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RESEARCH OF REINFORCED CONCRETE ELEMENTS STRENGTHENED BY REINFORCED CONCRETE JACKETING UNDER HIGH LEVEL LOADING

Подано результати експериментальних досліджень залізобетонних колон, підсилених залізобетонними обоймами. Залізобетонні обойми обрано для дослідження, оскільки такий метод підсилення є найпоширенішим під час відновлення та підсилення залізобетонних колон. Інженерні розрахунки під час проектування такого типу підсилення відрізнятимуться від звичайних методів розрахунку та проектування залізобетонних колон, адже виникає необхідність врахування впливу навантаження, що діє на колону в момент підсилення. Визначення впливу цього чинника є основною метою цього дослідження. Для досягнення відповідної мети виготовлено і випробувано дослідні зразки залізобетонних колон. Під час випробування дослідні зразки навантажено до різних рівнів, підсилено та випробувано короткочасним навантаженням до руйнування. Колони працювали за розрахунковою схемою позацентрово стиснутих шарнірно закріплених стержневих елементів. Зразки колон виготовлено довжиною 2200 мм, розміри поперечного перерізу становили 180 мм на 140 мм. Консольні ділянки з обох кінців зразка слугували для прикладання навантаження з ексцентриситетом, що дорівнює 150 мм. Чотири арматурні стержні діаметром 12 мм слугували як робоче поздовжнє армуванням (відсоток армування становив 1,8 %) Усі дослідні зразки мали ідентичні геометричні характеристики та були виготовлені з одних і тих самих матеріалів. Програма експериментальних досліджень містила випробування контрольних зразків, а також підсилених під навантаженням, що становило 70 % та 90 % від несучої здатності контрольних зразків.

Ключові слова – залізобетон, колони, підсилення обоймами.

In this article the results of experimental study of reinforced concrete columns strengthened by reinforced concrete jacketing are produced. Reinforced concrete jacketing was chosen as the strengthening method since it is the most commonly used for reinforced columns repair and strengthening. The design of such strengthening will differ from basic column design methods since the impact of the load supported by the existing structure during strengthening should be taken into consideration. Determination of the impact of that factor is the main objective of this research. To achieve this reinforced concrete column specimens were manufactured and tested. Column specimens were strengthened after preliminary loading to different levels and then tested to failure as pinned columns subjected to eccentric loading. The columns were 2200 mm long, with cross section dimensions equal 180 mm by 140 mm. On both sides columns had cantilever sections to apply loading with 150 mm eccentricity. Four 12 mm rebars were used as longitudinal reinforcement (reinforcement percentage equaled 1,8 %). All specimens had identical geometrical and were manufactured from same materials. Eexperimental program included testing of control unstrengthened specimens along with strengthened under loading level that equaled 70 % and 90 % of control specimens ultimate strength.

Key words: reinforced concrete, columns, jacketing.

Introduction

Currently in Ukraine, 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.

However, buildings retrofitting design and individual structural elements strengthening design has to consider a number of factors that characterize their current state. These factors include stress-strain state of the structures at the time of strengthening, defects and damage, the residual strength of the structures, different loading conditions etc. Consideration of all given factors conclude in greater design accuracy, thus, reliability of restored structures.

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.

Investigation of compressed-bent reinforced concrete elements were performed by many scientists [2, 4, 5] including at Lviv Polytechnic [1], but the features of structures strengthened under load were not studied enough, so the issue remained relevant. In addition, the existing design codes of concrete structures [6, 7] does not contain any recommendations for the calculation and design of strengthened reinforced concrete structures. The development of appropriate methods of considering the real stress-strain state of reinforced concrete element during strengthening is necessary .

Objective

The aim of this work is to study the compressed-bent reinforced concrete columns, strengthened by reinforced concrete jacketing under load. Selected load levels simulate full service loads and emergency loads close to ultimate strength. Conduct analysis of such structures based on experimental data and theoretical calculations.

Research program

To achieve the objective, six reinforced concrete column samples were manufactured and tested. Two samples labeled with letter “C” were tested without strengthening to determine their actual ultimate strength and deformability. The next four samples labeled “CS” were tested after strengthening. Strengthening was performed under loads that equaled 70 % and 90 % of the ultimate strength of columns C-01 and C-02.

Dimensions of the column samples were as follows: length 2200 mm, cross section width 140 mm, cross section height 180 mm. Samples were manufactured with corbels at both ends for noncentral load application with eccentricity of 150 mm. Samples were reinforced symmetrically with four rebar ∅ 12 mm A500C, transverse reinforcement was placed with 50–200 mm spacing. Concrete compressive strength class was C25/30. Column dimensions and reinforcement are shown in Fig. 1.

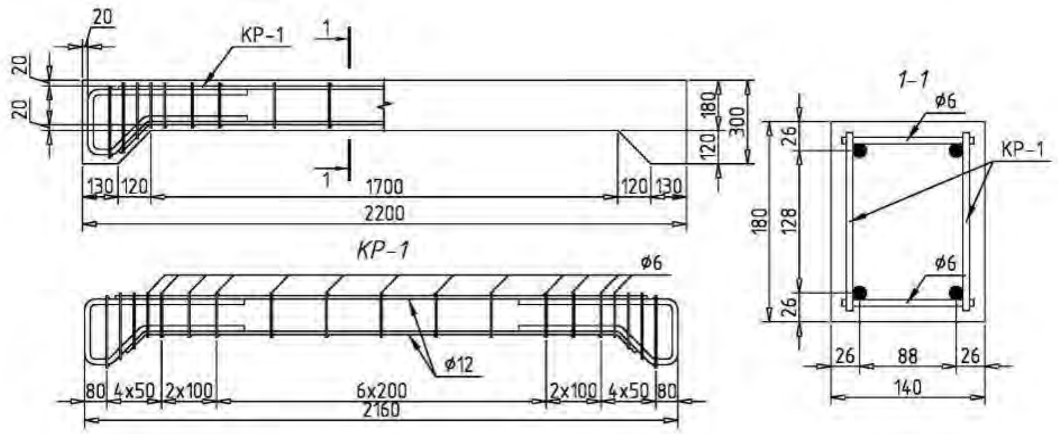


Fig. 1. Control unstrengthened column dimensions and reinforcement

Columns were strengthened between corbels. Jacketing length equaled 1700 mm. The thickness of the jacketing along the smaller face of the column was 40 mm, along the larger - 30 mm. In total, the size of the strengthened sample section equaled 260 by 200 mm. Jacketing was reinforced symmetrically with four rebar ∅10 mm A500C, transverse reinforcement was placed with 200 mm spacing. Jacketing concrete compressive strength class was C25/30, same as column concrete. Strengthened column dimensions and reinforcement are shown in Fig. 2.

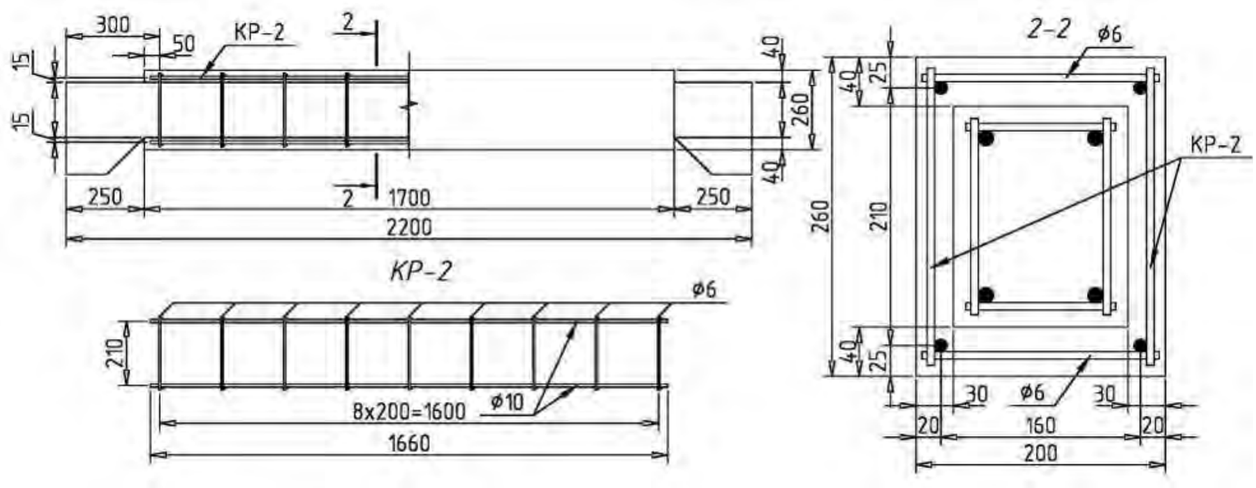


Fig. 2. Strengthened column dimensions and reinforcement

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 by 100 by 100 mm).

Samples were tested as noncentraly compressed hinged columns. Noncentral load was applied with eccentricity of 150 mm. Tests performed by the methodology developed at Lviv Polytechnic [1] on the stand for compression tests in horizontal position (Fig. 3).

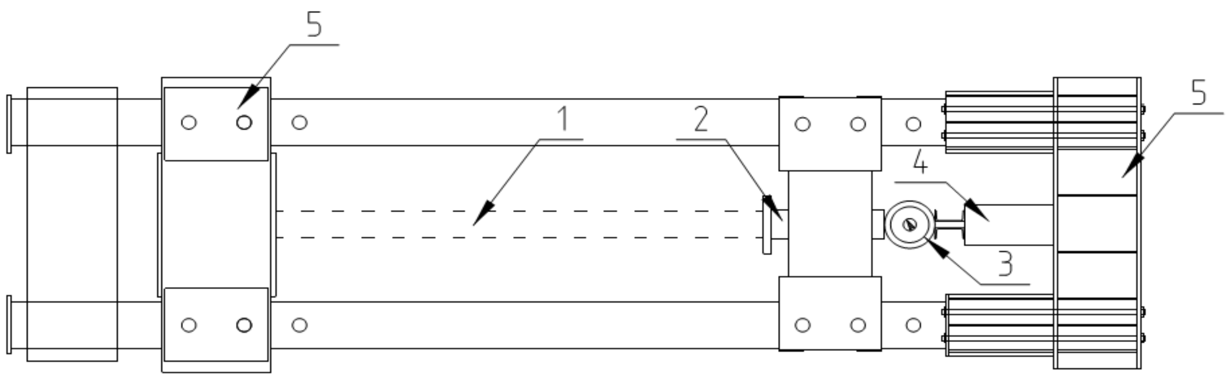
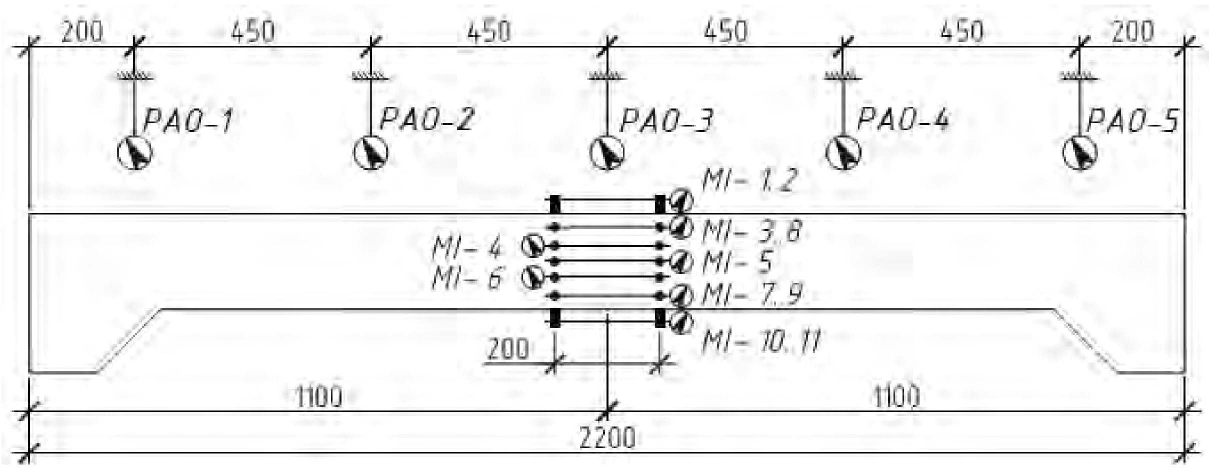
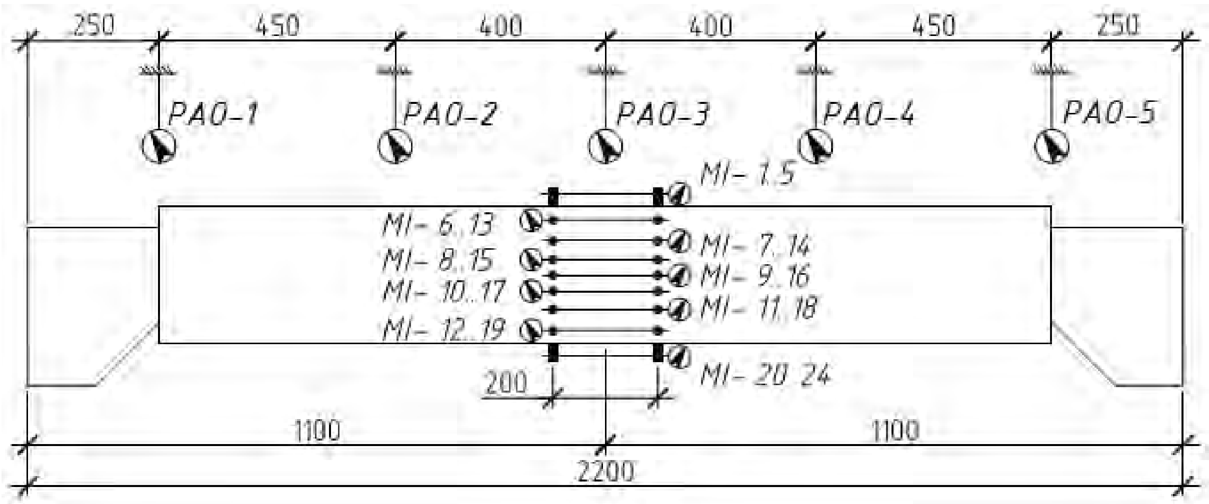


Fig. 3. Compression test stand:
1 – column; 2 – plunger; 3 – ring dynamometer;
4 – hydraulic jack; 5 – abutments

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 rods, 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 on Fig. 4.



a



b

Fig. 4. Measuring devices on column samples:
a – unstrengthened column; b – strengthened column.

Theoretical calculation of tested columns was performed taking into account the real mechanical properties of materials by the method presented in [3], taking into account the influence of the second order effects:

$$\begin{cases} F_1\left(\aleph, \varepsilon_{c(1)}\right) + F_2\left(\aleph^{ad}, \varepsilon_{c(1)}^{ad}\right) - N = 0 \\ \Phi_1\left(\aleph, \varepsilon_{c(1)}\right) + \Phi_2\left(\aleph^{ad}, \varepsilon_{c(1)}^{ad}\right) - M - M_2 = 0 \end{cases} \tag{1}$$

where F_1 and F_2 – functions to determine compression force in concrete N_c and tensile force in reinforcement N_s (for column and jacketing respectively); Φ_1 та Φ_2 – functions to determine moments of forces N_c та N_s about the neutral axe of cross section; N, M – compressive force and bending moment applied to a column; M_2 – second order effect moment.

M_2 can be calculated:

$$M_2 = N \cdot e_2 \tag{2}$$

$$e_2 = \frac{\aleph \cdot l_0^2}{c} \tag{3}$$

where e_2 – column deflection; $\aleph$ – curvature; l_0 – effective length of the column; c = 8.

Research results

Ultimate strength of columns C-01 and C-02 equaled $N_{u(C)}$ = 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. Results of experimental measurements and theoretical calculations of columns C-01 and C-02 are shows on Fig. 5.

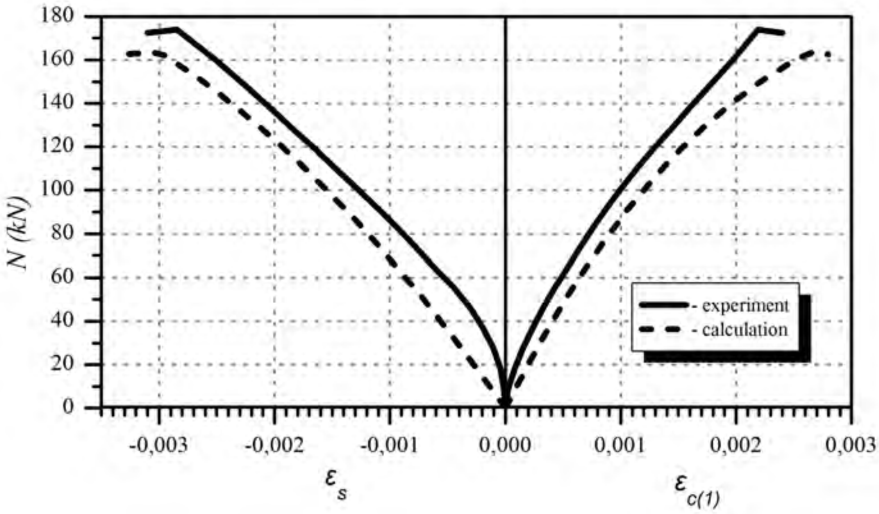


Fig. 5. Deformation plots of columns C-01 and C-02

Samples CS-09-0.7 and CS-10-0.7 were strengthened under load N_{str} = 124,52 kN that equaled 0,71 from $N_{u(C)}$. 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 $N_{u(07)}$ = 430,28 kN. Results of experimental measurements and theoretical calculations of columns CS-09-0.7 and CS-10-0.7 are shows on Fig. 6.

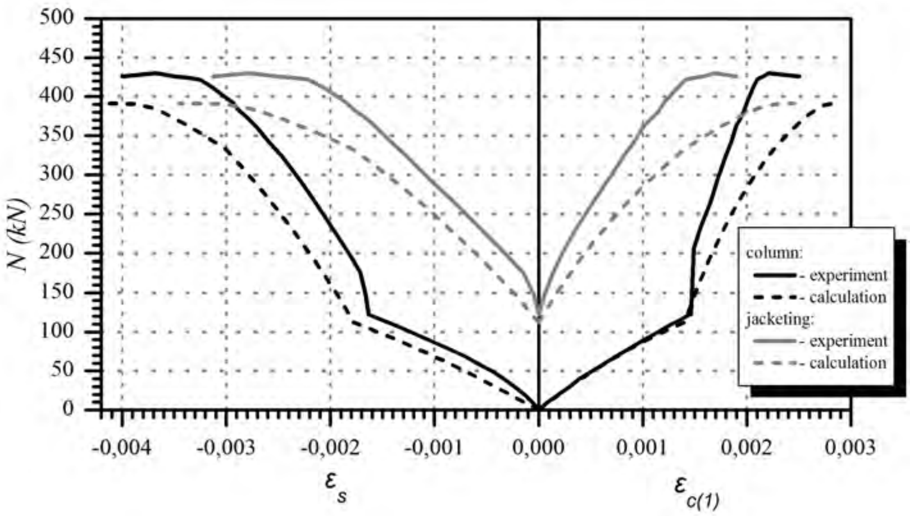


Fig. 6. Deformation plots of columns CS-09-0.7 and CS-10-0.7.

Samples CS-11-0.9 and CS-12-0.9 were strengthened under load N_{str} = 149,18 kN that equaled 0,85 from $N_{u(C)}$. 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 reinforcement of both, column and jacketing was torn. Ultimate strength of columns CS-11-0.9 and CS-12-0.9 equaled $N_{u(09)}$ = 397,51 kN. Results of experimental measurements and theoretical calculations of columns CS-11-0.9 and CS-12-0.9 are shows on Fig. 7.

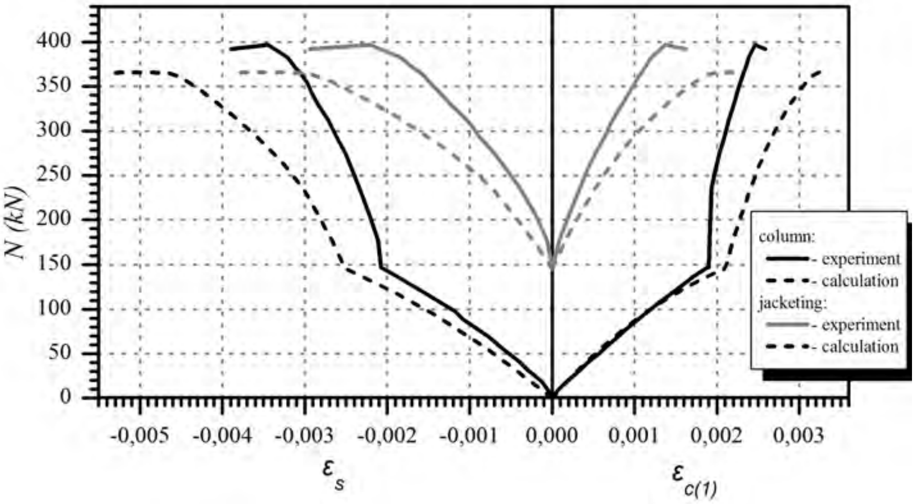


Fig. 7. Deformation plots of columns CS-11-0.9 and CS-12-0.9

Calculations and experimental results

Columns	Applied load during strengthening N_{str} (kN)	Ultimate strength (experimental) N_u (kN)	Strengthening effect	Ultimate strength (calculated) N_u^{teor} (kN)	N_u^{teor} / N_u
C-01 C-02	–	174,56	–	161,05	0,92
CS-09-0.7 CS-10-0.7	124,52	430,28	146 %	384,36	0,89
CS-11-0.9 CS-12-0.9	149,18	397,51	128 %	362,23	0,91

Conclusions

1. Reinforced concrete jacketing of reinforced concrete columns proved to be very effective even if it was applied under loads, close to ultimate strength. Samples CS-11-0.9 and CS-12-0.9 showed 128 % increase of ultimate strength.

2. Strengthening under service loads proved to be even more effective, since samples CS-09-0.7 and CS-10-0.7 showed 146 % increase in ultimate strength (18 % more than $N_{u(09)}$).

3. Calculations confirm the experimental results. Deviations between experimental and theoretical values are in range of 9–11 %.

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