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COMPUTER MODELLING OF RC BEAMS REINFORCED WITH HIGH STRENGTH REBARS AND STEEL PLATE

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Abstract: The use of computers provides the opportunity to analyse and design complex structures, taking into account the geometric and physical nonlinearity of construction materials. In the article the study of stress-strain state of mixed steel-concrete beams, were presented. The results of this study showed that the method of calculation according to designe codes gave satisfactorily results of calculated strength compared with experiments. However, these methodes do not provide complete information of structural performance at all levels of load. For a more complete study of the stress-strain state and the physical nature of the processes occurring in steel-concrete structures reinforced with a mixed reinforcement, the calculation method using "Lira" software complex is proposed. The method of calculation is based on the finite element method. The calculation is made taking into account physical nonlinearity and real diagrams of σ-ε of materials using the nonlinear deformation law №14 of "Lira" software complex. The proposed method of calculation allows to determine the values of bearing capacity, the development of deformations and the beginning of crack formation, as well as stresses at all load levels.
Keywords: load-carrying ability, deformability, mixed reinforcement, high-strength rebar, external reinforcement.

1. INTRODUCTION

Nowadays, reinforced concrete is one of the most common material used in construction. Since reinforced concrete is a composite material that combines the joint work of concrete and steel rebar, there is a questions of the most effective design solution for the efficient rebar placement and optimal rebar steel grade combination to ensure the economy and reliability of structures (Zhang et al., 2015; Blikhars'kyi and Obukh, 2018; Dudek et al. 2017; Selejdak et al. 2014). To date, many research have been conducted in the field of concrete mechanical properties improvement (Al Saffar et al., 2019; Fadhil et al., 2018; Sobol et al., 2014; Tayeh, et al., 2013; Abu-Tair, et al., 1996). Low reliability and insufficient bearing capacity of reinforced concrete structures is often a result of faults in manufacturing process and design (Koz, et al. 2017; Selejdak, et al., 2018), increased seismic resistance requirements (Alghuff, et al., 2019; Kramarchuk, et al., 2018) causing the need in strengthening or structural retrofitting (Blikharskyy et al. 2019; Blikharskyy, 2018; Brozda et al 2018; Khmil, et al., 2018; Krainskyi et al., 2018; Vegera, et al., 2018). Therefore, all these problems need to be taken into account in the design of reinforced concrete structures.

It is a common practice to carry out an experimental study of the newly designed structures before mass production. This ensures confidence in the reliability of the design and the compliance with the calculations. But during field experiments, there is always an issue of errors coming from slight deviations from the design. The presence of such inaccuracies makes it impossible to obtain clear and 100% correct results in analysis of the stressed state of various structures with combined reinforcement, which incorporate the combined work of concrete and reinforcement of several steel grades with significantly different modulus of elasticity. Therefore, the main task of this study is to develop a calculation model using the software complex "Lira" and compare the results obtained through simulation with the results of real laboratory testing. A broad modeling of steel concrete structures with combined reinforcement is planned after this comparison in order to provide recommendations on the optimal percentage of reinforcement of reinforced concrete structures with combined reinforcement.

Laboratory testing of structures with combined reinforcement (Bobalo et al., 2018) showed that the main difference from common reinforced concrete structures is the presence of residual strength after yielding in the lower grade reinforcement. The structure does not collapse immediately but shows the ductile behavior and continues to carry the load up to yielding in high-grade rebar.

Performance of flexural elements with combined reinforcement have been determined in previous studies (Bobalo et al., 2018). The further aim is to study the influence of the percentage of high-grade reinforcement without prestress on the strength and deformability of the structure, and to provide recommendations for optimal design of steel-concrete beams with combined high-grade rebar and external plate reinforcement.

2. RESEARCH METHODOLOGY

The correct calculation of structures depends on the accuracy of the input information on the physical and mechanical properties of materials. Therefore the real stress-strain diagrams "σ-ε" of materials were used when creating a calculation model.

A 2D model of the beam was split into rectangular and linear finite elements. The linear element that represents steel rebar is subjected to axial tension or compression only, and accordingly has four degrees of freedom. The rectangular element that represents concrete, is in a flat stressed state and has eight degrees of freedom.

Each node has two possible translations - x i z. The i-th linear finite element is represented by the coordinates of two points (1, 2), has a linear length L, and the dimensions of the cross section are B, H. The parameters of the material are described using the law of nonlinear deformation of material No. 14 (PC "Lira"), based on real nonlinear stress-strain diagrams of steel.

The linear element works only in tension and compression. It does not have any flexural deformations. The flat finite element is represented by the coordinates of the four nodes (1,2,3,4), the area S and the thickness H. Parameters of the material are described similarly, using the law of nonlinear deformation of material No. 14 (PC "Lear"), based on real nonlinear stress-strain diagram of concrete.
Finite element model is presented in Fig. 1.

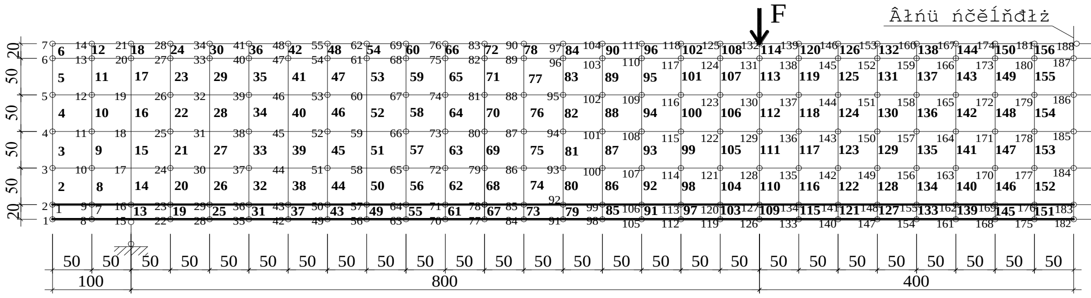

Fig. 1. Finite element model of the beam

In the calculation model, the loading of the reinforced concrete element with combined reinforcement was applied incrementally, adding10% of the failure load at each increment. The load increments corresponded to laboratory tests performed earlier (Bobalo et al., 2018). According to the analysis results for each stage of the load, the received stresses and strain data were compared with laboratory tests.
Laboratory tests consisted of eight reinforced concrete beams with a cross section of 0.12x0.24m, with a 2.4m span. Outer plate reinforcement was connected to the beam with U-shaped anchors welded to the plate.
Reinforcement details of test beams are shown on Fig. 2.

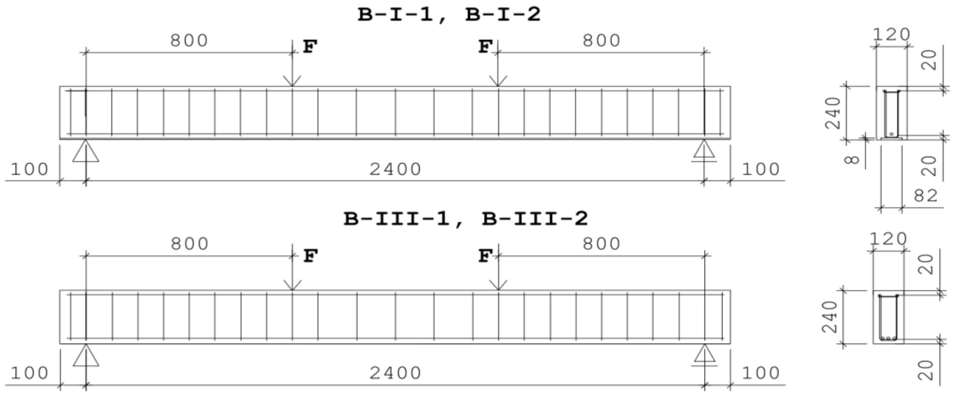

Fig. 2. Reinforcement details of test beams

In order to reduce the absolute error during laboratory testing, duplicate "twin" beams were tested. All samples were made from one concrete mix. This approach allowed us to obtain accurate experimental results (Bobalo et al., 2018).

Table 1.
Physical and mechanical properties of materials of the experimental beams

Notation of the beams		B - I - 1, B - I - 2	B - II - 1, B - II - 2	B - III - 1, B - III - 2	B - IV - 1, B - IV - 2
Concrete	$f_{ck,cube}$ / $f_{ck,prism}$, MPa	48,7 / 29,6	46,3 / 28,1	46,3 / 28,1	49,2 / 29,9
	f_{cd}, MPa	22,8	21,6	21,6	23,0
	$E_{cm}x10^3$, MPa	38,00	37,76	38,04	38,50
Reinforcement of the tension zone – longitudinal plate	B_s x t_s, mm	82x8	46x8	-	114x8
	f_{yk}, MPa	287	287	-	287
	f_{yd}, MPa	273	273	-	273
	$E_p x10^5$, MPa	2,05	2,05	-	2,05
	Grade	C275	C275	-	C275
Reinforcement of the tension zone – longitudinal bar	∅, mm	1ø10	2ø10	3ø10	-
	f_{yk}, MPa	1080	1080	1080	-
	f_{yd}, MPa	900	900	900	-
	$E_p x10^5$, MPa	1,85	1,85	1,85	-
	Grade	A1000	A1000	A1000	-
Reinforcement of the compression zone – longitudinal bar	∅, mm	8	8	8	8
	f_{yk}', MPa	594,5	594,5	594,5	594,5
	f_{yd}', MPa	495	495	495	495
	$E_p' x10^5$, MPa	2,05	2,05	2,05	2,05
	Grade	A400C	A400C	A400C	A400C
Ties – transverse bars	∅, mm	5	5	5	5
	f_{ywd}, MPa	296	296	296	296
	$E_p x10^5$, MPa	2,05	2,05	2,05	2,05
	Grade	A240C	A240C	A240C	A240C

3. RESULTS OF THE ANALYSIS AND THE EXPERIMENTAL STUDY

Finite element modeling and analysis allowed us to obtain the values of stresses and strain in concrete and reinforcement, at all stages of loading until failure.
The result of analysis obtained on the basis of finite element modeling using PC "Lira" considering physical nonlinearity and real diagrams of σ-ε of materials for the beam B-III is shown on Fig.3.

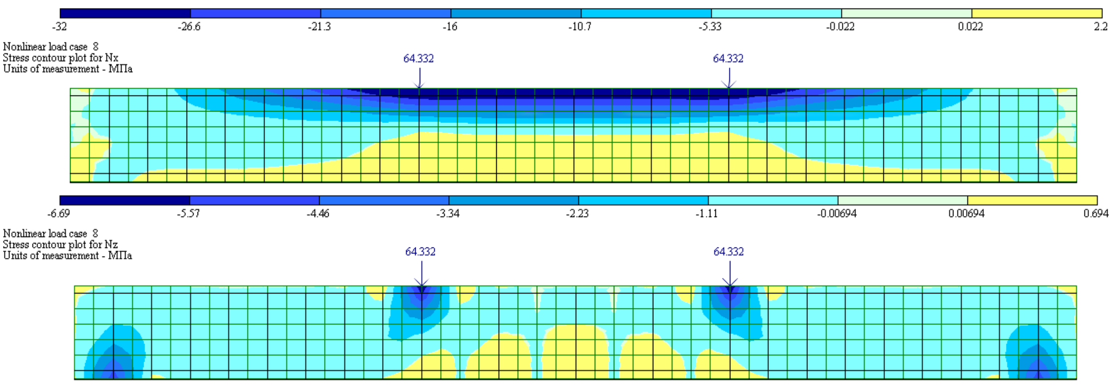

Fig. 3. Estimated stresses in beam B-III at failure load

Comparison of the results of computer calculations and experimental laboratory studies (Bobalo et al., 2018) is presented in Table 2.

Table 2.
Comparison of the numerical code verification, FE analysis and laboratory tests of reinforced concrete beams with combined reinforcement

Notation of the beams	Experimental value of bending moment M_{dr1} at yielding of plate reinforcement, kNm	FE analysis value of bending moment M_{fe1} at yielding of plate reinforcement, kNm	$(M_{dr1} - M_{fe1}) / M_{dr1}$, %	Bearing capacity (high-grade rebar yielding, concrete crushing)				
				Experimental value M_{dr2}, kNm	According to DBN B.2.6-98:2009 M^{DBN}_{max}, kNm	$(M_{dr2}-M^{DBN}_{max})/M_{dr2}$, %	FE analysis M^{fe}_{max}, kNm	$(M_{dr2}-M^{fe}_{max})/M_{dr2}$, %
B - I - 1	42,70	43.5	-1.9	51,52	51,38	0,3	51,4	0,2
B - I - 2	43,60		0.2	52,64		2,4		2,4
B - II - 1	31,10	30.1	3,2	55,20	52,10	5,6	52,3	5,3
B - II - 2	31,10		3,2	52,40		0,6		0,2
B - III - 1	-	-	-	55,36	52,85	4,5	53,7	3,0
B - III - 2	-		-	57,04		7,3		5,9
B - IV - 1	51,49	50.4	2.1	51,49	50,25	2,4	50,4	2,1
B - IV - 2	50,57		0.3	50,57		0,6		0,3

The obtained results of finite element analysis corresponds to the experimental data with sufficient accuracy. This confirms the possibility of using the such models for calculations of reinforced concrete structures with combined outer plate reinforcement and internal high-grade rebar.

The deviation of the results of the bearing capacity of beams according to finit element analysis does not exceed the experimental data more than 5.9% (Table 2).

Computer calculation using the software complex "Lira", based on finite element method, considering the real stress-strain diagrams "σ-ε" of materials, corresponds to the performance of a real reinforced concrete structures with combined reinforcement. This proves that the proposed design model allows to estimate the load bearing capacity, deformations, stress in the rebar and outer plate reinforcement with sufficient accuracy.

4. CONCLUSIONS

The implemented computer calculation program (based on finite element methods and successive approximations, considering real stress-strain diagrams of materials) corresponds to the performance of a real reinforced concrete structures with combined reinforcement.

The proposed method allows to carry out modeling and analysis of the behavior of reinforced concrete structures with sufficient accuracy. Also it is possible to compare

unlimited number of design solutions with the same characteristics of materials, which allows to study different patterns of the work of reinforced concrete structures.
The proposed program allows to obtain a real distribution of stresses and strain not only in concrete, but also in longitudinal and transverse reinforcement at all stages of loading.

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