

## DETERMINATION OF THE OPTIMUM PERCENTAGE OF HIGH STRENGTH BARS IN RC BEAMS WITH COMBINED REINFORCEMENT USING FEM

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**Abstract:** In this work on the basis of the developed and tested mathematical model, the numerical experiment is conducted in order to study in more detail the specifics of performance of concrete beams` with combined reinforcement. For this purpose nine series of reinforced concrete beams with different combination of steel bars (A400C, At800, A1000) and ribbon reinforcement (C275) were modeled. In the developed series two classes of concrete were used: C50/60, C35/45. The functions derived on the basis of mathematical modeling allow us to determine the recommended percentage of high-strength reinforcement of common reinforced concrete structures with single reinforcement. Therefore, the possibility is obtained to reduce the total structures` reinforcement percentage, increasing their deformability by the specified value without affecting the bearing capacity.

**Keywords:** deformability, serviceability, combined reinforcement, high-strength rebar, steel plate.

### 1. INTRODUCTION

Within the conditions of the economy growth and introduction of new structures` types in construction, there is an increasing need in calculations` modernization. Nowadays most of structures are damaged (Blikharskyy et al., 2019; Kos et al., 2017; Lobodanov et al., 2020; Lipinski et al., 2017; Selejdak et al., 2018; Yang et al., 2018) due to the variety of negative impacts and need to be strengthened and rebuilt (Abu-Tair et al., 1996; Blikharskyy et al., 2018; Krainskyi et al., 2018). There are various ways of strengthening and restoration reinforced concrete structures today (Blikharskyy et al., 2020; Brozda et al., 2017; Krainskyi et al., 2020; Khmil et al., 2018; Selejdak et al., 2020; Vejera et al., 2018). Therefore high topicality is reached in the issue of new reinforced concrete structures development with greater operational durability.

The development of structures with combined reinforcement or with new materials` types requires calculations` development and refinement. Most often these improvements were reduced to the introduction of new coefficients in the calculation, which led to formulas` complication and physical essence loss.

Reduce of metal consumption and improvement of RC structures manufacturing technology is an important issue of modern construction. Today a number of works for cements` modifications in order to reduce the concrete price are conducted (Sobol et al., 2014; Tayeh et al., 2013). However, the durability of such structures still has to be ensured. One of the approaches which provides for metal consumption reduce is the use of external steel plates and high-strength steels. The use of such rebar in steel-concrete elements increases the cross-section effective height. In addition it eliminates the necessity of multi-row rods` location along the cross-section height, which leads to steel savings.

Concentrated sheet reinforcement ranking on the external most stressed planes of steel-concrete structures provides better usage of materials` properties. Therefore economical characteristics are increased by 30-40% comparing with reinforced concrete structures.

In Europe and in Ukrainian regulations of DBN B.2.6-98: 2009 (DSTU B. 2.6-156: 2010) the preference is given to the deformation calculation method. With the global development of computer technology this method is easier to adapt to machine calculations as it is impossible to imagine modern construction without a computer.

The main advantage of the deformation technique with the use of real  $\sigma$ - $\epsilon$  diagrams of concrete and reinforcement is the ability to calculate various reinforced concrete elements, including those with the compound and combined cross-sections, including different types and classes of concrete and reinforcement. This method allows to objectively estimate the stress-strain state and strength of reinforced concrete structures, to calculate the stresses of the separate steel bars and determine the strength of each rebar in the combined reinforcement.

## **2. RESEARCH METHODOLOGY**

When using the armature package there is the possibility to more effectively choose a rational package cross-section by varying the bars or the ribbon reinforcement width. The influence of combined reinforcement on the work of the structure as a whole is interesting to study. It is necessary to study the inclusion in the work and the stresses` magnitude perceived by each of the rebar, the process and reasons of the samples` destruction, as well as the impact and expediency of high-strength rebar on the reinforced concrete structures` strength and deformability.

Therefore, the task was formulated to investigate in more detail the stress-strain state of reinforced concrete beams strengthened with the package of different classes` armature using the mathematical model. The main objective of the study is to provide recommendations concerning the impact of the percentage of reinforcement by high strength bars.

## **3. TECHNOLOGY OF TEST SAMPLES` MANUFACTURING**

On the basis of the developed and tested mathematical model the numerical experiment was conducted with the purpose to study in more detail the work characteristics of reinforced concrete beams with combined reinforcement. For this purpose nine series of reinforced concrete beams with different combination of rebar (A400C, At800,

A1000) and ribbon reinforcement (C275) were modeled. In the developed series two types of concrete were used: C50/60, C35/45. Within one series the materials of the test specimens were the same, the diversity was only in the different percentage ratio of the rebar and tape reinforcement.

First all beams were calculated according to the regulations of DBN B.2.6-98: 2009, valid at the experiment time; the cross-section was composed for the same destructive load; thus two forces of 85kN were applied at a distance of 1/3 of the span. The use of the same destructive load for all the beams made it possible to compare the effect of different percentage of different reinforcement classes on the beam performance. The load was carried out in stages of 10% of destructive.

With a higher portion of the high strength reinforcement, the total percentage of reinforcement decreased with the same strength of the beam determined according to the norms.

For the numerical experiment beams with the same basic parameters as those studied in the previous articles were accepted (Bobalo et al., 2020, Bobalo et al., 2018). The estimated span was 2400mm and cross-section was 120x240mm. In all beams, both the steel bars as well as the ribbon reinforcement had adhesion to concrete.

The process of steel plate reinforced concrete test specimens` manufacturing consisted of two stages:

1) manufacturing of frames; 2) concreting of steel-concrete specimens.

At the first stage the U-shaped rod anchors were welded with a certain step to the smooth S275 class steel plate.

The ends of rod anchors were directed upward and it served as a transverse armature. The weld seam length corresponded to the width of the plate. Therefore a reliable adhesion of external steel plate reinforcement with concrete was obtained. The transverse armature height was equal to 220mm. The next step was to weld rigid butts (Fig.1).

At the end of the frame manufacturing process, a high-strength reinforcement was installed with strain gauges glued on it in order to measure deformations.

Steel plate reinforced concrete specimens` concreting was carried out in specially made metallic shuttering. Concrete mixture consolidation was made with the use of deep vibrator. Simultaneously with specimens series` concretization, cubic specimens with 150 mm rib and 100x100 mm cross-section 400 mm length prisms were manufactured in special forms.

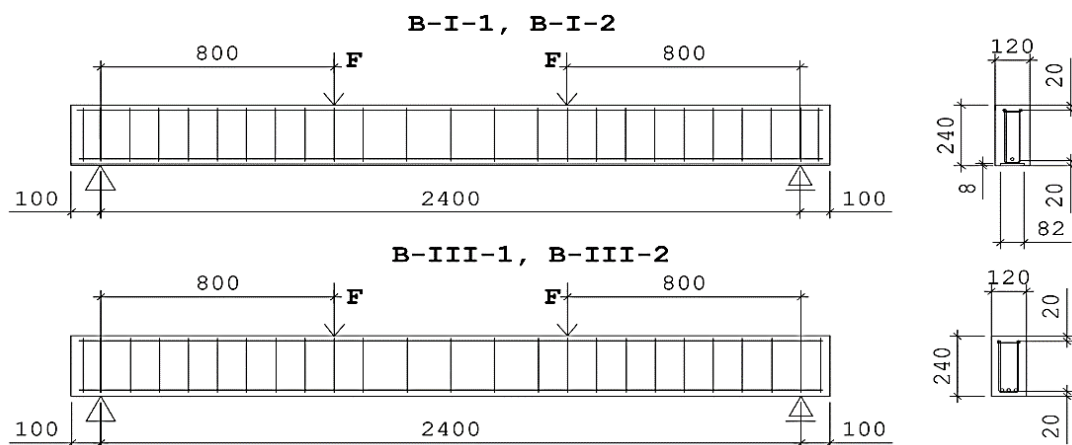


Fig. 1. The reinforcement frame construction for tested samples

Table 1  
Test results of steel rebar's

Beams` series		B - I	B - II	B - III	B - IV	B - V	B - VI
Heavy concrete	$f_{ck,prism}$ , MPa	43,8 (C50/60)	43,8 (C50/60)	43,8 (C50/60)	32,6 (C35/45)	32,6 (C35/45)	32,6 (C35/45)
	$f_{ctk,}$ , MPa	2,55	2,55	2,55	2,24	2,24	2,24
	$E_{cm} \times 10^3$ , MPa	40,80	40,80	40,80	38,20	38,20	38,20
	$\epsilon_{cu3,ck}$	0,00216	0,00216	0,00216	0,00255	0,00255	0,00255
The tensed zone reinforcement– ribbon, longitudinal	$f_{yk}$ , MPa	287	287	287	287	287	287
	$E_p \times 10^5$ , MPa	2,05	2,05	2,05	2,05	2,05	2,05
	$\epsilon_{uk}$	0,025	0,025	0,025	0,025	0,025	0,025
	Mark	C275	C275	C275	C275	C275	C275
The tensed zone reinforcement– steel bars, longitudinal	$f_{yk}$ , MPa	1080	904	478	1080	904	478
	$E_p \times 10^5$ , MPa	1,85	1,91	2,03	1,85	1,91	2,03
	$\epsilon_{uk}$	0,018	0,018	0,025	0,018	0,018	0,025
	Class	A1000	At800	A400C	A1000	At800	A400C
The compressed zone reinforcement steel bars, longitudinal	$\varnothing$ , mm	8	8	8	8	8	8
	$f_{yk}$ , MPa	478	478	478	478	478	478
	$E_p \times 10^5$ , MPa	2,03	2,03	2,03	2,03	2,03	2,03
	$\epsilon_{uk}$	0,025	0,025	0,025	0,025	0,025	0,025
	Class	A400C	A400C	A400C	A400C	A400C	A400C
The transverse steel bars	$\varnothing$ , mm	5	5	5	5	5	5
	$R_{sw}$ , ( $f_{ywd}$ ), MPa	296	296	296	296	296	296
	$E_{sw}(E_p) \times 10^5$ , MPa	2,05	2,05	2,05	2,05	2,05	2,05
	Class	A 240	A 240	A 240	A 240	A 240	A 240

#### 4. RESULTS OF THE FEM STUDY

The results of numerical experiments have shown that in the beams with a higher percentage of high strength reinforcement the outer tape yield level is reached earlier. However, after reaching the yield stress level the tape armature continues to perceive the loading.

With further loading of the beam the stresses in the high-strength reinforcement begin to accelerate their growth and the deflection values are increased more quickly. It is hard to visually identify the moment of reaching the yield stress in outer ribbon reinforcement, in both experimental samples, as well as in mathematically modelled beams of mathematical modeling. Thus, there are no sudden deflection jumps, the beam construction works in the plastic state, which contributes to such structures` higher safety. The bearing capacity exhaustion of the beams reinforced with the armature package occurs after the conditional yield strength is achieved by the stronger reinforcement, which causes the formation of plastic hinge in the compressed zone, after which the beam is no longer able to perceive additional loads.

After analysis of the results it was established that the increase of high-strength reinforcement percentage causes the deflections increase and at its large amount the deflections exceed the limit values. Therefore, it is important to pay attention to the optimum ratio of different armature classes use, depending on their characteristics, which would allow to provide admissible deflections, strength and crack resistance at the minimum reinforcement percentage for beam construction.

**5. RECOMMENDATIONS FOR REINFORCED CONCRETE BEAMS` DESIGN STRENGTHENED BY THE REBAR`S PACKAGE**

The analysis of the experimental data obtained from the test results of the experimental samples and the numerical experiment showed significant difference between the work of reinforced concrete beams reinforced with different percentage of high-strength rebar in combination with the ribbon reinforcement. The revealed such structures` specifics cause certain features of their design.

According to the mathematical modeling results graphical dependencies were built (Fig. 2) showing the deflections` increase with the increase of the percentage of A1000, At800 or A400C classes` rebar in concrete beams with the combined reinforcement.

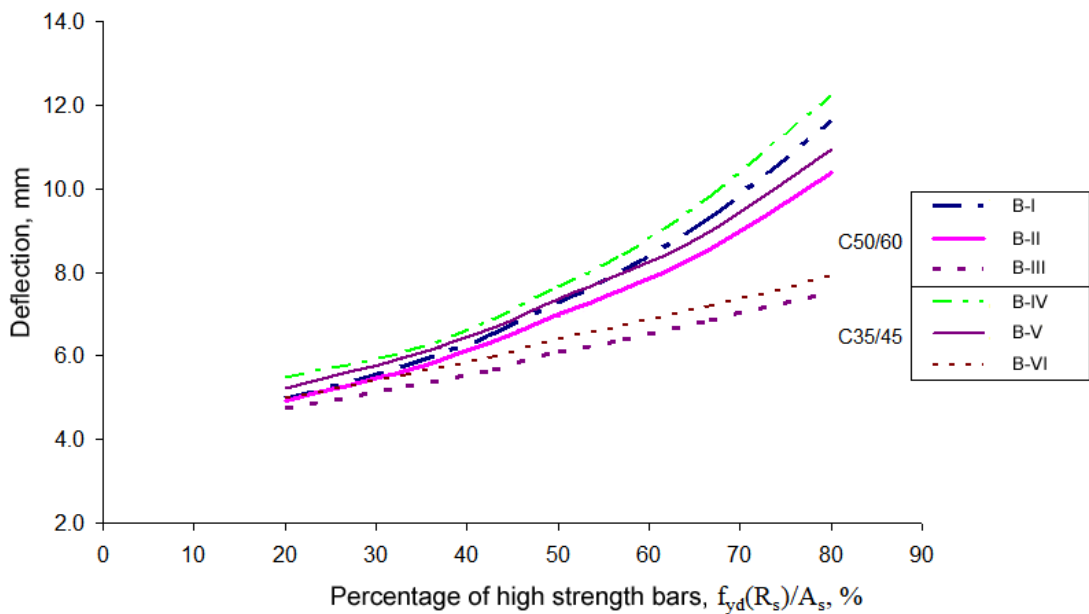


Fig. 2. The dependence of deflections on the concrete classes and high strength rebar percentage in the concrete beams with combined reinforcement

In order to simplify the design of structures with combined reinforcement, the functions of the dependence of the deflection increase on the percentage of reinforcement by high strength reinforcement are derived. These functions are obtained through the graphical dependencies approximation (Fig. 2):

$$L_n = \sum_{i=0}^n y_i \frac{\omega_n(x)}{(x - x_i)\omega'_n(x_i)} \tag{1}$$

$$\omega_n(x) = (x - x_0)(x - x_1) \dots (x - x_i) \dots (x - x_n) \tag{2}$$

where  $\{x_i\}_{i=0,n}$  - interpolation nodes,  $y_i = \Delta f(x_i), i = \overline{0,n}$  - value of function  $\Delta f(x)$ .

Thus, in this case as the interpolation nodes is taken the deflection increment  $\Delta f$  and as the function value- the percentage of high strength rebar. Formulas are given in the table 2.

Table 2

Functions of dependence of the high strength rebar percentage on the deflection increment in the case of combined reinforcement of RC beams with the adhesion of ribbon reinforcement to concrete

Armature class	% of reinforcement, depending on the deflection increment $\Delta f$
A1000	$\rho_{l,s} = 0.193\Delta f^3 - 5.99\Delta f^2 + 67.3\Delta f - 199.7$
At800	$\rho_{l,s} = 0.01\Delta f^3 - 3.41\Delta f^2 + 45.13\Delta f - 136.4$
A400	$\rho_{l,s} = 0.534\Delta f^3 - 11.1\Delta f^2 + 96.2\Delta f - 249.7$

where  $\Delta f$  – deflection increment, mm;  $\rho_{l,s}$  - the high strength rebar percentage for RC beams, reinforced with armature package, taken by the dependency  $\frac{f_{un}}{f_{max,sheet} + f_{un}} \cdot 100\%$ , where  $f_{un}$  – the limit allowable deflection, and  $f_{max,sheet}$  – the

calculated deflection for the RC beam with the single reinforcement.

This functions make it possible to identify the optimal percentage of high strength rebar for common RC beam with single reinforcement, knowing the bearing capacity and difference  $\Delta f$  between the limit allowable and calculated deflections. The recommended percentage of high strength reinforcement will have no influence on beam strength, however, it will allow to identify the deflection increment in pre-assumed value (mm), reducing, therefore the total reinforcement percentage.

## 6. CONCLUSIONS

The functions, derived from the mathematical modeling data allow us to determine the recommended percentage of high-strength reinforcement for common single-reinforced concrete structures, which allows to reduce the overall percentage of structures` reinforcement, increasing their deformability by the specified value without affecting the bearing capacity.

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