Yaroslav Blikharskyy, Roman Khmil, Oleg Yovchyk

RESEARCH OF STRENGTHENING EFFECT OF REINFORCED CONCRETE ELEMENTS SUBJECTED TO COMBINED AXIAL LOAD AND BENDING WITH DIFFERENT PERCENT OF ADDITIONAL REINFORCEMENT

Introduction

During creation of new productions there often appears a need for new buildings or reconstruction of the old ones. Typically, reconstruction or recovery of existing buildings is a more economical and effective variant than to build new ones. Also buildings need recovery for many other reasons. They can be the increase in requirements for design, thorough changing of the functional purpose, the negative environment's influence, installation of new equipment, upgrading engineering networks, improving architectural qualities of the building. During the reconstruction of industrial buildings there is a need for dismantling structures, replacement of some constructions, 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 requires to perform strengthening existing structures.

For today there are many methods of strengthening building structures. Some of them that we used for a long time are using reinforced concrete jackets, concrete layers, reinforced with steel, changing design scheme.

One of modern methods of strengthening is using carbon fiber reinforced polymers (CFRP) [1, 2]. Their advantages are:

- the great corrosion resistance to environmental factors,
- no need for serious scaffolding,
- no significant changes in geometrical dimensions of the construction,
- little time to perform work,
- high stiffness and strength,
- low weight in comparison with other materials (unit weight of the composite is 1/4 of the weight of steel).

However, the material has some disadvantages. When compared with steel, the cost of composites is larger, there is a negative effect of ultraviolet rays, there are some problems with the clutch material with reinforced construction, low resistance of composites to high temperatures (such as in a fire). However, not all disadvantages are unconditional. For example, if we keep in mind the higher cost of materials, it is necessary to take into consideration completely all expenses. If we take into account the strengthening with composite materials, the cost of its placement will be reduced, for example, by the use of simpler technology installation, duration of works, the cost of installation. With regard to resistance to high temperatures or the negative influence of ultraviolet rays, we can cover it with special materials that will provide protection against such factors. If we consider all the factors in the implementation of activities to reinforce the above, the relative cost of strengthening this way is cheaper. However, the material is quite expensive, so the actual research question is the investigation of strengthening effect from additional reinforcement value.

1. Reference analysis

Strengthening with composite materials is a very promising direction for strengthening construction. The first composite materials for strengthening building structures appeared not long ago and their uses with different types of constructions are still being researched.

Experimental studies of composite tapes were conducted in many European countries (Switzerland, Germany, Poland). Currently, there are normative documents on the use of CFRP, such as in the US - ACE 440.2R-02 (2002), in Europe - FIB Bulletin 14 (2001) and in the UK - TR55 (2004) [3-5]. In Ukraine this question is studied by many researchers [6-9].

2. Goal and objectives

The goal of this work is:

- to determine the parameters of strength and deformability of reinforced concrete columns unstrengthened and strengthened by additional carbon laminate with width of 25 and 50 mm,
- to compare columns strengthened by different percent of additional carbon laminate with unstrengthened columns, setting efficiency of strengthened ones,
- to check the joint operation of the main and additional armature. To determine when an additional armature starts working and its impact to the strain of main armature,
- to check chosen type of anchoring laminate and its reliability until specimens' destruction.

3. Methods of experimental research

To achieve the goal experimental samples of columns with dimensions 2200 x 180 x 140 mm were made. At the edges of columns cantilevers were constructed to transmit load eccentrically. In the research the accepted eccentricity equals 150 mm. The construction of experimental samples is shown in Figure 1.

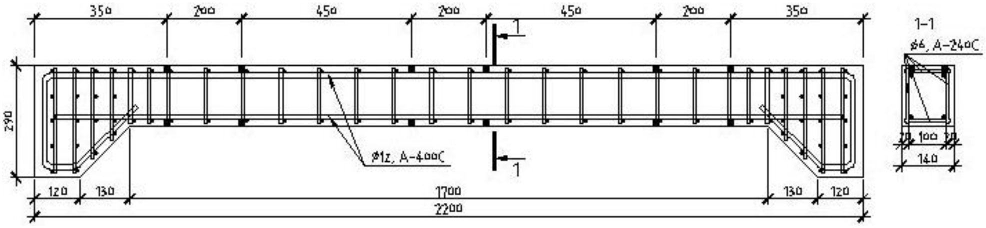


Fig. 1. Design and reinforcement of unstrengthened samples

During the production process special fasteners were attached to reinforcing bars. They serve for attaching mechanical devices to determine the deformation of steel reinforcement.

Carbon laminate was attached to the stretched face of the column. The prepared laminate and wrap before gluing want to activate. To do this we performed the surface cleaning of laminate and wrap using liquid Colma Reinger. Time of activation was 30 min.

To ensure laminate anchoring two layers of Sika Wrap fabric were applied on the cantilever area.

For applied Sika Wrap fabric was used two part, thixotropic epoxy based impregnating resin Sikadur-330 [10]. It consists of parts A and B mixed with proportion A:B = 4:1. They are mixed together for at least 3 minutes with a mixing spindle attached to a slow speed electric drill (max. 600 rpm.) until the material becomes smooth in consistency and of a uniform grey color. The glue Sikadur-330 was applied to the surface with a brush, trowel or roller.

Then we placed the Sika Wrap fabric in the required direction onto the Sikadur--330. Carefully we pushed the fabric into the resin with the Sika plastic impregnation roller parallel to the fiber direction until the resin was squeezed out between and through the fiber distributed evenly over the whole fabric surface [10].

For applied laminate Sika Carbodur there was used a thixotropic, structural two part adhesive, based on a combination of epoxy resins and special filler Sikadur-30. It consists of parts A and B mixed with proportion A:B = 3:1. Then parts A+B were mixed together for at least 3 minutes with a mixing spindle attached to a slow speed electric drill (max. 600 rpm.) until the material became smooth in consistency and of a uniform grey color. Then we placed the laminate Sika Carbodur in the required direction onto the Sikadur-30 and used a roller for pressing laminate to column. Excess resin was picked up with a spatula. After that a day later the second layer on Sika Wrap was applied by technology described earlier (shown in Fig. 2). In this way all samples were strengthened by carbon laminate Sika Carbodur S512 (shown in Fig. 3). Laminate width was 25 and 50 mm.

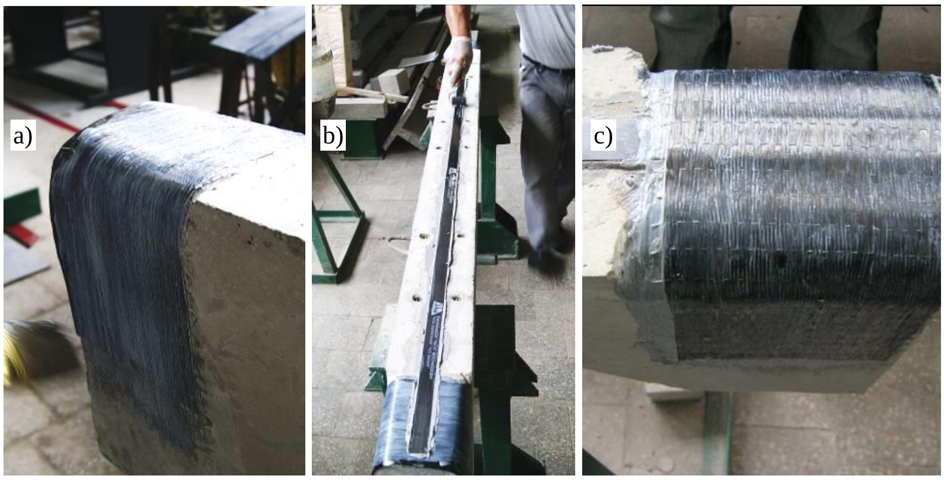


Fig. 2. Applying of first layer of Sika Wrap (a), applying of laminate Sika Carbodur (b), applying of second layer of Sika Wrap (c)

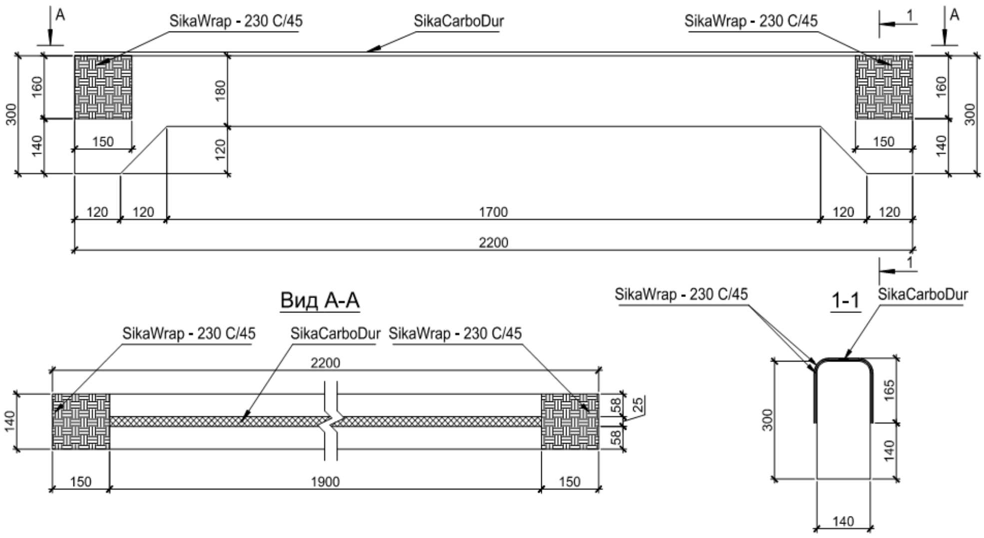


Fig. 3. Reinforcement of samples strengthened by carbon laminate

Strengthened samples were tested to failure. Loading was applied in steps 10 kN each with 15 minutes between steps. The load was applied by hydraulic jack (shown in Fig. 4).

Fig. 4. The loading equipment for testing of samples

Experimental samples were tested in the horizontal position. To determine the deformation characteristics of columns generally 28 strain indicators were used during unstrengthened columns test and 35 strain indicators during strengthened columns test. By the indicators the strain of reinforcement and concrete was measured. To measure the curvature of the columns 5 deflectmeters were placed along its length (shown in Fig. 5).

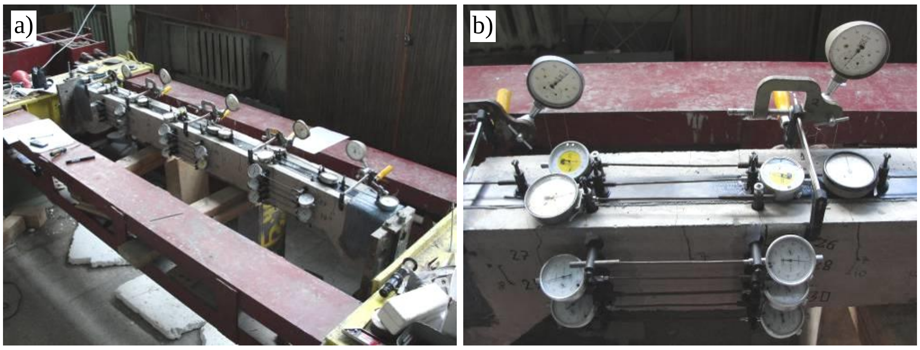


Fig. 5. Strengthened sample during test. The general view (a) and first cross-sections (b)

4. Results and discussion

In all experimental samples three cross-sections were considered. In each cross-section two indicators were placed on stretched reinforcing bars and one indicator on concrete of compressed edge of the column. Indicators of the additional reinforcement were placed along the length of the laminate. The largest strains in reinforcement and concrete were concentrated in the middle section, so based on these data graphs "load-strain" for stretched reinforcement, laminate and compressed concrete were plotted (shown in Figs. 6, 8, 11).

The character of deformation of columns CU-0.1 and CU-0.2 during the tests was similar. Deformation of stretched armatures had equal step, which we can see from graph results (shown in Fig. 6). Increased growth in deformation of armature occurred after reaching its yield strength. Average value compressive force of reinforcement yield for two samples was 127.4 kN. After loading growth about 5 kN destruction happened in the compressed area of concrete columns (shown in Fig. 7). Average value of compressive force at concrete failure was 133.25 kN.

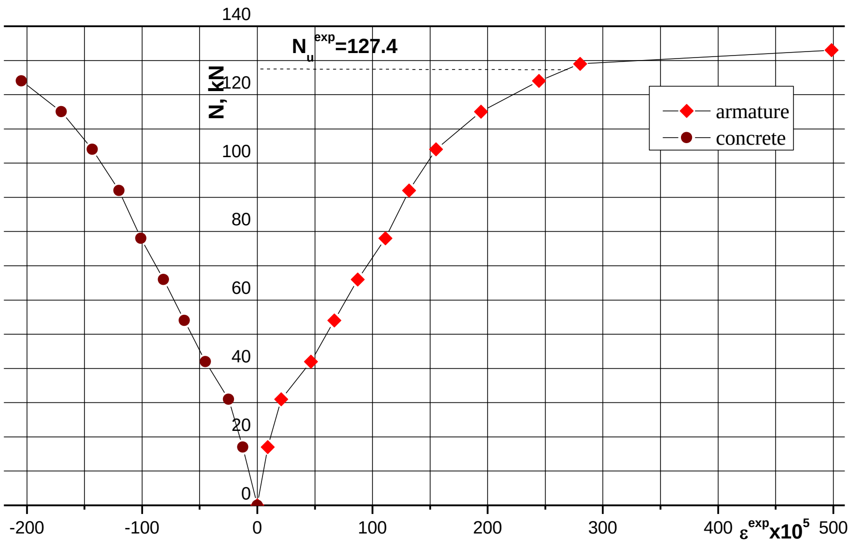


Fig. 6. Strain in stretched reinforcement (armature), compressed concrete of unstrengthened columns CU-0.1 and CU-0.2 (CU-0 - average of twins)

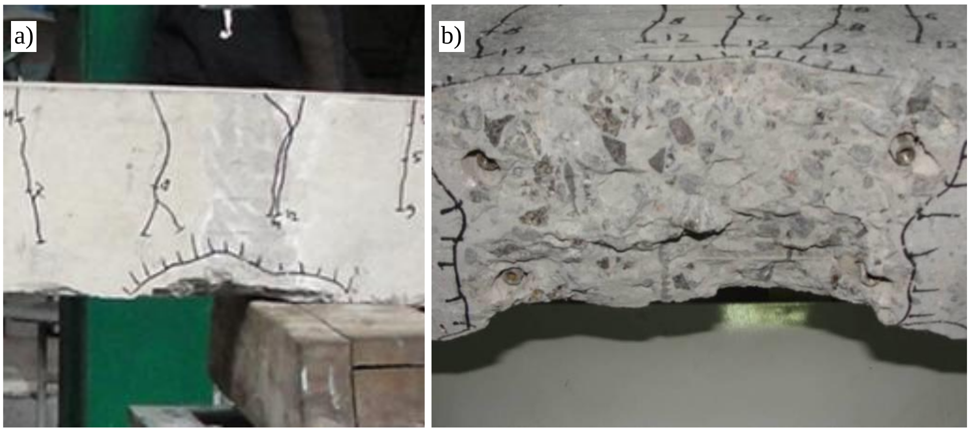


Fig. 7. Compressive area of columns CU-0.1 (a) and CU-0.2 (b) after failure

When researching columns CSL-1.3 and CSL-1.4, it should be noted that the laminate from the beginning was included in the work (shown in Fig. 8). 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 167.5 kN. We may assume that after it only the laminate takes all additional efforts in stretched area. In the results laminate limit state began after 5.7 kN at compressive force by 173.2 kN. After that, with increase in force by 9.3 kN, at 182.5 kN there was crushing of concrete compressed area (shown in Fig. 10).

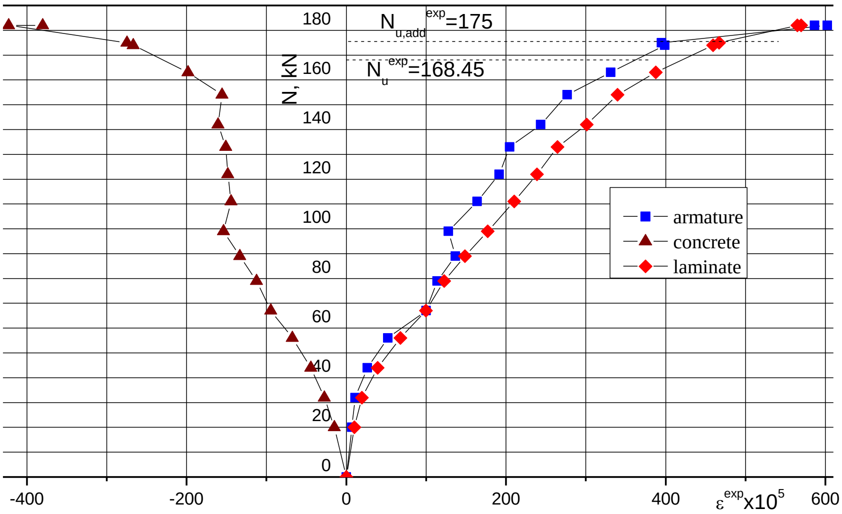
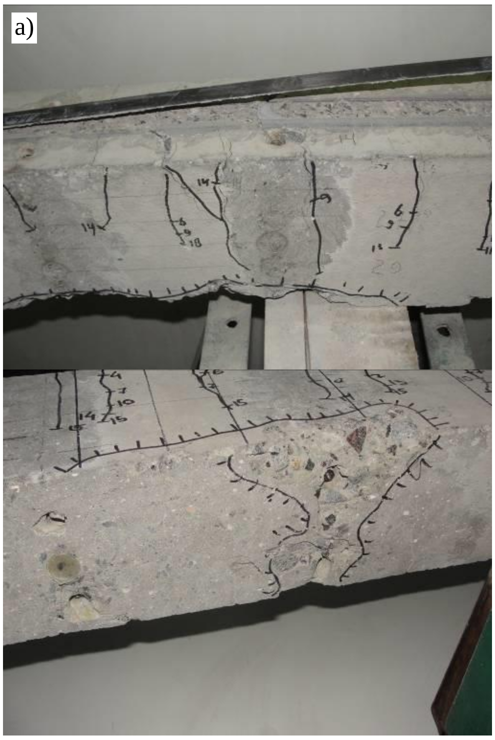


Fig. 8. Strain in stretched reinforcement (armature), laminate and compressed concrete of columns CSL-1.3 and CSL-1.4 (CSL-1 - average of twins)

It should be noted that in a sample of CSL-1.3 there was slipping of the laminate at the site of anchoring (shown in Fig. 9). However, it happened after the destruction of the compressed area and it was a result of a rapid deformation growth. So we can conclude that the premature destruction of anchoring did not occur. In the sample CSL-1.4 slipping anchoring was not seen.

Fig. 9. The character slipping of the laminate from anchoring in a sample CSL-1.3. In place of anchoring (a), general view (b)



b)

Fig. 10. Compressive area of columns CSL-1.3 (a) and CSL-1.4 (b) after failure

When testing the columns CSL-2.11 the laminate was also included in the work from the first stages of loadings (shown in Fig. 11). An increase in the width of the laminate (from 25 to 50 mm) increased adhesive area with concrete, loss of anchoring is not observed. Yield of main armature was at compressive force by 187 kN. Then, after 27.8 kN, at force 214.8 kN laminate reached its limit state. After that the load increases for 4 kN and average value of compressive force at concrete failure was 218.95 kN (shown in Fig. 12).

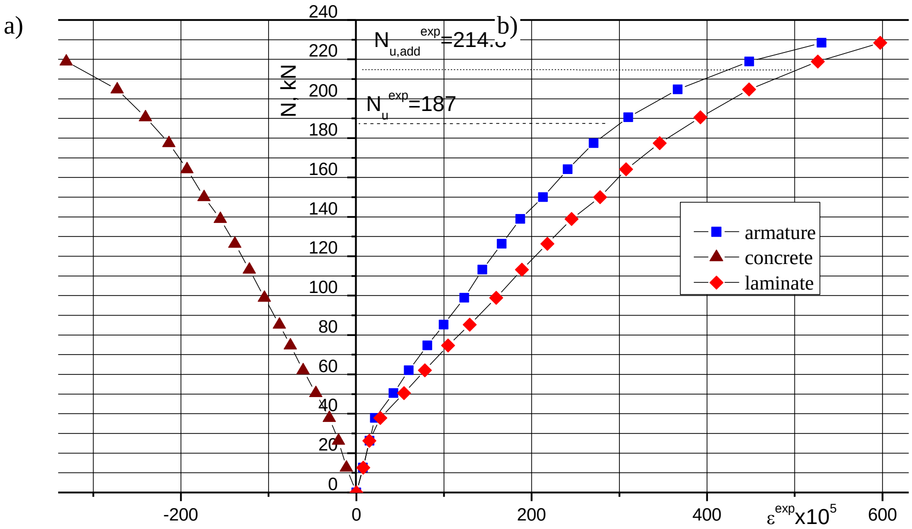


Fig. 11. Strain in stretched reinforcement (armature), laminate and compressed concrete of column CSL-2.11

Values of the compressing force for different limit states are presented in Tables 1-3. The comparison of samples' loading when yield of the main armature occurs is presented in Table 1.

Fig. 12. Compressive area of column CSL-2.11 after failure. Side view (a), bottom view (b)

TABLE 1

The compressive force at main reinforcement's yield state

Sample code	Cross-section dimensions		Compressive force at reinforcement yield [kN]		Strengthening effect [%]	
	concrete, b x h [mm]	laminate width [mm]	sample	average	sample	average
CR-0.1	140 x 180	25	127.4	128	–	–
CR-0.2			128.6		–	
CSL-1.3			168.45	167.5	31.6	30.9
CSL-1.4			166.55		30.1	
CSL-2.11		50	187	187	46.1	46.1

Strengthening effect for samples CSL-1.3 and CSL -1.4 was 30.9%, for samples CSL-2.11 - 46.1%. Strengthening effect by main reinforcement's yield state for CSL-2 (with laminate width 50 mm) in comparison with CSL-1 (with laminate width 25 mm) increased 1.5 times, when additional reinforcement increased 2 times.

Also the comparison of samples' loading when strain in laminate equals limit state was made (shown in Table 2).

According to Table 2 strengthening effect for samples CSL-1.3 and CSL-1.4 was 30.9%, for samples CSL-2.11 - 67.8%. The sample CSL-2 in comparison with samples CSL-1 increased the strengthening effect 1.92 times, when additional reinforcement increased 2 times.

After strengthening of the columns by carbon laminates, main reinforcement and additional one work redistribute applied stress among each other. When stress in steel reinforcement reaches the yield level, all tensile stress transfers to the laminate. Failure of the sample occurs after concrete crushing in compressed face of the column.

In Table 3 the comparison of samples at concrete failure is presented.

TABLE 2

The compressive force at laminate limit state

Sample code	Cross-section dimensions		Compressive force at laminate limit state [kN]		Strengthening effect [%]	
	concrete, b x h [mm]	laminate width [mm]	sample	average	sample	average
CR-0.1	140 x 180	25	127.4	128	–	–
CR-0.2			128.6		–	
CSL-1.3			175	173.2	36.7	35.3
CSL-1.4			171.4		33.9	
CSL-2.11		50	214.8	214.8	67.8	67.8

TABLE 3

The compressive force at concrete failure

Sample code	Cross-section dimensions b x h [mm]	Compressive force at concrete failure [kN]		Strengthening effect [%]	
		sample	average	sample	average
CR-0.1	140 x 180	133.5	133.25	–	–
CR-0.2		133		–	
CSL-1.3		183.6	182.5	37.8	37.0
CSL-1.4		181.4		36.1	
CSL-2.11		218.95	218.95	64.3	64.3

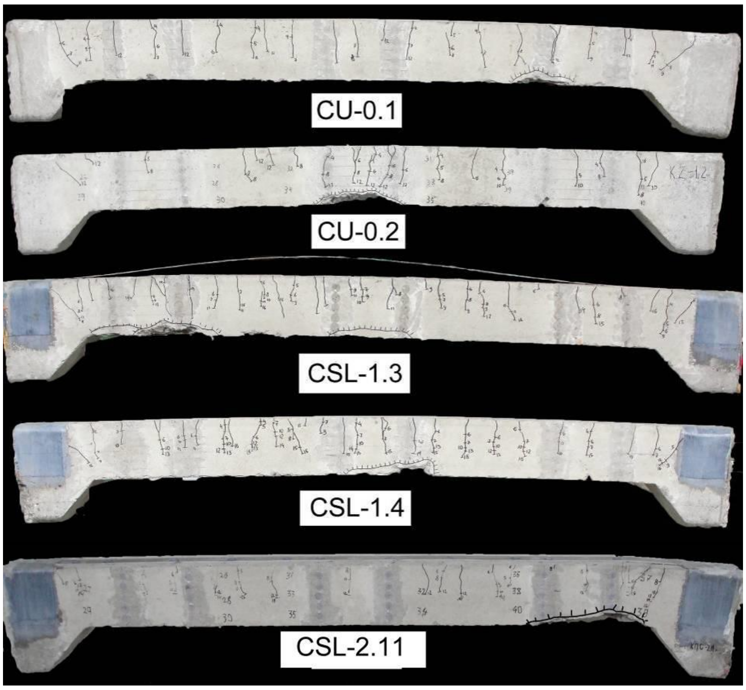


Fig. 13. Columns CU-0.1, CU-0.2, CSL-1.3, CSL-1.4, CSL-2.11 after testing

The strengthening effect of concrete failure for samples CSL-1 was 37% and for sample CSL-2.11 - 64.3%. It’s almost the same value of strengthening effect by laminate limit state.

Scheme of the destruction of samples columns is shown in Figure 13.

Conclusion

1. With strengthening the concrete columns reinforced by carbon laminate Sika CarboDur positive results can be achieved. It was also established that after experimental studies of reinforced concrete columns strengthened by carbon laminate Sika CarboDur S512 there was that the laminate started to work with

the main reinforcement simultaneously. This is confirmed by graphs of the experimental researches.

2. Ensuring secure anchoring of the strengthening laminate at the used method was achieved. The loss of adhesion of the laminate happened in only one sample (CSL-1.3), however, it happened after the destruction of the compressed area and as a result of a rapid growth deformations. In other samples the losses of adhesion were not observed.
3. Strength of reinforced concrete columns subjected to combined axial loading and bending after strengthening by carbon laminate with width 25 mm can be increased up to 35.3% and with width 50 mm - 67.8% at their laminate limit state.
4. With increasing value of the additional reinforcement in 2 times strengthening effect increased 1.92 times, which indicates that there is a almost linear dependence of the value of additional reinforcement and efficiency of its use. But for it is necessary to provide the high strength of compressive concrete, that not occurred its failure before limit state of additional reinforcement.

References

[1] Cambell F.C., Structural Composite Materials, ASM International, 2010.

[2] Harris B., Engineering Composite Materials, The Institute of Materials, London 1999.

[3] ACI 440.2R-02, 2002: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures, Published by the American Concrete Institute, Farmington Hills, MI, 46 p.

[4] FIB Bulletin 14 (2001), Design and use of externally bonded fibre reinforced polymer reinforcement (FRP EBR) for reinforced concrete structures, by 'EBR' working „party of FIB TG” 9.3, July 2001, 138 p.

[5] The Concrete Society, Technical Report No. 55, 2004: Design guidance for strengthening concrete structures using fibre composite materials (Second Edition).

[6] Borisyuk O.P., Konopchuk, Rozrakhunok nesuchoi zdatnosti normalnikh pereriziv zalizobetonnikh zginalnikh elementiv, pidsilenikh zovnishnoyu kompozitnoyu armaturoyu za dii malociklovikh navantazhen [Calculation of bearing capacity of normal cross-sections flexural reinforced concrete elements reinforced with external composite reinforcement for the actions of little cyclic loads], Rekomendacii - Rivne: „NUVGP” [Recommendations - Rivne: NUVGP], 2012, 38 p.

[7] Kvasha V.G., Melnik I.V., Klimpush M.D., Eksperimentalne doslidjennya zalizobetonnoi mostovoi balki za TP vipusk 56, pidsilenoi kompozitnoyu strichkoyu z vuglecevikh volokon CFRP [Experimental research of reinforced concrete bridge beams for TP Vol. 56, reinforced composite tape of carbon fibers CFRP], ZB. „Avtomobilni dorogi i dorozhnye budivnictvo”, Vip. 62 [Collection “Highways and road construction”] Kyiv 2001.

[8] Melnik I.V., Dobryanskiy R.Z., Murin A.Y., Micnist i deformativnist zalizobetonnikh balok pidsilenikh konstrukciynimi kompozitami pri riznikh umovakh poperednyogo zavantazhennya [Strength and deformability of concrete beams reinforced structural composites under different preload conditions], Zb. nauk. prac “Budivelni construkcii” [Col. of scientific works „Building constructions”, Vol. 56] Kyiv, 2005.

[9] Murin A.Y., Micnist normalnikh pereriziv zalizobetonnikh balok, pidsilenikh zovnishnyoyu kopmozitnoyu armaturoyu [Strength of concrete beams reinforced with external composite laminate], Vidavnictvo Nacionalnogo universitetu “Lvivska Politechnika” [Publication by Lviv Polytechnic National University] 2008.

[10] Strengthened technology by composite materials [Online], Available at http://ukr.sika.com

[11] Franca P., Costa A., Behavior of flexural strengthened beams with prestressed CFRP laminates, Proceedings of the FRPRCS-8, Patras, Greece 2007.
[12] Lamanna A.J., Bank L.C., Borowicz D.T., Arora D., Strengthening of concrete beams with mechanically fastened FRP strips, Proceedings of ICCI, 2002.
[13] The Vinh A., Flexural strengthening of reinforced concrete beams with prestressed FRP laminates, MSc dissertation, University of Padwa, Italy 2009.
[14] Rosenboom O., Rizkalla S., Analytical modeling of flexural debonding in CFRP strengthened reinforced or prestressed concrete beams, Proceedings of the FRPRCS-8, Patras, Greece 2007.
[15] Rusinowski P., Taljsten B., Sand B., Peeling failure at the cut-off end of CFRP strengthened RC beams, Denmark 2009.
[16] Starnes M., Duthinh D., Strengthening of reinforced concrete beams with carbon FRP, [in:] Composites in Constructions, J. Figueiras et al. (eds.), Swets & Zellinger, Lisse 2001.

Abstract

This paper presents results of research of reinforced concrete elements subjected to combined axial load and bending with different percentage of additional reinforcement. As an additional reinforcement there was used carbon laminate with width of 25 and 50 mm. The comparative analysis was carried out and strengthened effectiveness was determined.

Badania efektu wzmocnienia elementów żelbetowych poddanych jednoczesnemu działaniu sił osiowych i zginania z różnym procentem dodatkowego zbrojenia

Streszczenie

W artykule przedstawiono wyniki badań wzmocnionych elementów żelbetowych narażonych na jednoczesne działanie obciążenia osiowego oraz zginania z zastosowanym różnym procentem dodatkowego zbrojenia. Jako dodatkowego zbrojenia użyto laminatu węglowego o szerokościach 25 i 50 mm. Przeprowadzono analizę porównawczą i określono skuteczność wzmocnienia.