

## RC BEAMS STRENGTHENED BY RC JACKETING UNDER LOAD

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### ABSTRACT

This article is devoted to experimental researches of the reinforced concrete beams strengthened by a RC jacketing under load. The program of experimental researches of reinforced concrete beams was envisaged to test four series with a total number of 16 beams 2,100 mm long, of which 14 reinforced beams were additionally pre-loaded. In all experimental samples the longitudinal working reinforcement were steel bars of 2 Ø14 mm A500C. The beams were reinforced by jacketing with the use of two unstressed reinforcement rods of 2 Ø10 A500C mm. To simulate the real life conditions, the loading levels of 30%, 50%, 70% and 90% of the non-strengthened beam bearing capacity were maintained during jacketing. The strengthening effect decreased from 92 to 76% depending on the actual load level (30–90% of the load-bearing capacity of non-strengthened beams). The results of the study could be taken into account in designing reinforced concrete beams strengthened by a RC jacketing under previous loading.

**Key words:** RC beams, RC jacket, loading, bearing-capacity, strengthening, bending

### INTRODUCTION

At the present stage of economic development, the need for rapid restructuring of production with the use of new high technologies comes to the fore. Changing the equipment is usually associated with an increase in structural loads, which in turn leads to the need to increase the load-bearing capacity of the structures by means of their reinforcement (Blikharskyy, Brózda & Selejdak, 2018; Blikhars'kyi, 2019).

Reinforced concrete structures are a large part of the load-bearing structures of buildings in the industry, as they are characterized by significant predicted durability and low costs during the operation of structures. Usually, all load-bearing structures of buildings and structures are influenced by load. The level of load may vary: from the weight of the structures to the value of the full operational load. Therefore, to ensure the strength and reliability of the reinforcement of such structures,

in addition to ensure the compatibility of the reinforcement materials and the main cross-section of an element, a comprehensive consideration of the presence of load action during the reinforcement of the element is necessary. Therefore, the study of bending elements, especially reinforced by the load, is relevant.

Reinforcement of reinforced concrete structures was investigated by many scientists (Bobalo, Blikharskyy, Kopyika & Volynets, 2020), what allowed to develop effective structural solutions for strengthening reinforced concrete structures (Ashour, El-Refaie & Garriety, 2004; Martinola, Meda, Plizzari & Rinaldi, 2010; Usama, 2011; Krainskyi, Blikharskyy & Khmil, 2015; Lobodanov, Vegera & Blikharskyy, 2020; Selejdak, Blikharskyy, Khmil & Blikharskyy, 2020). However, the analysis shows that most of the performed studies concern the reinforcement of structures without taking into account the effect of loading and the initial stress-strain state caused by it. The effect of magnitude of

a current load level of the structure on the efficiency of the reinforcement method has also not been sufficiently studied. The magnitudes of correction coefficients of the operating conditions given in the current regulatory documents (Mosley, Hulse & Bungey, 2012) do not fully correspond to the results obtained experimentally (Blikharsky, Vashkevych, Vegeera & Blikharsky, 2020; Krainskyi, Blikharsky, Khmil & Vegeera, 2020). The purpose of this work was to experimentally test reinforced concrete beams, reinforced with reinforced concrete clamp under load actions of different levels. The efficiency of this method of beam reinforcement is established, depending on the level of acting load. The results will be a basis for a development or improvement of existing methods of calculations of the load-bearing capacity of reinforced concrete beams.

## MATERIALS AND METHODS

The program of experimental researches of reinforced concrete beams was envisaged to test four series with a total number of 16 beams 2,100 mm long, of which 14 beams were reinforced by load.

The cross-section of the beams was 100 × 200 mm with working reinforcement 2 Ø14 mm of class A500C.

Prism strength of concrete beams for 28 days was  $f_{cd} = 29$  MPa, Young modulus of deformation was  $E_{cd} = 28,500$  MPa.

In aim to study the effectiveness of the use of reinforced concrete clamp, it was provided a reinforcement of clamp, namely two rods Ø8 mm, Ø10 mm and Ø12 mm A500C. To simulate the real life conditions, the loading level of 30%, 50%, 70% and 90% of the non-strengthened beam bearing capacity was

maintained during jacketing. The thickness of the concrete of the casing is 20 mm across three faces and 40 mm along the lower elongated face to provide the required protective layer of concrete for additional reinforcement.

Accordingly, the following marking is accepted for the test specimens – “Bs-3.1-0.3”, where B denotes the beam, s – tested for short-term load after reinforcement, 3.1 – the series and number of the test specimen, 0.3 – the load level for which the reinforcement by the clip is performed. To determine the limit load at the first stage of the study, tests were performed on basic, non-reinforced beams of the first series B-1.1 and B-1.2 for the effect of short-term loading.

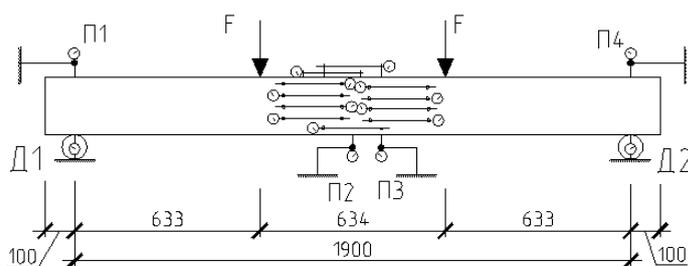
This article describes the results of studies of series of three beams reinforced with a concrete clip with the same amount of additional reinforcement (two of 10 mm of class A500C), made at different loading levels equal to 30%, 50%, 70% and 90% of the non-strengthened beam bearing capacity.

In the study of the experimental load samples, two concentrated forces were applied to the upper face of the beams in thirds of the span (Fig. 1).

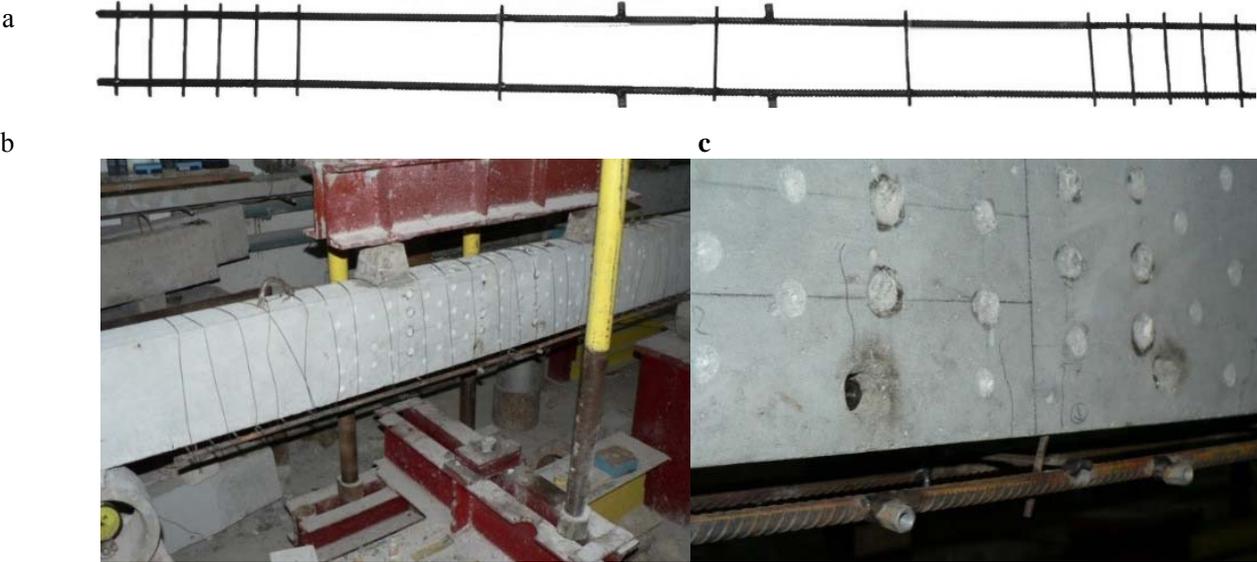
After loading the beams up to the design level, the load was fixed with the help of a power spring and work was performed on the arrangement of the concrete clip. The technological sequence is shown in Figures 2–5.

No earlier than 28 days after mounting of the device, the reinforced beams were tested by applying a short-term load to failure.

The deflections of the beams were measured using four clock-type deflectors with an accuracy of 0.01 mm. Two of them were mounted on supports on the upper face of the beam. The other two indicators



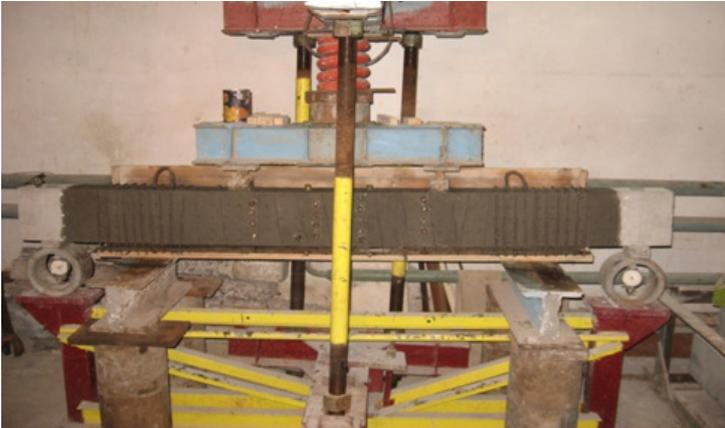
**Fig. 1.** General view of gauges in experimental sample



**Fig. 2.** Scheme (a) and general view (b) of jacket reinforcement and preparation of sample for strengthening (c)



**Fig. 3.** General view of sample with jacket reinforcement before strengthening



**Fig. 4.** Application of special glue material Cerinol ZH to the sample



**Fig. 5.** Application of reinforce concrete jacket to the sample (final process of strengthening)

were mounted on tripods, which remained constant during the deformation of the beam and were brought to the bottom face in the middle of the beam.

The deformations of the beam along the height of the concrete cross section were measured using 19 clock-type micro-indicators with a scale of 0.001 mm. Amongst these nine were placed on “old” concrete and 10 on “new” concrete with base dimensions of approximately 200 mm. The deformations of each rod (main and secondary) were also measured by microindicators with a scale of 0.001 mm. For this purpose, special holders were provided in the process of manufacturing of reinforcement frames. The general layout of the devices during the tests is shown in Figure 6.

## RESULTS AND DISCUSSION

Determination of load and effort, which corresponds to the flow of the reinforcement, was performed according to the obtained graphs of the average relative deformations of the reinforcing rods. After mounting the clamp, a noticeable decrease in the intensity deflection is observed with the same increase in the magnitude of the acting torque. This decrease in the deflection is explained by the fact that the reinforcement increased the geometric dimensions of the cross section, and therefore the stiffness of the section increased. Only in the last stages of loading their increase intensifies, what indicates the beginning of the flow of steel reinforcing



**Fig. 6.** General view of RC beam strengthened by RC jacket during test

bars. A graphic method determined the amount of force corresponding to the flow of the reinforcing rods. The results for all beams are presented in the table.

Since the reinforced concrete beam has two rows of reinforcement (main and in the clip), therefore, the flow occurs in them not at the same time but at different bending moment magnitude. This is explained by a different working height of the reinforcement in the section and the presence of initial stresses in the main reinforcement at the moment of reinforcing.

As a criterion of determination of the bearing capacity of such a complex reinforced structure, it is proposed to assume the magnitude of the bending moment at which the flow occurred in all reinforcing rods, i.e. their deformations reached the limit  $\varepsilon_s \geq \varepsilon_{s0}$ , and the corresponding stresses – the yield strength  $\sigma_s \geq f_{yd}$ .

Taking into account the accepted criterion of destruction, the effect of reinforcement of the tested beams was determined as the ratio of the greater magnitude of the bending moment corresponding to the yield strength of the reinforcement (main or secondary) in the series to the magnitude of the bending moment of the non-reinforced beams of the first series (the table).

In the case of the reinforced concrete beams, additionally strengthened with jacketing and pre-loaded at the level of 70% and 90% of bearing capacity of the non-strengthened beams, yield of the beam reinforcement was reached earlier than in the case of the jacket reinforcement, whereas in the case of the strengthened beams, pre-loaded at the level of 30% and 50% of bearing capacity of the non-strengthened beams, yield of the jacket reinforcement was reached earlier than in the case of the beam reinforcement.

This conclusion is valid for this ratio of additional and main reinforcement assumed in the experiment.

The physical destruction of reinforced beams was due to the destruction of the compressed zone of concrete after reaching the flow with all the reinforcement of the beam.

## CONCLUSIONS

The study investigated performances of reinforced concrete beams strengthened with reinforced concrete jacketing and pre-loaded at the level of 30%, 50%, 70% and 90% of the non-strengthened beam bearing capacity, maintained during jacketing. The

**Table.** The bearing-capacity of experimental samples

Series	Beams	Reinforcement [mm]		Moment [kN·m <sup>-1</sup> ]				Efficiency of strengthening [%]	
		main	jacket	yielding of main rebars		yielding of jacket rebars		sample	average
				sample	average	sample	average		
1	B-1.1			24.1	24.3				
	B-1.2		–	24.5					
3	Bs-3.1-0.3	2 Ø14	2 Ø10	46.4	45.9	41.5	41.9	91	89
	Bs-3.2-0.3			45.4		42.4		87	
	Bs-3.3-0.5			48.1	46.6	45.2	44.0	98	92
	Bs-3.4-0.5			45.2		42.8		86	
	Bs-3.5-0.7			44.2	42.8	48.1	46.3	98	90
	Bs-3.6-0.7			41.4		44.5		83	
	Bs-3.7-0.9			38.6	40.3	40.8	42.7	68	76
	Bs-3.8-0.9			41.9		44.5		83	

strengthening effect decreased from 92 to 76% depending on the actual load level (30–90% of the load-bearing capacity of non-strengthened beams). The results could be taken into account in designing reinforced concrete beams strengthened by a RC jacketing under previous loading.

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## BELKI ŻELBETOWE WZMOCNIONE PŁASZCZEM ŻELBETOWYM POD OBCIĄŻENIEM

### STRESZCZENIE

W artykule przedstawiono badania eksperymentalne belek żelbetowych wzmocnionych płaszczem żelbetowym pod obciążeniem. Program badań eksperymentalnych belek żelbetowych obejmował analizę 4 serii o łącznej liczbie 16 belek, których długość wynosiła 2100 mm, z czego 14 wzmocnionych belek zostało wcześniej dodatkowo obciążonych. Wszystkie badane próbki zostały wzmocnione zbrojeniem podłużnym, które stanowiły pręty stalowe 2 Ø14 mm A500C. Belki wzmocniono płaszczem żelbetowym, którego zbrojenie stanowiły pręty zbrojeniowe 2 Ø10 mm A500C. Aby zasymulować rzeczywiste warunki eksploatacji, podczas wzmocniania belek zastosowano różne poziomy obciążenia, a mianowicie 30%, 50%, 70% i 90%, dla granicznej nośności niewzmocnionych belek. Na podstawie badań stwierdzono, że efekt wzmocnienia belek zmniejszył się z 92 do 76% w zależności od poziomu aktualnego obciążenia (30–90% nośności belek niewzmocnionych). Uzyskane wyniki badań eksperymentalnych mogą zostać uwzględnione w projektowaniu belek żelbetowych wzmocnionych płaszczem żelbetowym po ich wcześniejszym obciążeniu.

**Słowa kluczowe:** belki żelbetowe, płaszcz żelbetowy, obciążenie, nośność, wzmocnienie, zginanie