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# Research of RC columns strengthened by carbon FRP under loading

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**Abstract.** The usage of carbon fiber-reinforced polymers (FRP) are described as modern methods of strengthening for reinforced concrete constructions. The advantage of these materials are the great corrosion resistance to environmental factors, high stiffness and strength and weight in comparison with other materials. The disadvantage of relatively high cost is offset by the cost reduction and labor when performing work on strengthening, by decreasing of performance time, by lack of needs to use the expensive equipment, installed and used without unloading the structures. This paper presents experimental results of 6 reinforce concrete columns strengthened by CFRP strips Sika Carbodur S512 with 50 mm width. The comparative analysis was carried out and strengthened effectiveness was determined for 2 unstrengthen control specimens, 2 specimens strengthened without initial load and 2 specimens strengthened at 1/2 of experimentally determined destructive efforts of the unstrengthen column.

## 1 Introduction

Typically, reconstruction or recovery existing buildings are more economical and effective way than to build new ones. During the reconstruction of industrial buildings there is need for dismantling structures, replacement of some constructions, a full dismantling of structures or moving of buildings. The feature of this work is that there is always a need to ensure the durability of the building, and it needs to perform strengthening existing structures.

One of strengthening methods is using of carbon fiber reinforced polymers (CFRP). Application of CFRP often has been used for strengthening existing reinforced concrete (RC) columns. The advantages of CFRP are the great corrosion resistance to environmental factors, no significant changes geometrical dimensions of the construction, little time to perform work, high stiffness and strength, low weight in comparison with other materials.

But in comparing with other materials for strengthening of RC constructions the carbon-FRP more expensive material. So, it is important to research of strengthening effect from additional reinforcement value.

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## 2 Short historical review of the topic

Externally bonded FRP systems have been used to strengthen and retrofit existing concrete structures around the world since the mid 1980s. In Europe, FRP systems were developed as alternates to steel plate bonding. Bonding steel plates to the tension zones of concrete members with epoxy resins were shown to be viable techniques for increasing their flexural strengths Fleming and King at 1967 [7]. This technique has been used to strengthen many bridges and buildings around the world.

Today strengthening with composite materials is a very perspective direction for strengthening construction. Experimental studies of composite tapes were conducted in many European countries (Switzerland, the United Kingdom, Germany, Poland). Currently, there are normative documents and design guides on the use of CFRP, such as in the U.S. – ACI 440.2R-08 [1], in Europe – FIB Bulletin No. 14 [6], in China – CECS 146 [3], and in Japan – JSCE [11].

Also, there are some European normative documents and guides. In the United Kingdom it is the Technical Report No. 55 [17], in Italy – CNR – DT 200 [4] and in Germany [5]. There are increasing interest and more works direct for strengthening reinforce concrete constructions by using different CFRP systems [8,9,10,12,15,16]. Also, there are such researchers in Ukraine [2,13,14].

## 3 Experimental researches program

This research was made to study the effect of the current loading on ultimate limit state of RC columns strengthened by carbon FRP.

The main stages of our research were:

- testing unstrengthen specimens of columns;
- testing specimens of columns strengthened by additional carbon FRP without active loading;
- testing specimens of columns strengthened by additional carbon FRP under loading at 1/2 of limit loading of unstrengthen specimens of columns;

The experimental specimens of columns with dimensions 2200x180x140 mm were made. At the edges of columns cantilever was constructed to apply the eccentrically load. In the research the accepted eccentricity equals to 150 mm. The construction of experimental specimens is shown in Fig.1.

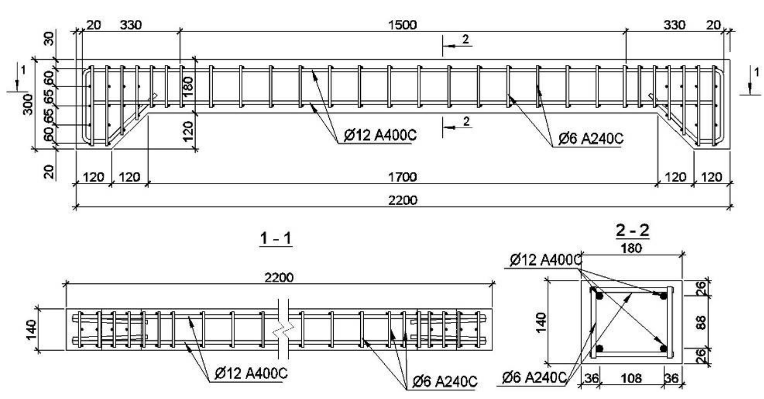


**Fig. 1.** Design and reinforcement of unstrengthen specimens

During the production process special connectors were attached to reinforcing bars. They serve for attaching mechanical gauges to determine the deformation of main steel reinforcement. To simulate the real working conditions of RC columns the specimens before strengthening were loaded to the level 1/2 of experimentally determined limit forces of unstrengthen specimens. For comparison two columns also were strengthened without loading. Then specimens were strengthened by carbon FRP strip (50 mm in width) of Sika Carbodur S512 (Fig. 2).

Carbon FRP strip was attached to the stretched edge of the column. Despite the practice of symmetrical reinforcement of columns, we do not attaché the strip on the compressed edge because it does not work efficiently under compression. For reliable strip anchoring two layers of fabric SikaWrap were applied to the cantilever.

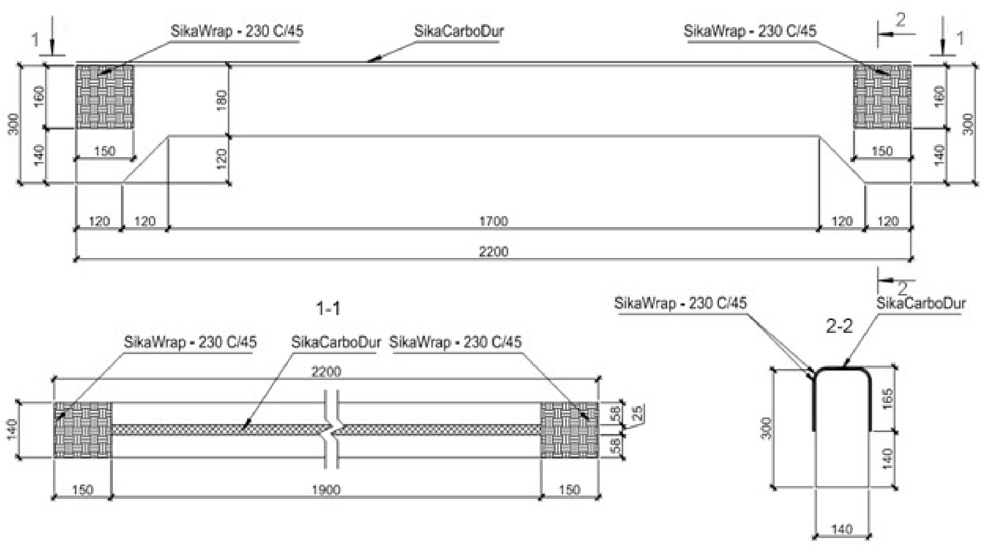


**Fig. 2.** Reinforcement of specimens strengthened by CFRP strip

The following labeling for experimental specimens was chosen: CU – column unstrengthen, CSL – column strengthened by carbon FRP strips. The first number in column label indicates the batch number, the second one – number of column in the series and the number that stands after the dash indicates – the loading level during strengthening. During the experimental studies 6 specimens were tested, namely two unstrengthend columns (CU-0.1 and CU-0.2), two columns (CSL-2.11 and CSL-2.12) were strengthened without loading, and two specimens (CSL-2.13-0.5 and CSL-2.14-0.5) were strengthened under 0.5 from ultimate strength of unstrengthen columns.

Strengthened specimens were tested to failure. Loading was applied in steps 10 kN each with 15 min. between steps. The load was applied by the hydraulic jack. Experimental specimens were tested in the horizontal position.

To determine the deformation characteristics of columns generally 28 strain gauges were used during not strengthened columns test and 35 strain gauges during strengthened columns test. There by the gauges the strain of reinforcement and concrete was measured. To measure the curvature of the columns 5 deflection gauges were placed along its length (Fig. 3).

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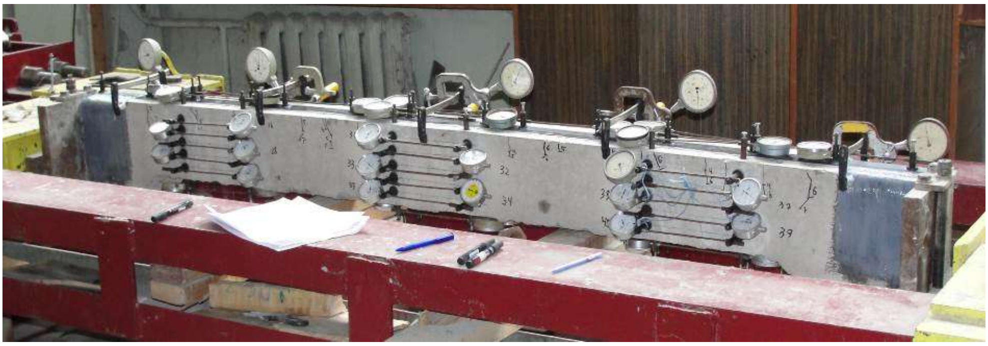

**Fig. 3.** Specimen CSL-2.13-0.5 during testing

## 4 Experimental results and discussion

In all experimental specimens three cross-sections were considered. In each cross-sections two strain gauges were placed on stretched reinforcing bars and one on concrete of compressed edge of the column. The mechanical gauges to the additional reinforcement CFRP were placed along the length of the strip.

Using previous studies we have got that yielding of steel reinforcement begins at $\varepsilon_u=280\times10^{-5}$ (Young's modulus E=205 GPa), limit state for CFRP for these specimens starts at the strip deformation $\varepsilon_{uL}=500\times10^{-5}$ (Young's modulus 165 GPa) [6] and for compressed concrete determined the limit deformation $\varepsilon_{cu1}=310\times10^{-5}$.

Using obtained experimental results we plotted the averaged diagrams of deformations of compressed concrete, stretched steel bars and carbon FRP strip in depending from loading for all columns (Fig. 4).

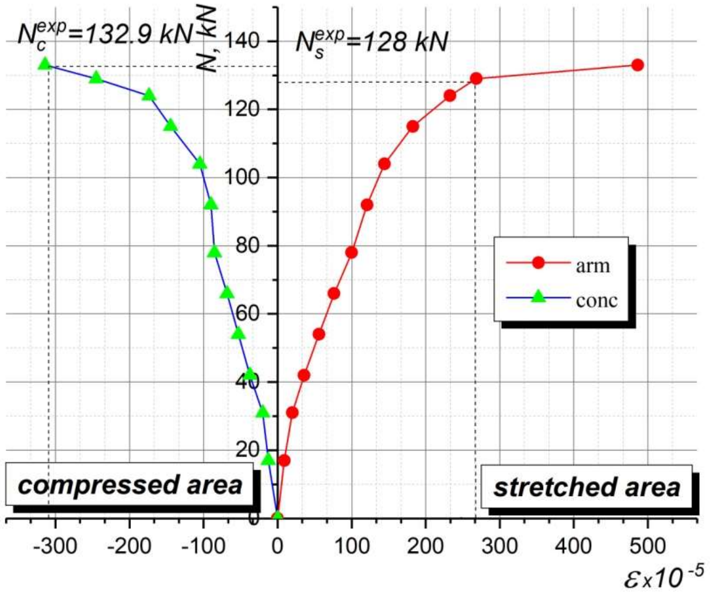


**Fig. 4.** Strain in stretched reinforcement (arm) and compressed concrete (conc) of unstrengthen columns CU-0.1 and CU-0.2 (average of twins)

The character of deformation of specimens CU-0.1 and CU-0.2 during the tests was similar. Deformation of stretched bars had equal step, which we can see from diagrams results. The increased growth deformation of steel bars occurred after its yielding at 128 kN. After loading growth about 5 kN destruction happened in the compressed area concrete columns. The crushing of compressed concrete detect at 132.9 kN.

The specimens strengthened with carbon strip of Sika Carbodur S512 (50 mm in width) deformation of strips were less than $\varepsilon_{sL}$=500×10$^{-5}$. In researching specimens CSL-2.11 and CSL-2.12 the strips from the beginning started working. This can be obvious from the character of deformation of the strips (lam) (Fig. 5).

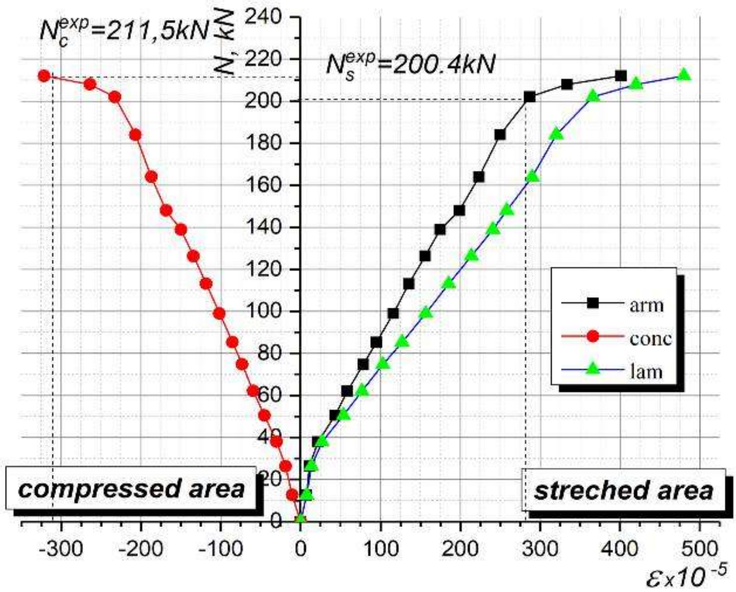


**Fig. 5.** Strain in stretched reinforcement (arm), strip (lam) and compressed concrete (conc) of columns CSL-2.11 and CSL-2.12 (average of twins)

As a result of the distribution of deformations between the main and additional reinforcement, there was a compressive force at yield of main reinforcement increase to 200.4 kN. We may assume that after it the strip takes most of additional efforts in the stretched area. The crushing of concrete compressed area was at 211.5 kN. The deformation of strip at crushing concrete at 211.5 kN was $\varepsilon_f$=482×10$^{-5}$. That is 96.4% from limit deformation CFRP, according to FIB [6].

The specimens CSL-2.13-0.5 and CSL-2.14-0.5 strengthened under initial load at 60 kN. The load corresponds roughly 1/2 of experimentally determined forces of ULS of unstrengthen specimens. After strengthening the deformation of carbon strip (lam) started its increasing directly from the beginning of testing (Fig. 6).

Also, after strengthening, the deformation of main reinforcement was less than at CU-0.1 and CU-0.2 in the same loading after 60 kN. The crushing of concrete compressed area was at 191.1 kN (Fig. 7). The maximum deformation of the strip $\varepsilon_f$=356×10$^{-5}$ was detected at 191.1 kN. The deformability characteristic of strip reached 71.2% from the limit value according to FIB (6).

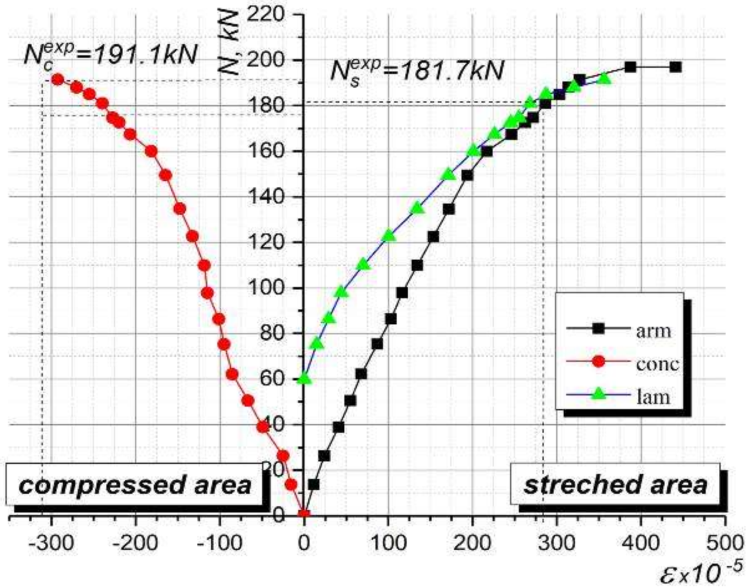


**Fig. 6.** Strain in stretched reinforcement (arm), strip (lam) and compressed concrete (conc) of columns CSL-2.13-0.5 and CSL-2.14-0.5 (average of twins)

For comparison of all specimens the experimental data were summarized in the table 1.

**Table 1.** Results of research

| Specimens | Compressive force at main reinforcement yield, kN | | Strengthening effect, % | | Compressive force at crushing of concrete, kN | | Strengthening effect, % | |
|---|---|---|---|---|---|---|---|---|
| | specimen | average | specimen | average | specimen | average | specimen | average |
| CU-0.1 | 127.4 | 128 | - | - | 131.6 | 132.9 | - | - |
| CU-0.2 | 128.6 | | - | | 134.2 | | - | |
| CSL-2.11 | 198.5 | 200.4 | 55.1 | 56.6 | 207.1 | 211.5 | 55.8 | 59.1 |
| CSL-2.12 | 202.3 | | 58.0 | | 215.9 | | 62.5 | |
| CSL-2.13-0.5 | 177.5 | 181.7 | 38.7 | 42.0 | 187.9 | 191.1 | 41.4 | 43.8 |
| CSL-2.14-0.5 | 185.9 | | 45.2 | | 194.3 | | 46.2 | |

According to table 1 the strengthening effect for compressive force at reinforcement yield for specimens CSL-2.11 and CSL-2.12 was 56.6%, for specimens CSL-2.13-0.5 and CSL-2.14-0.5 – 42.0%. The strengthening effect for compressive force at crushing of concrete for specimens CSL-2.11 and CSL-2.12 was 59.1%, for specimens CSL-2.13-0.5 and CSL-2.14-0.5 – 43.8%.

As can be seen from the test results, the strengthening effect decreases with existing loading level on construction during strengthening. The effect has decreased from 56.6% to 42 % by ULS and from 59.1% to 43.8 % by crushing of compressed concrete when loading was 50% from ULS unstrengthen one. The scheme of the failure of specimens' columns is shown in Fig. 7.

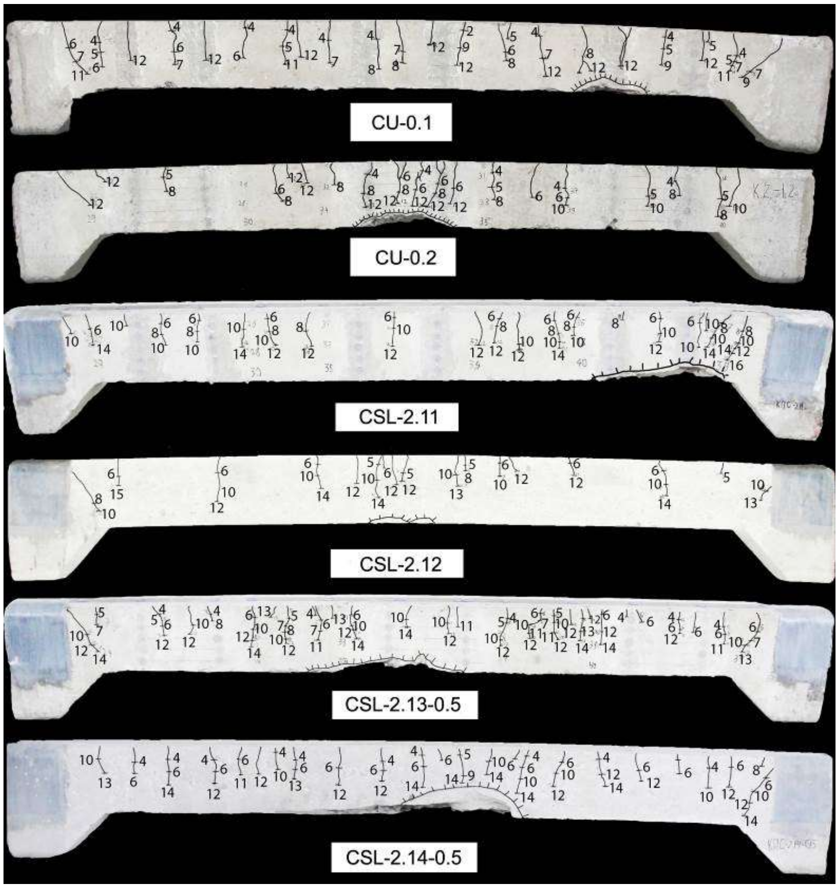


**Fig. 7.** Columns CU-0.1, CU-0.2, CSL-2.11, CSL-2.12, CSL-2.13-0.5, CSL-2.14-0.5 after testing

## 5 Conclusion

1. After experimental research of reinforced concrete columns strengthened by carbon FRP strip Sika CarboDur S512 there was determined that the strip starts working with the main reinforcement immediately after application.
2. The strengthening effect by reinforcement yield for specimens CSL-2.11 and CSL-2.12 was 56.6%, for specimens CSL-2.13-0.5 and CSL-2.14-0.5 – 42.0%. The strengthening effect by crushing of compressed concrete for specimens CSL-2.11 and CSL-2.12 was 59.1%, for specimens CSL-2.13-0.5 and CSL-2.14-0.5 – 43.8%.
3. The strengthening effect has decreased from 56.6% to 42 % by ULS and from 59.1% to 43.8 % by crushing of compressed concrete when loading was 50% from ULS unstrengthen one.
4. The maximum deformation of the carbon FRP strip was achieved 96.4% from its limit value for specimens strengthened without loading and was achieved only 71.2% for specimens strengthened under loading.
5. These obtained features should be taken into account when we design the system of strengthening by carbon FRP applied to real constructions.

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