitting method for the concrete columns and to make a classification of different test procedures based on their influence in increasing the columns' ductility and load bearing capacity.
Carbon fiber was used for confinement; for the lateral retrofitting in bending there were used steel rebars.
One important aspect of the study was that the retrofitting systems were divided into their main components, each configuration being individually tested. There were studied the contributions brought up by the different parts of the strengthening systems.

Key-Words: strengthening, confinement, bending, RC columns, experimental tests, FRP, ductility.

1 Introduction

The FRP composite materials are widely used to retrofit structural elements such as beams, columns or slabs. In the European [1] or American [2] codes, each retrofitting procedure is presented individually, not taking into consideration the superposition of two or more retrofitting procedures. The main interest was to develop a retrofit method for reinforced concrete columns that will allow the use of additional NSM steel reinforcement as in [3] [4] and confinement with FRP wrapping as presented in [5]. Consequently, a testing program was proposed in which all the different parts of the retrofitting system were applied on the reinforced concrete columns in certain order, and tested one by one.

2 Finite Element Modeling

The finite element modeling was done using the ABAQUS and the AxisVM programs.

In the Abaqus model, we tried to simulate the theoretical behavior of the specimens. A T-shape model was subjected to both vertical and lateral loading. In figure 1 are presented the principal stresses, in the initial unstrengthened model. The AxisVM program was used in order to have a comparison of the static efforts in the element.

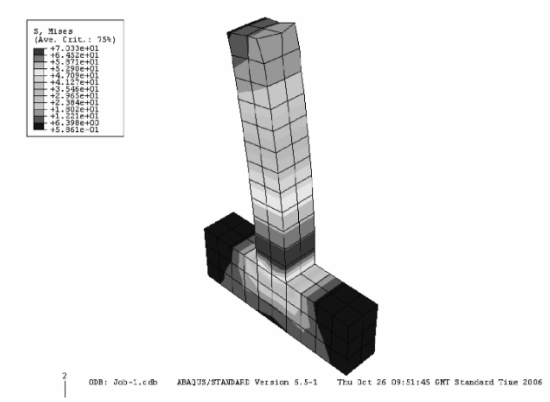

Fig. 1 Principal stresses in Abaqus

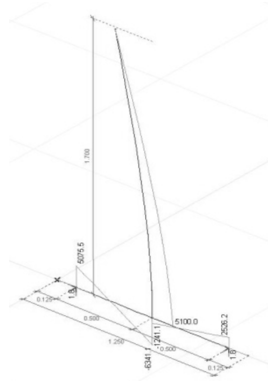

Fig. 2 Bending moments in AxisVM

3 Experimental Study

In the following, six experimental tests are presented, completing the series presented in [6]. Monotonic and cyclic tests were done for the same type of strengthening step, using the test set-up presented in figure 5. A similar approach can be found in [3] [7].
The reinforcing lay-out is presented in figures 3 and 4.

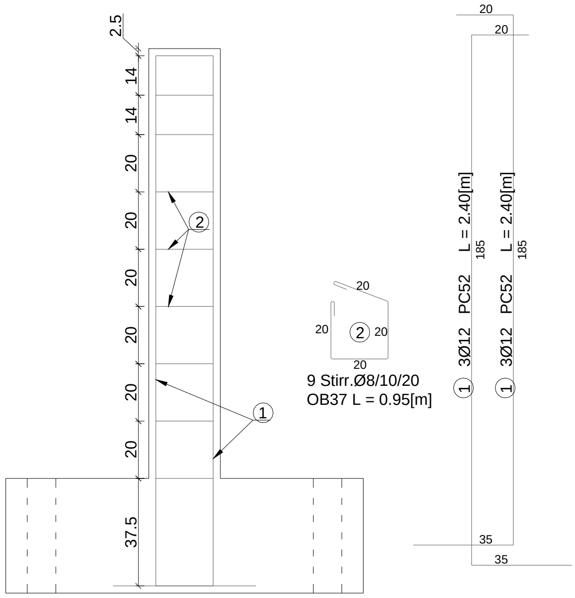

Fig. 3 Reinforcing lay-out of the specimens

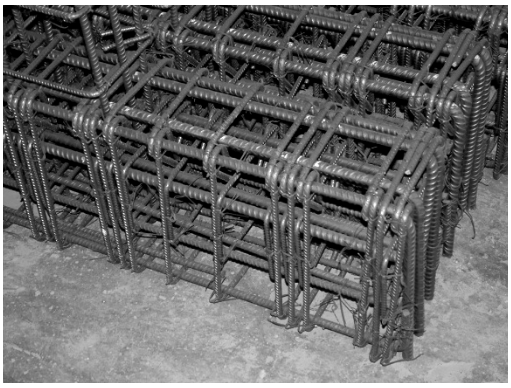

Fig. 4 Effective reinforcement of the specimens

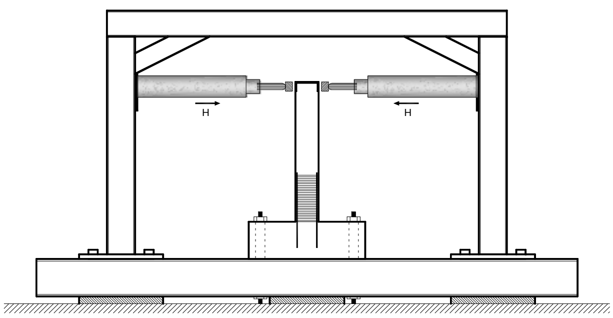

Fig. 5 Test set-up

3.1 Strengthening procedure

The reference specimens were tested in their initial condition, without any interventions.

For the others, vertical silts were cut into the cover concrete, about 2cm deep, as it can be seen in figure 6. After that, holes were drilled in the column's foundation for the chemical anchorage of the vertical steel bars.

Fig. 6 Vertical silts and anchorage holes

The additional steel bars were then modeled in order to fit the shape of the holes. After that, they were placed into the holes and were chemically anchored.

Fig. 7 Modeling and anchoring of the bars

There followed the filling of the vertical silts using an epoxy mortar, as it can be seen in figure 8. An important aspect was the complete filling of the silts, especially between the steels bar and the concrete column.

Fig. 8 Filling the vertical silts

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3.2 Monotonic tests

Three monotonic tests are presented here.

Specimen C1M is the reference specimen, without any strengthening system applied. There followed:

C3M-BM-AF - Monotonic test using Bars of Metal Anchored into the Foundation

C4M-BM+CW - Monotonic test using Bars of Metal Anchored into the foundation and a Carbon fabric, Wrapped around the base of the column.

The strengthening system was applied partially in each case. The first specimen was tested without any retrofitting system applied, serving as reference specimen. The next one, C3M-BM-AF, had two steel bars chemically anchored into the foundation and near surface mounted in grooves cut into the cover concrete. The C4M-BM+CW specimen had both the steel bars and the confining wrap applied.

3.2.1 C1M

This specimen was tested with no strengthening system applied. We did not use any axial force in order to emphasize better the bending effect.

The maximum lateral load applied was about 3500daN, which corresponded to a maximum top displacement of 86mm.

In figure 9 is presented the test layout and a failure detail. Figure 10 presents the load – displacement diagram for the top measuring point.

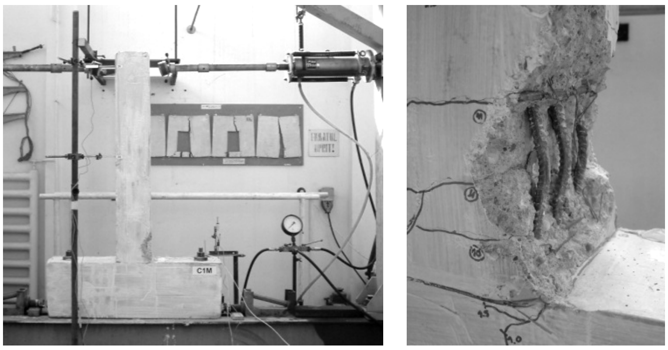

Fig. 9 Test set-up and failure detail for C1M

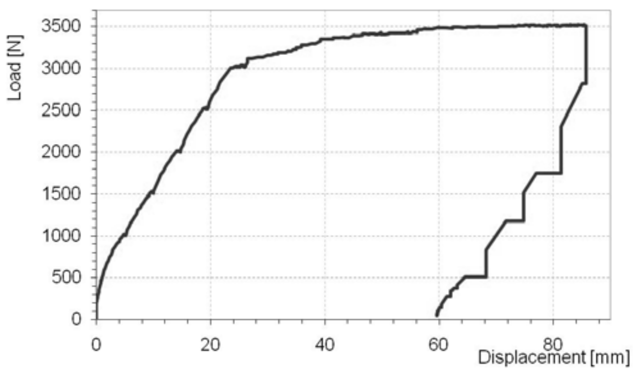

Fig. 10 Load-displacement diagram for C1M

3.2.2 C3M-BM-AF

In this phase of the program, we strengthened the column in bending using two metallic bars, chemically anchored into the foundation. These additional bars were applied in grooves up to 75cm height from the base of the column (half of the column height) and anchored about 18cm into the foundation. The testing was done monotonically. Figure 11 is presenting the test lay-out and a failure detail.

At the failure point, the lateral bars debonded off the column. This meant that they did not reach their design capacity.

Figure 12 presents the load-displacement diagram for the C3M-BM-AF element.

Fig. 11 Test set-up and failure detail for C3M-BM-AF

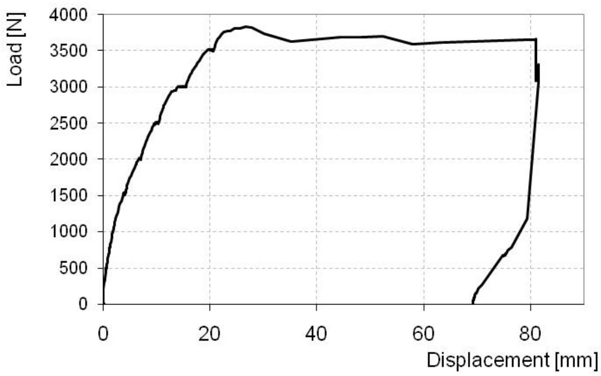

Fig. 12 Load-displacement diagram for C3M-BM-AF

3.2.3 C4M-BM+CW

At this point of the testing program, we superposed the two methods of strengthening used in the above presented tests, in order to achieve the final retrofitting procedure. The testing was done monotonically.

Figure 13 presents the tested specimen. The maximum measured lateral displacement was about 125mm over a total height of 1500mm for the column.

Figure 14 shows the load-displacement diagram for the C4M-BM+CW specimen.

Fig. 13 Test set-up and failure detail for C4M-BM+CW

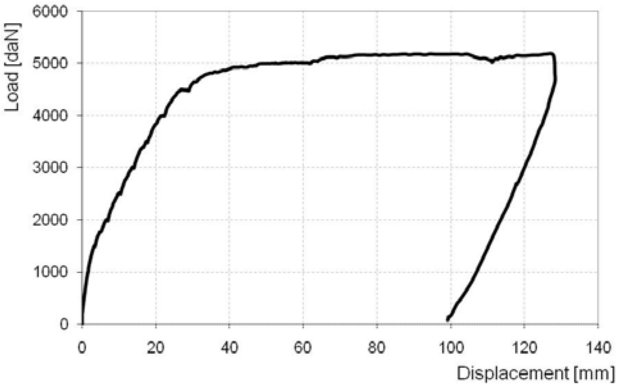

Fig. 14 Load-displacement diagram for C4M-BM+CW

3.3 Cyclic tests

Three cyclic tests are presented in the following.

Specimen C1C is the reference specimen, with no strengthening system applied. There followed:

C3C-BM-AF - Cyclic test using Bars of Metal Anchored into the Foundation

C4C-BM+CW - Cyclic test using Bars of Metal Anchored into the foundation and a Carbon fabric, Wrapped around the base of the column.

The strengthening system was applied partially in each case, similarly to the monotonically tested ones presented above.

For all the tested specimens, both monotonically and cyclically, the concrete used had an $f_{ck,150}$ = 27.5N/mm^2. The internal and external steel rebars used were tested in tension and they had an f_{yk} = 500 N/mm^2.

3.3.1 C1C

The column was tested in identical conditions to the C1M, but the loading was applied cyclic. Figure 15 presents the test set-up and a failure detail. In Figure 16 is shown the envelope curve for the load displacement diagrams.

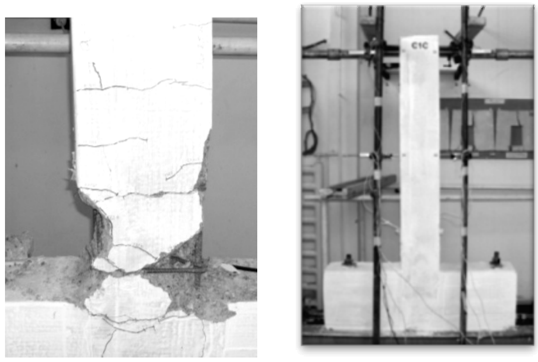

Fig. 15 Test set-up and failure detail for C1C

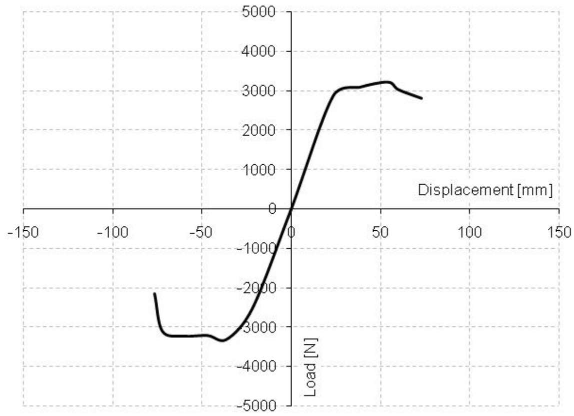

Fig. 16 Load-displacement diagram for C1C

3.3.2 C3C-BM-AF

The column was strengthened in bending using two metallic bars, chemically anchored into the foundation.

The bars were near surface mounted on both sides of the column, into grooves cut in the concrete cover of the initial bars. The height of the vertical silts was 75cm. The bottom anchorage depth was about 18cm.

The testing was done cyclic.

Figure 17 presents the test set-up and a failure detail. In Figure 18 is shown the envelope curve for the load displacement diagrams.

Fig. 17 Test set-up and failure detail for C3C-BM-AF

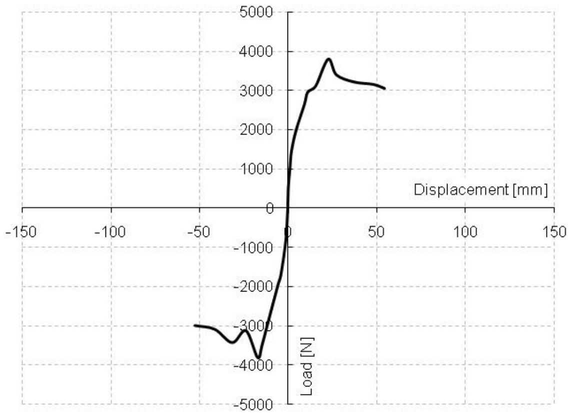

Fig. 18 Load-displacement diagram for C3C-BM-AF

3.3.3 C4C-BM+CW

This experimental test is the pair of the C4M-BM+CW test presented above. The strengthening was done also in bending and by confinement, as previously shown, but the testing was done cyclic. Figure 19 presents the test set-up and a cracking detail for the base of the column, in the final cycle. Figure 20 presents the envelope curve for the cyclic test.

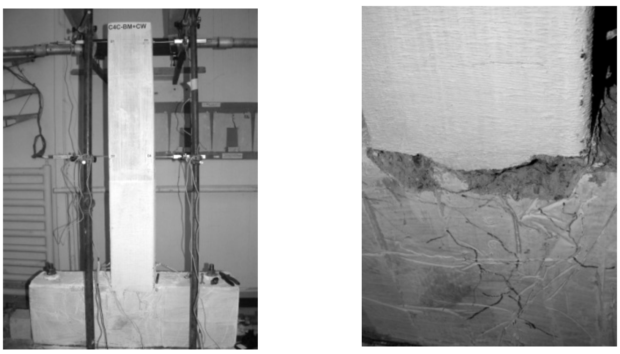

Fig. 19 Test set-up and failure detail for C4C-BM+CW

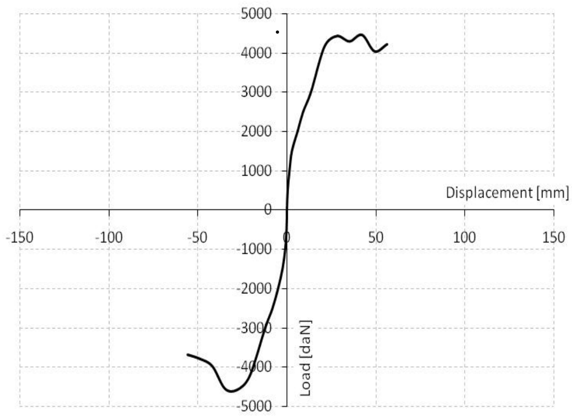

Fig. 20 Load-displacement diagram for C4C-BM+CW

Conclusions

In figure 21, there are presented the load-displacement diagrams for the monotonically tested elements. There can be observed the similarities and the differences regarding the maximum displacement and the initial rigidity of the specimens.

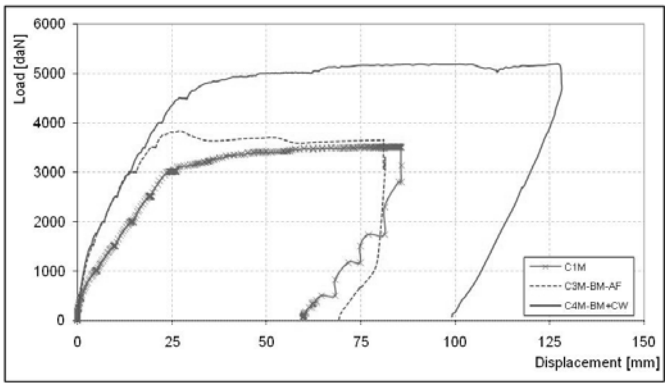

Fig. 21 Superposition of the monotonic tests

The cyclic tests were carried out using specimens in the same configuration of strengthening as the monotonically tested ones. This means that the first to be tested was a reference specimen, which failed through a plastic hinge development at the base of the column.

The C3C-BM-AF specimen followed and for it the failure was achieved through the debonding of the near surface mounted rebars, starting from the upper part, as it can be observed in figure 17.

The next test involved a complete strengthening system, using as wrapping material a carbon fabric.

In the case of the carbon wrapped specimen, a slip surface developed at the base of the column, just under the confinement, and at this level one of the longitudinal bars failed in tension. The carbon fabric used had an elastic modulus $E=231000N/mm^2$ and an ultimate strain $\varepsilon_u=1.7\%$.

In figure 22, there is presented the superposition of the cyclic tests.

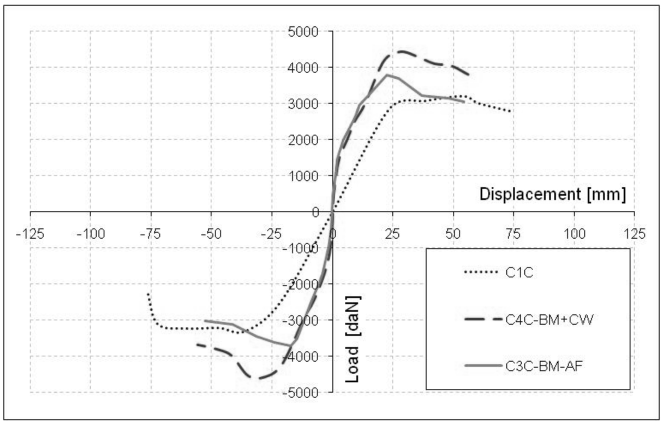

Fig. 22 Superposition of the cyclic tests

After this series of six experimental tests, the following conclusions can be drawn:
- the retrofitting method studied can lead to a significant increase in the ultimate horizontal load and displacement;
- the ductility increase ranges between 8.5% and 75% for the monotonically tested specimens and between 13% and 46% in the case of the cyclically tested columns.
- the stiffness of the elements is influenced only by the additional rebars applied in grooves. The confining wrap had only the role of holding the bars in place; the confining of the concrete proves not to have an important influence.

Element	Ultimate horizontal load [kN]	Difference in the ultimate horizontal load [%]	Displacement ductility factor - μΔ	Difference in the displacement ductility factor [%]
C1M	35.00	-	3.64	-
C3M-BM-AF	38.30	+9.4	3.95	8.5
C4M-BM+CW	52.00	+48.0	6.39	75
C1C	32.15	-	3.08	-
C3C-BM-AF	38.00	+18.2	3.50	13.6
C4C-BM+CW	45.70	+42.0	4.50	46.1

Table 1 Results of the experimental tests

The experimental program is in progress. Future tests are planned in which other types of composite wraps and lateral strengthening systems will be used.

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