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THE INFLUENCE OF LOADING LEVELS ON STRENGTH OF RC COLUMNS STRENGTHENED BY RC JACKETING

Introduction

Nowadays many industrial and civil buildings have already exceeded their estimated lifetime. Demolition expenses for these buildings and new construction costs are extremely high. It is therefore appropriate to consider strengthening and retrofitting of old structures to continue their serviceability and bring them to accordance with the requirements of modern codes and standards.

While strengthening different structures it is not always possible to offload them completely or partially. Therefore, in this study, we focused our attention on the impact of the stress-strain state of the structures during strengthening on its future work. Compressed-bent reinforced concrete elements strengthened by reinforced concrete jacketing were selected as the object of the study. Reinforced concrete jacketing is a well known strengthening method and has a broad implementation in practice [1, 2].

RC jacketing work equally well for compressive and flexure ones. Investigation of compressed-bent reinforced concrete elements were performed by many scientists [3-5] but there are very little that consider strengthening after initial loading, so the issue remained relevant. Therefore the subject still needs some research.

1. Experimental program

For this study twelve RC columns were designed and tested. Column's length equaled 2200 mm including cantilever sections on both ends. Cross section between the cantilevers had dimensions of 180 mm by 140 mm. Cantilevers were made to apply eccentric load to a column. Four 12 mm rebar were used as longitudinal reinforcement and 6 mm wire was used for ties with 50÷200 mm spacing.

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Columns were cast from C25/30 concrete. Strengthening process had begun after columns were loaded to a planned level according to the test program. Columns were kept under loading during strengthening process. New reinforcement was placed around the column and C25/30 concrete was cast. Cross section dimensions of a column after jacketing became 260 mm by 200 mm. The length or RC jacketing equaled 1700 mm. Four 10 mm rebar were used as longitudinal reinforcement and 6 mm wire was used for ties with 200 mm spacing. Overall view of column is presented in Figure 1.

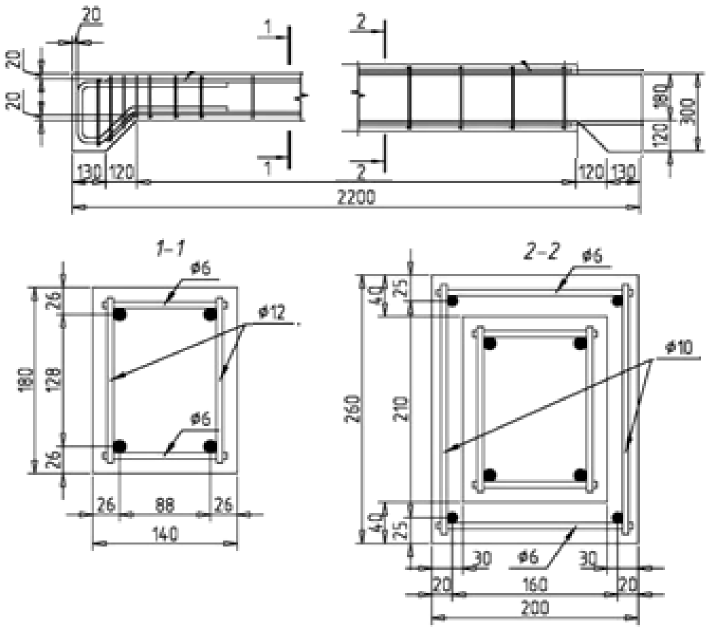

Fig. 1. The overall view of columns and its reinforcement:
1–1 - controle one, 2–2 - strengthened one

Columns were tested according to the following program:

- 2 *columns* (C-01 and C-02) tested to failure without *strengthening* to experimentally determine their ultimate strength N_u;
- *2 columns* (CS-03-0.0 and CS-04-0.0) *strengthened without previous loading then tested to failure*;
- *8 columns* (CS-05-0.3 and CS-06-0.3; CS-07-0.5 and CS-08-0.5; CS-09-0.7 and CS-10-0.7; CS-11-0.9 and CS-12-0.9) loaded to $0.3N_u$, $0.5N_u$, $0.7N_u$, $0.9N_u$ *then strengthened and tested to failure*.

Mechanical characteristics of column's and jacketing reinforcement were determined by tensile test. To determine mechanical properties of concrete, samples for concrete compression test were made while forming columns and jacketing (concrete cubes 100 x 100 x 100 mm).

Tests performed by the methodology [3] on the stand for compression tests in horizontal position (Fig. 2). The view of columns during testing is presented in Figure 3.

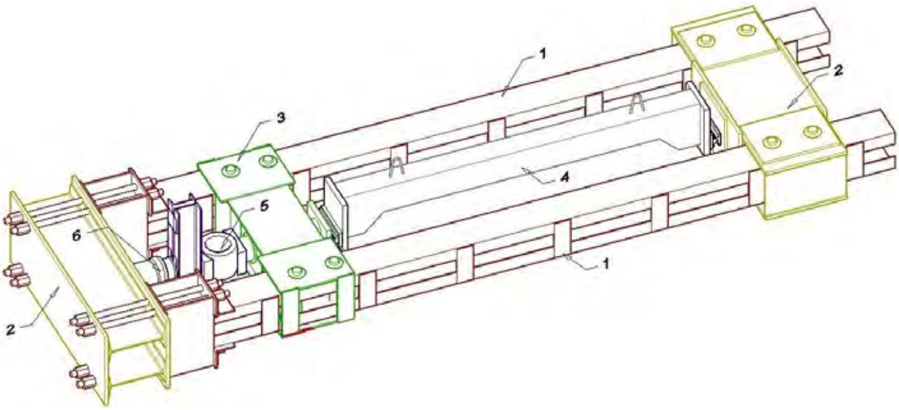

Fig. 2. Compression test stand: 1 - longitudinal elements of the stend, 2 - abutments, 3 - a traverse of the plunger, 4 - column, 5 - ring dynamometer, 6 - hydraulic jack

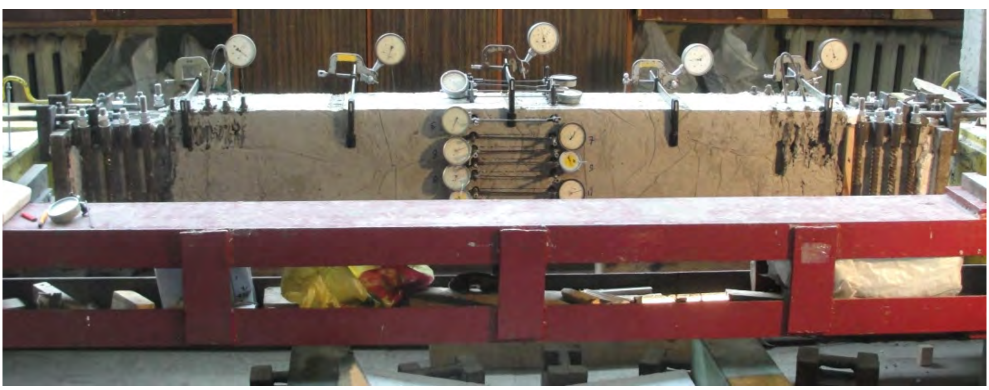

Fig. 3. Overall view of columns on the test stand

All specimens were tested as eccentrically loaded pinned columns. For every column eccentricity equaled 150 mm. Load to the columns was applied incrementally (10 kN at a time).

To measure the deformation of materials (reinforcement, concrete) dial indicators (MI) with accuracy of 0.001 mm were installed. Indicators were fixed on both, column and jacketing. To measure the deformation of the longitudinal reinforcement bars, special fasteners were welded to it before concreting. Five deflectometers (PAO) were installed along the length of the columns. The location of the measuring devices is shown in Figure 4.

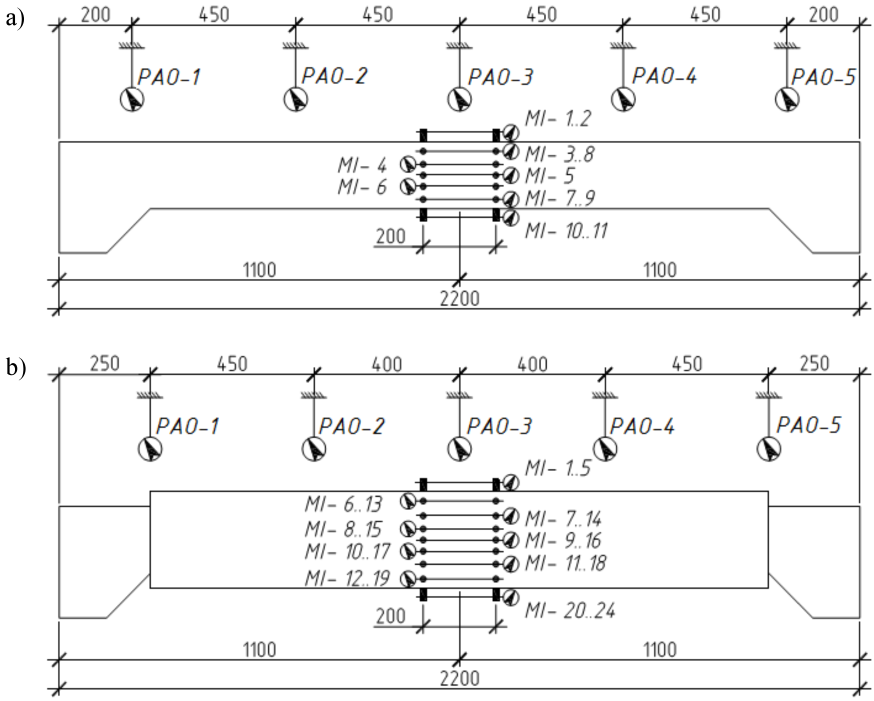

Fig. 4. Measuring devices on column samples: a) unstrengthened column, b) strengthened column

2. Experimental results of the research

Ultimate strength of control columns C-01 and C-02 was $N_{u(C)} = 174.56$ kN. Ultimate strength was reached after tensile reinforcement yield. With further load a significant increase in deflection was observed until the compressed zone of concrete was destroyed (Fig. 5).

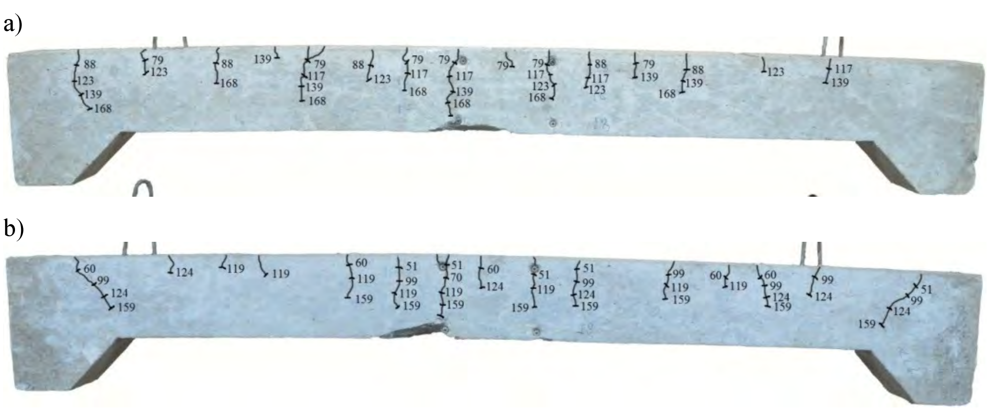

Fig. 5. Columns C-01 (a) and C-02 (b) after failure

In every specimens that were strengthened under level less than 50% from $N_{u(C)}$, a yield of jacketing reinforcement occurred sooner than a yield of column's reinforcement. We consider a load when the yield in both reinforcement layers occurs as a limit strength of the specimen. For columns SC-1-0.0 and SC-2-0.0 average limit strength was 480.5 kN. For columns SC-3-0.3 and SC-4-0.3 average limit strength was 460.9 kN. For columns SC-5-0.5 and SC-6-0.5 average limit strength was 441.3 kN (Fig. 6).

a)

b)

Fig. 6. Columns CS-05 (a) and CS-07 (b) after failure

In specimens that were strengthened under level more than 50% a yield of column's reinforcement occurred sooner than a yield of jacketing reinforcement. Such samples CS-09-0.7 and CS-10-0.7 were strengthened under load equaled 0.7 from $N_{u(C)}$ and the yield in tensile reinforcement occurred firstly in column and then in jacketing. Ultimate strength was reached when both layers of reinforcement yielded. Samples failed after the compressed zone of concrete was destroyed. Ultimate strength of columns CS-09-0.7 and CS-10-0.7 equaled 430.28 kN.

For samples CS-11-0.9 and CS-12-0.9 the yield in tensile reinforcement also occurred firstly in column and then in jacketing. Ultimate strength was reached when both layers of reinforcement yielded. Samples failed after the reinforcement of both, column and jacketing was torn. Ultimate strength of columns CS-11-0.9 and CS-12-0.9 equaled 397.51 kN.

Specimens review after tests found no signs of displacements, cracks or adherence loss between columns and jacketing. Test results of all specimens are summarized in Table 1.

Maximum strengthening effect was achieved by columns CS-03-0.0 and CS-04-0.0. Their average failure load increased by 172% in comparison with C-01 and C-02. With the increase of initial loading before strengthening the effect was decreasing. Columns CS-11-0.9 and CS-12-0.9 showed the minimum strengthening effect by 128%.

a)

b)

Fig. 7. Columns CS-10 (a) and CS-11 (b) after failure

TABLE 1

Columns experimental ultimate strength test results

No	Column	Ultimate loading N_u [kN]		Strengthening effect
		Specimen	Average value	
1	C-01	176.52	174.56	– (control)
2	C-02	172.60		
3	CS-03-0.0	480.53	474.93	172%
4	CS-04-0.0	469.33		
5	CS-05-0.3	460.91	465.62	167%
6	CS-06-0.3	470.33		
7	CS-07-0.5	451.11	442.52	155%
8	CS-08-0.5	437.93		
9	CS-09-0.7	421.69	430.28	146%
10	CS-10-0.7	438.86		
11	CS-11-0.9	392.86	397.51	128%
12	CS-12-0.9	402.15		

3. Theoretical results of the research

The limit strength of all specimens was calculated according to design codes [8] and design scheme at Figure 8. Concrete stress-strain relation for non-linear analysis was used. Calculations were performed by solving a system of non-linear equations:

$$\begin{cases} N_1\left(\aleph, \varepsilon_{c(1)}\right) + N_2\left(\aleph^{ad}, \varepsilon_{c(1)}^{ad}\right) - N = 0 \\ M_1\left(\aleph, \varepsilon_{c(1)}\right) + M_2\left(\aleph^{ad}, \varepsilon_{c(1)}^{ad}\right) - M = 0 \end{cases} \quad (1)$$

where:

$N_1(\aleph,\varepsilon_{c(1)})$ and $N_2(\aleph^{ad},\varepsilon^{ad}_{c(1)})$ are functions that represent axial forces held by concrete N_c, N^{ad}_c and reinforcement N_s, N^{ad}_s of the column and jacketing;

$M_1(\aleph,\varepsilon_{c(1)})$, and $M_2(\aleph^{ad},\varepsilon^{ad}_{c(1)})$ are functions that represents moments of forces N_c, N_s, N^{ad}_c and N^{ad}_s about the neutral axis in the cross section;

N, M are the compressive force and bending moment that are applied to a column.

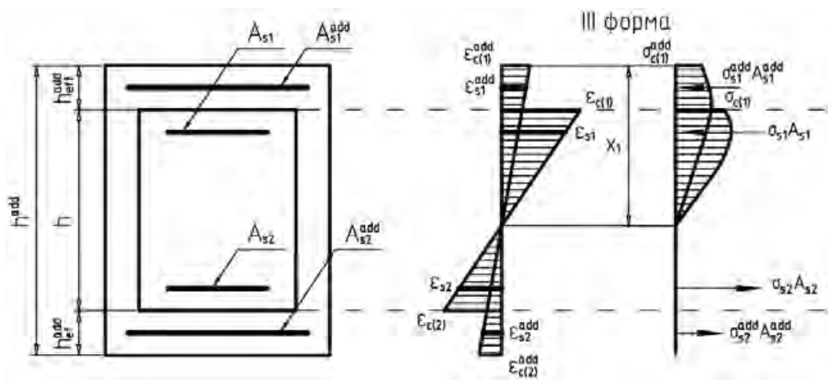

Fig. 8. Diagrams deformations and stresses taken to calculation

System of equations (1) is solved using gradual approximation method. Calculation results are given in Table 2.

TABLE 2

Columns theoretical ultimate strength test results

No	Column	Ultimate loading N_u [kN]		Deviation
		experimental	theoretical	
1	C-01	174.56	161.05	7.7%
2	C-02			
3	CS-03-0.0	474.93	419.77	11.6%
4	CS-04-0.0			
5	CS-05-0.3	465.62	414.39	11.0%
6	CS-06-0.3			
7	CS-07-0.5	442.52	402.62	9.0%
8	CS-08-0.5			
9	CS-09-0.7	430.28	384.36	10.7%
10	CS-10-0.7			
11	CS-11-0.9	397.51	362.23	8.9%
12	CS-12-0.9			

Calculations confirm the experimental results. Deviations between experimental and theoretical values are in good range of 7÷12%.

Conclusions

RC jacketing proved to be very effective in terms of column strength improvement and allowed us to obtain up to 172% increase of ultimate loading. Strengthening effect decreased with the increasing of an existing loading level during strengthening. In comparison with SC-1-0.0 and SC-2-0.0, those were strengthened *without previous loading*, at SC-11-0.9 and SC-12-0.9 that were strengthened *under previous loading 90%*, the strengthening effect decreased by 44%. This peculiarity should be taken into account in the design of strengthened structures. Experimental strength of test specimens was close to calculated values. Maximum deviation was 12%.

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Abstract

In this article strength of reinforced concrete columns, strengthened by reinforced concrete jacketing was investigated. Performance of reinforced concrete columns, strengthened after initial loading were studied. Different loading levels before strengthening were considered.

Keywords: RC structures, strengthening, columns

Wpływ poziomu obciążenia na nośność słupów żelbetowych, wzmocnionych poprzez obetonowanie

Streszczenie

W artykule zaprezentowano wyniki badań eksperymentalnych dotyczących nośności słupów żelbetowych przed i po wzmocnieniu poprzez obetonowanie. Wzmocnione słupy badano po przyłożeniu wstępnego obciążenia zewnętrznego. Badania wykonano przy kilku różnych wartościach obciążenia wstępnego.

Słowa kluczowe: konstrukcje żelbetowe, wzmocnienie, słupy