Experimental Investigation Of Reinforced Concrete Columns Strengthened By Jacketing

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***Abstract*—Each year the significance of structural rehabilitation in construction industry increases. Throughout the structure's exploitation period some damages and deteriorations occur, new requirements considering service loads may appear, which makes a structure unfit to present demands. Considering the cost of new construction, in many cases structural rehabilitation of a building is much cheaper and can greatly increase structures estimated service time. In this article we have focused on reinforced concrete jacketing, which is one of the most common strengthening methods for reinforced concrete columns. Twelve column specimens were tested to failure to study strength and durability of jacketed reinforced concrete columns. All specimens had identical geometrical characteristics, material properties and were tested as pinned columns. Before jacketing test specimens were loaded to different levels to determine the influence of prior loading on the Reinforced concrete jacketing proved to be a very effective strengthening method that allowed us to achieve up to 290% of strength increase. Neither interface preparation methods nor adhesive materials were used to increase bonding between the new concrete and the column. Nevertheless, no displacements, cracks or adherence loss between columns and jacketing were noticed.**

Keywords—reinforced concrete jacketing; columns; strengthening.

I. INTRODUCTION

In Ukraine the greater part of civil and industrial buildings were constructed using precast reinforced concrete (RC) members. In many cases their estimated service time has already run out and some structural elements are extremely deteriorated. In addition to that, during the last 10 years a lot of national regulations and buildings codes were revised and edited which makes structures that were designed previously unfit to present design demands. Considering very high construction costs of a new buildings the significance of structural rehabilitation of existing ones is increasing permanently.

Jacketing is one of the most common strengthening method for RC structural members. Conventional jacketing techniques include RC jacketing and steel jacketing. RC jacketing is performed by placing additional reinforcement around the structural member and concreting it. This method significantly increase member's cross section and thereby its stiffness, shear and axial strength. Steel jacketing doesn't much increase member's size, nevertheless, can significantly increase its stiffness. Modern jacketing techniques use fiber reinforced polymers (FRP) sheets which are lightweight, durable, easy to install and have high tensile strength.

This paper presents the results of the experimental investigation of RC columns strengthened by RC jacketing. A lot of studies has been carried out in this field [1-7]. Main objectives of these studies were to determine effectiveness of RC jacketing as strengthening method and to study the bond between the column and RC jacketing. All researchers came to a conclusion that RC jacketing was very effective in terms of strength and stiffness increase. Reference [1] indicates that RC jacketing is labor-intensive in comparison to other jacketing methods. At the same time [3] states that RC jacketing does not require specialized workmanship and additional corrosion or fire protection. References [2, 3] indicate that monolithic behavior of the jacketed column can be achieved without increasing their surface roughness or using bonding agents and steel connectors if the column surface is not deteriorated or damaged. Considering all the factors given above one can come to a conclusion that RC jacketing is an optimal choice for columns structural rehabilitation.

Although RC jacketing has been studied by many researchers there are still some issues that demand further investigations. Among them is the influence of the load carried by the column during jacketing. In practice an opportunity to completely unload a column before strengthening is very rare, since the structure has to support at least its own weight and permanent load from the upper floors. In some cases it is impossible to remove variable loads like the weight of equipment and strengthening has to performed when the structure is close to its limit state. Reference [2] mentions that presence or absence of axial load has no significant influence on bonding between the column and RC jacketing. At the same time, nothing is said about the influence on strength or stiffness of structural member after strengthening. Therefore, determining the impact of the load supported by the structure during strengthening on its future performance was the main objective of this research.

II. Experimental Program

For this research twelve RC column specimens were constructed. All specimens had identical geometrical and mechanical characteristics and were tested to failure as pinned columns. Test program is described in Table I.

TABLE I. Test Program

Specimen Designation*	Type of Test
C-01	Tested without strengthening
C-02	
SC-03-0.0	Strengthened without prior loading
SC-04-0.0	
SC-05-0.3	Strengthened under load that equald 30% of column limit strength
SC-06-0.3	
SC-07-0.5	Strengthened under load that equald 50% of column limit strength
SC-08-0.5	
SC-09-0.7	Strengthened under load that equald 70% of column limit strength
SC-10-0.7	
SC-11-0.9	Strengthened under load that equald 90% of column limit strength
SC-12-0.9	

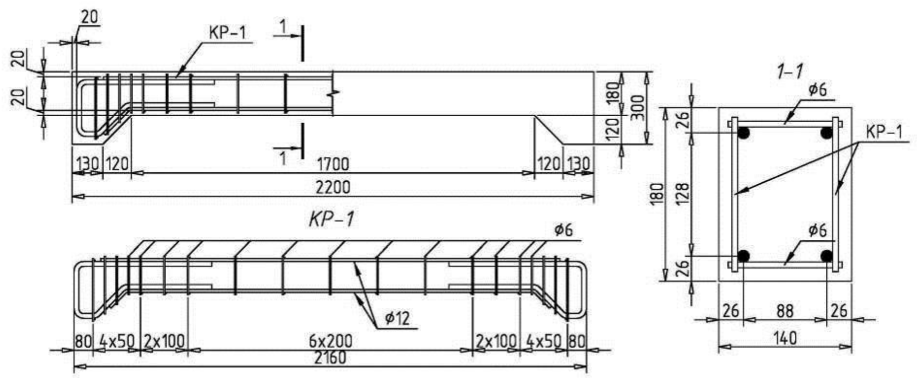
** Designation explanation: C – column; S – strengthened; whole number (e.g. 04, 11) – ordinal number of a column; decimal number (e.g. 0.3, 0.7) – loading level before strengthening according to type of test.*

To determine the actual limit load for the column specimens two of them were tested to failure without strengthening (C-01 and C-02). Load level when yielding of longitudinal reinforcement occurred was accepted as a limit load for the column due to excessive deflections and crack widths (serviceability limit state exceeded).

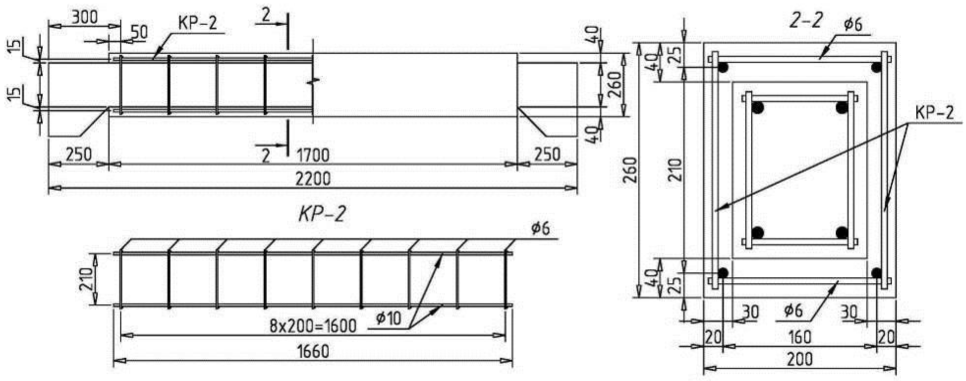
A. *Test Specimens*

Column specimens dimensions were as follows: length – 2200 mm; cross section height – 180 mm; cross section width – 140 mm. On both sides columns had cantilever sections that allowed to apply loading with eccentricity of 150 mm. Reinforcement percentage equaled 1.8 %. Four 12 mm rebar were used as longitudinal reinforcement with following mechanical characteristics: rupture strength – 722.8 MPa; yield stress – 636.9 MPa; yield strain – 0.3 %; Young’s modulus – 211 GPa. Average concrete strength equaled 37.7 MPa.

Cross section of a strengthened column was 260 mm by 200 mm. RC jacketing length equaled 1700 mm. Reinforcement percentage equaled 1.17 %. Four 10 mm rebar were used as jacketing longitudinal reinforcement with following mechanical characteristics: rupture strength – 701.5 MPa; yield stress – 610.7 MPa; yield strain – 0.29 %; Young’s modulus – 210 GPa. Average jacketing concrete strength equaled 38.9 MPa. 6 mm wire was used for ties both in columns and jacketing Drawings of test specimens before and after strengthening are presented in Fig. 1.



a) main column



b) strengthened column

Fig. 1. *Column specimens drawings (Dimensions in mm).*

B. Testing procedure

All specimens were tested as pinned columns on a compression test stand (Fig. 2). This stand was designed to conduct compression tests in horizontal position which makes it more convenient to read data from mechanical gauges. eccentrically loaded For every column eccentricity equaled 150mm. Load to the columns was applied incrementally by hydraulic jack. Loading level was determined from the readings of a ring dynamometer.

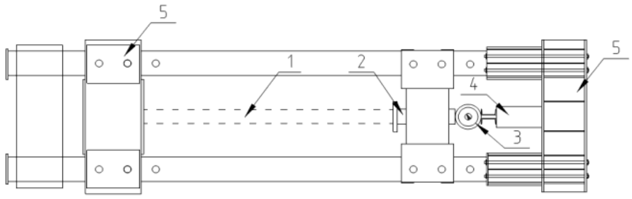
Only first two columns were tested without strengthening (C-01 and C-02) which means they were tested to failure during one continuous test. Measurements from gauges were taken after each load increment. Dial indicators (Di) were used to measure linear elongation of concrete and longitudinal reinforcement at the midsection of the columns. Strain of the column's materials were later calculated from this measured elongations. Deflectometers (Def) were installed along the length of the column to measure its deflection. Position of the gauges on the column during test can be seen in Fig. 3.

In case of strengthened columns test had to be divided into two parts. During the first part of the test columns were loaded to precise level according to a test program and fastened under constant load throughout the strengthening process. Loading was also performed incrementally and readings from the gauges were taken after each increment. Since the strengthening process took a reasonable amount of time columns were kept under constant loading by two rebar tensioned between two steel beams (Fig. 4). Such structure allowed to remove the pressure from hydraulic jack for the strengthening period.

During the strengthening process all the gauges were removed from the column. Column surface was cleaned from the dust. No interface preparation methods such as surface roughness increasing, bonding agent application or steel connectors installation were used to increase bonding between the new concrete and the column. Strengthening was performed in the following order:

- Four 10 mm rebar that represented jacketing longitudinal reinforcement were placed around the perimeter of the column. They were firmly fastened to prevent displacement during concreting. Ties were welded to the rebar with 200 mm spacing;
- Wooden forms were fixed around the column. While fixing the forms, column surfaces were soaked in watter;
- High workability concrete was poured into the forms and left for curing for 28 days.

After the forms were remover gauges were installed on the column (Fig. 5) and the testing process resumed. Strengthened columns were loaded incrementally to failure. Gauge readings were taken after each increment.



1- tested column ; 2- plunger; 3- ring dynamometer; 4- hydraulic jack; 5- rigid steel beam

Fig. 2. *Stand for columns compression test*

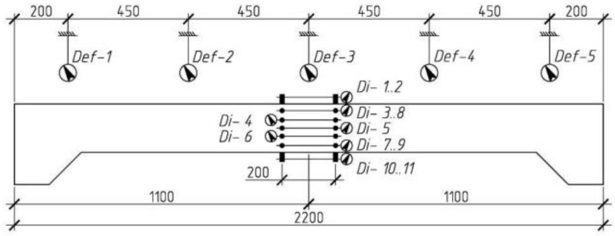


Fig. 3. *Gauge placment on unstrengthened column*

Fig. 4. *Column in the strengthening proces*

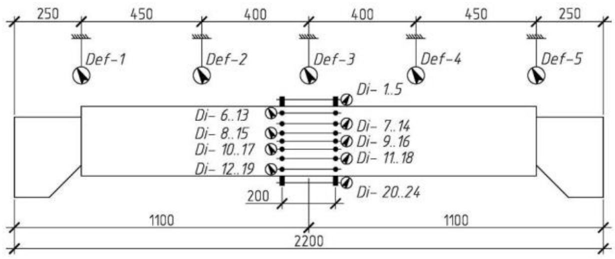


Fig. 5. *Gauge placment on strengthened column*

III. Results

All columns failed in a flexural manner at midsection. In case of columns C-01 and C-02 serviceability limit state was exceeded after column's tensioned reinforcement yielded, thus we consider the load when it happened a limit load. All strengthened specimens exceeded serviceability limit state after yielding of both column and jacketing reinforcement which was accepted as a limit load for the strengthened specimens.

Based on data acquired during tests average results for columns tested by the same type were calculated and presented as graphic dependences "load vs materials strain" (Fig. 6).

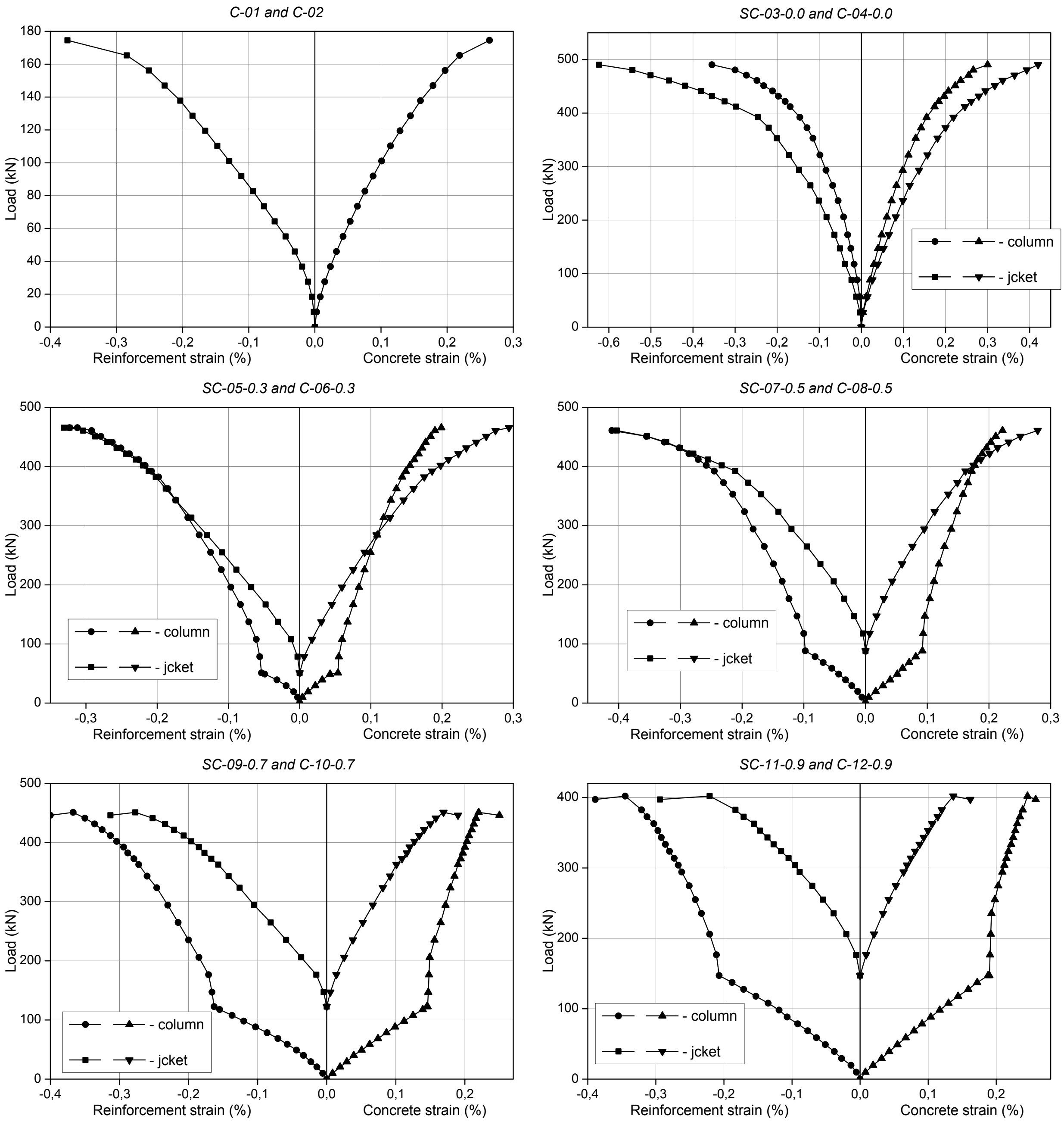


Fig. 6. *Load vs reinforcement (concrete) strain for all tested columns*

For columns C-01 and C-02 average limit load equaled 165.7 kN. For columns SC-03-0.0 and SC-04-0.0 average limit load was 480.5 kN. Strengthening effect eqaled 290 %.

Columns SC-05-0.3 and SC-06-0.3 were strengthened at 51 kN load. Average limit load for these columns equaled 460.9 kN which gives us 278 % strengthening effect.

Columns SC-07-0.5 and SC-08-0.5 were strengthened at 88 kN load. Their average limit load was 441.3 kN. Strengthening effect – 266 %.

Columns SC-09-0.7 and SC-10-0.7 were strengthened at 122 kN load. Their average limit load was 451.1 kN. Strengthening effect – 272 %.

Columns SC-11-0.9 and SC-12-0.9 were strengthened at 147 kN load. Their average limit load was 402.1 kN. Strengthening effect – 243 %.

IV. CONCLUSIONS

- RC jacketing is a very effective method of structural retrofitting of RC columns. By increasing columns cross section approximately two times we achieved limit load increase up to 290 %.
- RC jacketing proved to be very effective even if performed when column had almost exhausted it strength. Columns SC-11-0.9 and SC-12-0.9 showed strengthening effect of 243 %.
- The more it is possible to unload a column before strengthening the better effect can be achieved.

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