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FLEXURAL DESIGN ANALYSIS ACCORDING TO STAS 10107/0-90 *VERSUS* EN 1992-1-1/2004–EUROCODE2

BY

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Abstract. Several years after the end of World War II, projects of reconstruction started in all Europe’s countries for the great cities destroyed by the war. Before the war, design standards concerning with reinforced concrete structures existed in the developed countries. After the end of war, national standard started also to be published in countries less developed. The first Romanian code provided for designing of reinforced/prestressed structural members was STAS 1546-50. For design, the load factor method was provided. After a decade, a design standard, P8-62, for reinforced/prestressed structural members based on limit state method, was published. Subsequently, an improved version, based also on limit state method, entitled STAS 10107/0-76, replaced it. New versions of the standard 10107/0 were published in 1986 and 1990. All these versions have included the reinforced/prestressed concrete knowledge of the age. The last one is the most sophisticated edition providing aseismic prescriptions for RC structural elements.

In the next decades the design of the civil structures in Romania will be based on the Eurocodes. For reinforced/prestressed concrete structures the Eurocode2 will became of paramount importance to the design of the structural members.

Comparative analysis based on flexure design relations, provided by the codes for singly reinforced and doubly reinforced range, are figured. Also,

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additional amount of reinforcement in the flexure design based on STAS 10107/-90 about EC2 are underlined.

Key words: reinforced concrete; structural members; flexure design; Eurocode2.

1. Introduction

Since 1991, in Romania the design of reinforced/prestressed concrete structural members was based on the national standard STAS 10107/0-90. This edition seems to be the last one before the validation of the Eurocode2 (EC2) as standard for the design. It is worth to mention that the initial edition of the national standard 10107/0-76 was improved in 1986 and 1989 in accordance with developing of the research.

Beginning with 2004 the European Committee for Standardization approved a new EC2's edition for design of the reinforced concrete structures, which is valid throughout Europe (STAS 10107/0-90, 1991). This actual edition contains slightly improvements regarding to the last edition published in 1994. Based on this new edition of the EC2, the Romanian Association for Standardization (ASRO) has published an integral copy of the European Standard in Romanian language (SR EN 1992-1-1, 2006), and also two years later the first edition of the National Annex (SR EN 1992-1-1, 2008).

2. Flexure Design According to EC2

For the design of cross-section, EC2 provides three types of idealized stress distributions which may be applied. The first is a parabola–rectangle stress distribution. The second one is a bilinear and the last one is an equivalent rectangular stress distribution (STAS 10107/0-90, 1991). It is well known that the parabola–rectangle is the most conservative approach which may be deemed. Nevertheless, if the parabola–rectangle stress distribution for concrete

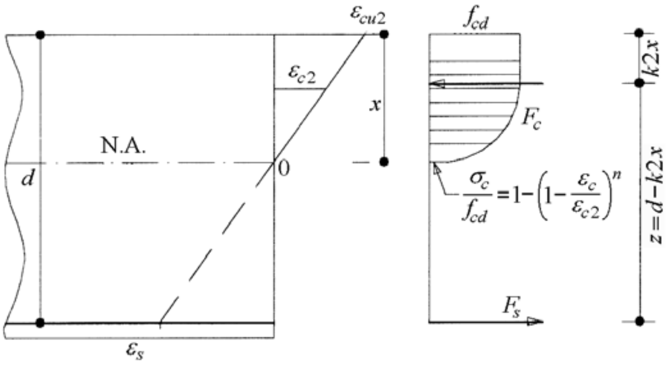

Fig. 1 – Parabola–rectangle stress distribution on RC section according to EC2.

in compression is deemed, as presented in Fig. 1, the design of cross-section can be carried out relatively easy for all strength classes of concrete (Roşca & Mihai, 2009).

Comparatively, calculations using both stress distributions, namely parabola–rectangle and rectangle, shows that, as for strength classes of concrete smaller than 50 MPa, as for classes higher than 50 MPa, the differences between the required areas of reinforcement are less than 1% for singly reinforcing section and less than 2% for doubly reinforcing section (Roşca & Mihai, 2009).

The idealized rectangular stress distribution on concrete section is widely spread among designers because is easiest to apply by hand calculation. As it can be seen in Fig. 2, the stress distribution on concrete section is established at the design value of the concrete compressive strength, f_{cd} , and other two factors. The factor λ, defining the effective height of the compression zone, and the factor η, defining the effective strength, both specified in EC2, are shown in Table 1.

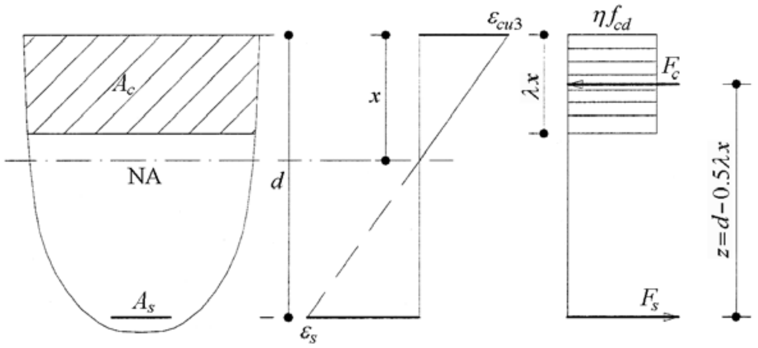

Fig. 2 – Rectangular stress distribution according EC2 §3.1.7.3.

Table 1

Factors λ and η provided by EC2 §3.1.7.3

Concrete strength	λ	η
$f_{ck} \le 50$ MPa	0.8	1
$50 < f_{ck} \le 90$ MPa	$0.8 - (f_{ck} - 50)/400$	$1.0 - (f_{ck} - 50)/200$

The relations for design, considering the rectangular stress distribution on section, are based on equilibrium of the internal forces and may be expressed as

$$\omega = \lambda\eta\xi = \frac{A_s}{bd}\cdot\frac{f_{yd}}{f_{cd}} \qquad (1), \qquad\qquad \mu = \lambda\eta\xi\left(1-0.5\lambda\xi\right) \qquad (2),$$

where ω and μ are mechanical coefficient ratio and the reduced bending moment, respectively.

It can be noted that the parameters which define the stress block, namely the lever arm, z, and the average stress, ηf_{cd} , decrease for strength classes of concrete higher than C50/60.

For a rectangular RC section, the design relations, that comply with STAS 10107/0-90 for the rectangular stress distribution, are

$$\xi = \alpha = \frac{A_a}{bh_0} \cdot \frac{R_a}{R_c} \quad (3), \qquad m = \xi\left(1 - 0.5\xi\right) \quad (4).$$

In relations (3) and (4), α is the mechanical coefficient ratio and m is the reduced bending moment according to STAS 10107/0-90 (Agent *et al.*, 1992).

3. Comparatively Design Analysis

Based on the strain compatibility on RC section, in Table 2 are comparatively presented, for both standards EC2 and 10107/0-90, the ductile failure limiting values for strength classes below 60 MPa.

Table 2

Ductile Failure Limiting Values in Accordance with EC2 and 10107/0-90

Standard	Classes	Steel	ξ_b	μ_b
EC2	≤50/60	S400	0.668	0.392
		S500	0.618	0.372
		S600	0.572	0.353
10107/0	<35/40	PC52	0.700	0.403
		PC60	0.667	0.391
		STNB	0.654	0.386
10107/0	≥35/40	PC52	0.660	0.389
		PC60	0.632	0.378
		STNB	0.619	0.373

The tensile stress in reinforcement depends on the depth of the concrete area in compression. Thus, for both standards EC2 and 10107/0-90, the tensile

Table 3

Relationships for Stress in Reinforcement According to EC2 and 10107/0-90

Depth of NA for	Stress in steel reinforcing according with	
	10107/0-90	EC2
$\xi \le \xi_b$	$\sigma_a = R_a$	$\sigma_s = f_{yd}$
$\xi_b < \xi \le 0.8$	$\sigma_a = \frac{\xi_b}{\xi} \cdot \frac{1-1.25\xi}{1-1.25\xi_b} R_a$	$\sigma_s = E_s\left(\frac{1}{\xi} - 1\right)\varepsilon_{c2}$
$\xi > 0.8$	$\sigma_a = -R_a\left(5\xi - 4\right)$	

stress relationships are comparatively presented in Table 3 (Eurocode2, 2004; STAS 10107/0-90, 1991).

For comparison purposes, diagrammatic representation of the relationships between the reduced moment and the mechanical reinforcement percentage are plotted. Thus, in Figs. 3 and 4 charts representing the relationship of the singly reinforced section for various steel grades are plotted.

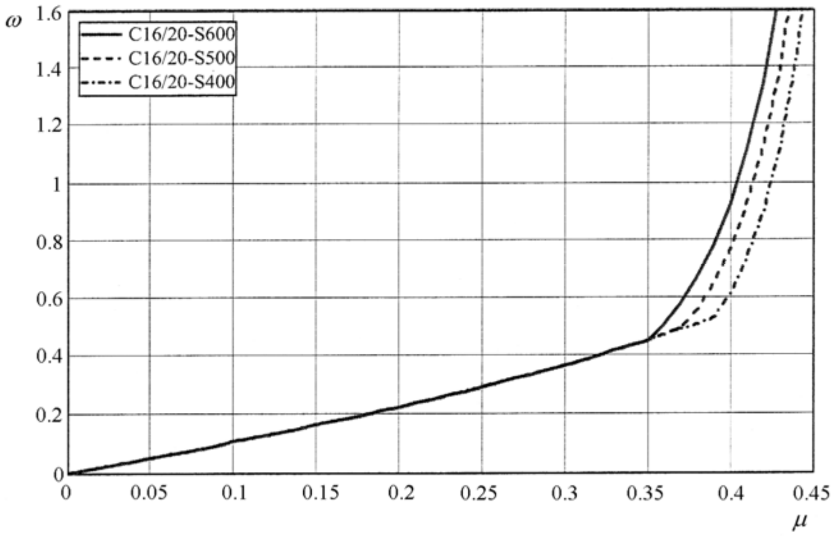

Fig. 3 – Relationship *μ vs. ω* for the singly RC section according with EC2.

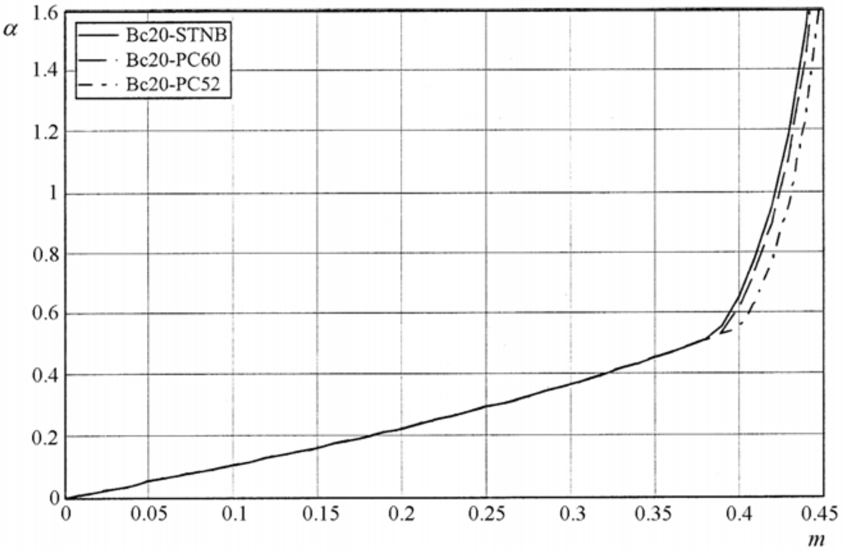

Fig. 4 – Relationship *m vs. α* for the singly RC section according to 10107/0-90.

The diagrams μ *vs.* ω from Fig. 3 are plotted based on relations (1), (2) and accounting for the relations from Table 3, which complies to EC2. The steel grades are those mentioned in EC2, namely, S400, S500 and S600. Equally, the diagrams from Fig. 4 are plotted based also on equilibrium design relation and accounting for relations from Table 3, which complies to 10107/0-90. The steel grades are those mentioned in STAS 10107/0-90 for RC structural members, namely, STNB, PC60 and PC52.

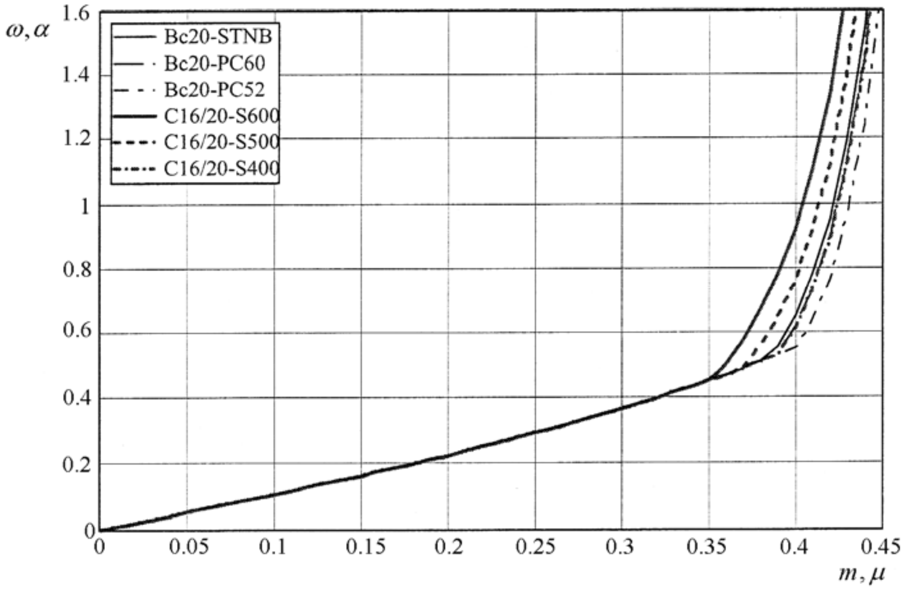

Fig. 5 – 10107/0-90 *vs.* EC2; diagrams between the reduced moment and the mechanical reinforcement percentage for the singly RC section.

If the curves from Figs. 3 and 4 are over-shaped, it can be seen that the slope is identical for all steel grades in the light of both standards (Fig. 5). As is expected, the curves change the slope into inflexion points which represent the balanced limit where the doubly reinforcing should be applied. It should be noted that the branch beyond the balanced limit, μ_b , for the curves plotted above, exists theoretically. Practically, in the ordinary design starting with balanced limit, μ_b, the doubly reinforcing of the section should be provided.

In Figs. 6 and 7 are illustrated the flexure design diagrams for RC section in accordance with EC2 and STAS 10107/0-90, respectively. The diagrams are provided for two of the most involved strength classes of concrete used in the ordinary design of structural reinforced members, and for the steel grades provided by both standards. It should be mentioned that the flexure design diagrams cover the singly and doubly RC section domain and the reinforcement percentage, *p*, is provided for the reinforcement bars in tension. Comparatively, in Figs. 8,…,11 flexure design diagrams are plotted. In each figure the curves are calculated based on equivalent strength classes of concrete provided by both standards

Summarizing the analysis of diagrams presented in foregoing figures, Table 4 presents the additional amount of reinforcement for a concrete section subjected at the same value of bending moment when designing is based on STAS 10107/0-90 *versus* the EC2. The differences are expressed in % of reinforcement, Δp, which is calculated at the minimum value of the balanced reduced bending moment, μ_b, of the compared reinforcing steels.

Table 4

Additional Amount of Reinforcement in the Flexure Design Based on STAS 10107/0-90 about EC2 for Equivalent Strength Classes of Concrete

10107/0-90 EC2		Δp, [%]			
		Bc20		Bc30	
		PC52	PC60	PC52	PC60
C16/20	S400	0.143	–0.111	–	–
	S500	0.448	0.211	–	–
C25/30	S400	–	–	0.285	–0.108
	S500	–	–	0.763	0.384

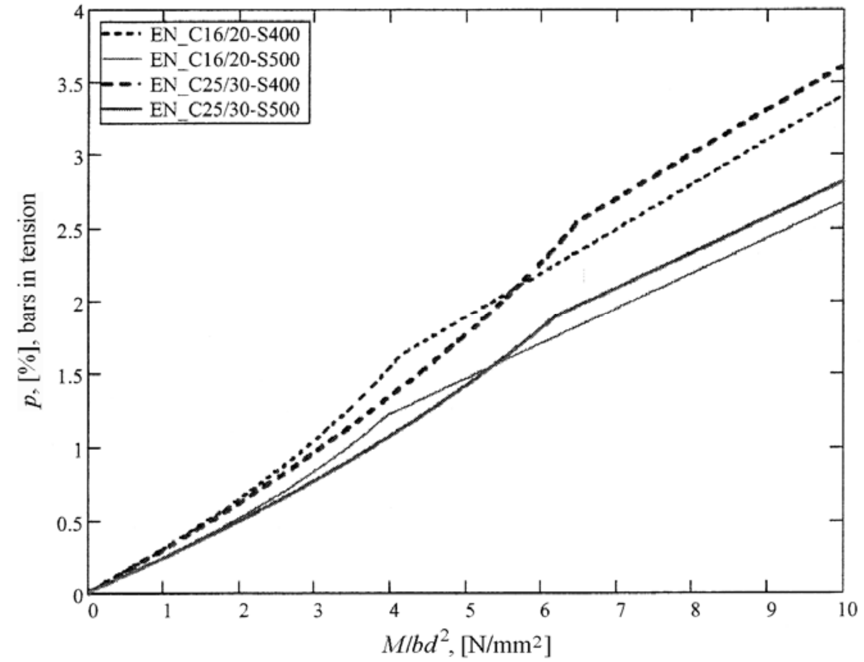

Fig. 6 – Flexure design diagrams for the RC section in accordance with EC2; concrete – C16/20, C25/30; steel – S400, S500; $a/d = 0.05$.

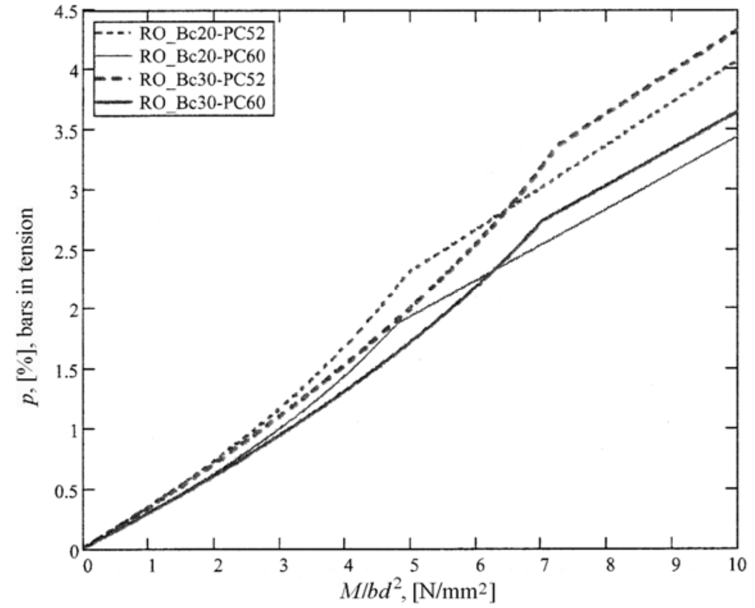

Fig. 7 – Flexure design diagrams for the RC section in accordance with STAS 10107/0-90; concrete – Bc20, Bc30; steel – PC52, PC60; $a/d = 0.05$.

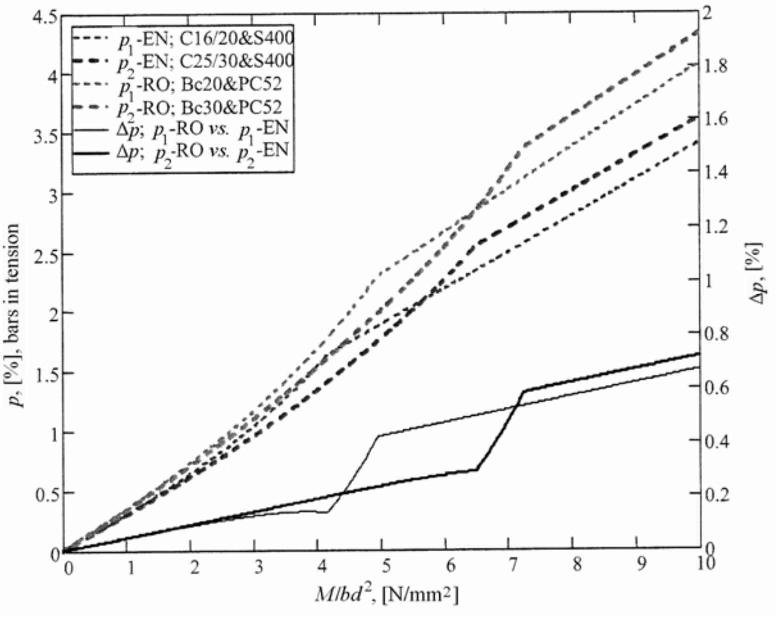

Fig. 8 – Flexure design diagrams steel reinforcing PC52 *vs.* S400; EC2-S400 *vs.* 10107/0-90-PC52; $a/d = 0.05$.

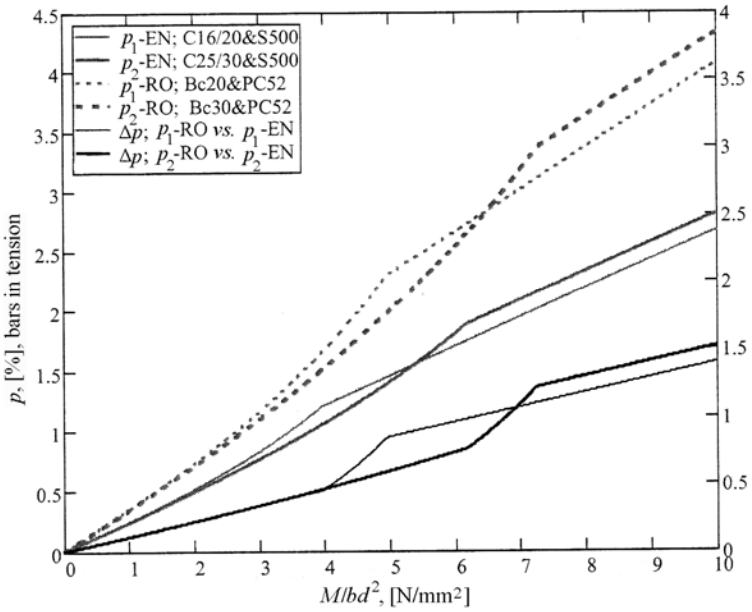

Fig. 9 – Flexure design diagrams steel reinforcing PC52 *vs.* S500;
EC2-S500 *vs.* 10107/0-90-PC52; $a/d = 0.05$.

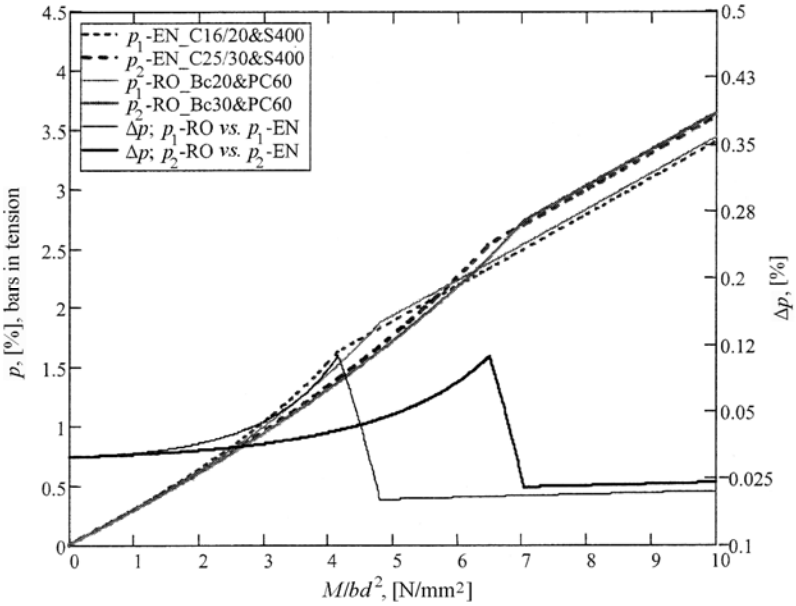

Fig. 10 – Flexure design diagrams steel reinforcing PC60 *vs.* S400;
EC2-S400 *vs.* 10107/0-90-PC60; $a/d = 0.05$.

For mostly considered cases it can be emphasized that the amount of reinforcing steel calculated with mechanical characteristics of materials required by EC2 is smaller than that required by a calculation based on STAS 10107/0-90. There is one case, PC60 *vs*. S400 reinforcing steel, where are registered negative differences indicating a small saving of steel based on the Romanian standard.

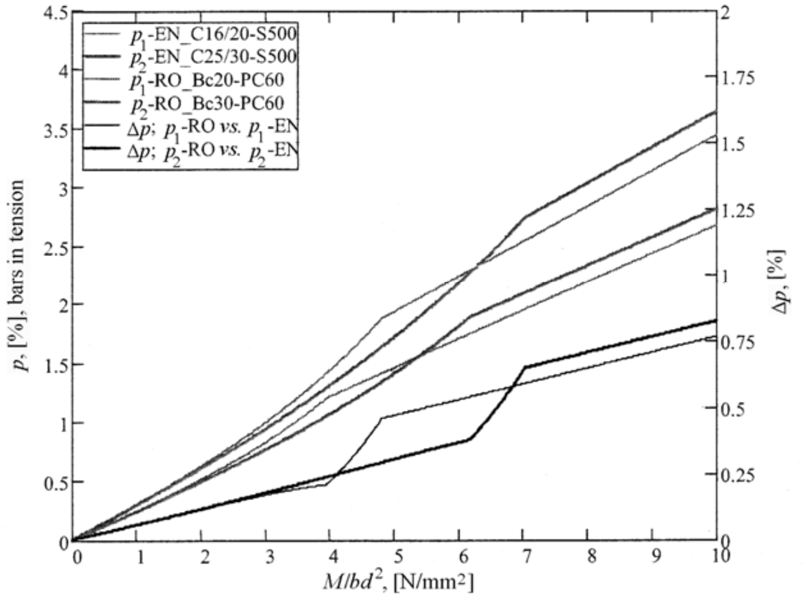

Fig. 11 – Flexure design diagrams steel reinforcing PC60 *vs.* S500; EC2-S500 *vs.* 10107/0-90-PC60; $a/d = 0.05$.

4. Conclusions

Considerable progress has been achieved in the last 50 years in the design of reinforced concrete structures. Nowadays, the Eurocode2 constitutes a very comprehensive code for reinforced concrete design and also includes rules for precast and prestressed members.

The design can be carried out considering a parabola–rectangle stress distribution on concrete section or a simplified rectangular distribution. Moreover, there is a bilinear diagram provided for flexure design of RC section. The stress distribution on concrete section for the parabola–rectangle assumption, is ruled by the stress–strain relationship, which is established for each strength class of concrete. An important feature of the strain–stress relationship is power degree, *n*, adopted.

The existent slight differences for calculated reinforcement area in flexure design are mainly due to the characteristic tensile and compression properties of the steel and concrete grades which are mentioned in both standards.

For flexure design the EC2 is more economic, less reinforcement is required. Mainly, this saving of reinforcement derives from the reinforcing steel with superior yielding strength required by EC2 about the reinforcing steel provided by STAS 10107/0-90.

The foregoing conclusions are concerned with the design at ULS (Ultimate Limit State) of sections for RC members as beams or slabs. Neither deep beams nor corbels are included.

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ANALIZA COMPARATIVĂ A PROIECTĂRII LA ÎNCOVOIERE CONFORM CU STAS 10107/0-90 ŞI EN 1992-1-1/2004 – EUROCODE2

(Rezumat)

După câţiva ani de la terminarea celui de-al doilea război mondial în mai toate ţările europene au fost lansate proiecte de reconstrucţie ale marilor oraşe distruse de război. Standarde privitoare la proiectarea structurilor de beton armat existau înainte de 1940 mai ales în ţările dezvoltate economic. După război standarde naţionale de proiectare au inceput să fie publicate şi în ţările mai puţin dezvoltate. In România STAS 1546-50 a fost primul standard de proiectare al elementelor de beton armat. Acest standard prevedea prescripţii de calcul bazate pe metoda la rupere. Primul standard ce prevedea prescripţii de calcul ale elementelor de beton armat bazate pe metoda stărilor

limită a fost P8-62. După cel puţin un deceniu apare prima versiune a standardului 10107/0-76. Versiuni îmbunătăţite ale acestui standard au fost publicate în 1986 şi, respectiv, 1990. Toate aceste versiuni au fost îmbunătăţite considerând avansul ştiinţific înregistrat în ingineria de construcţii a acelor decenii. Ultima ediţie a standardului este cea mai sofisticată, incluzând prescripţii de proiectare antiseismică a elementelor de beton armat şi precomprimat.

In următoarele decenii proiectarea construcţiilor civile va fi realizată conform cu normele europene, cunoscute şi sub denumirea de Eurocoduri. In proiectarea elementelor structurale ale construcţiilor de beton armat şi precomprimat Eurocod2 constituie standardul de bază.

Problemele discutate în acest articol sunt legate de particularităţi privind proiectarea la încovoiere a elementelor de beton armat pe baza standardului românesc aflat încă în vigoare comparativ cu norma europeană ce trebuie adoptată odată cu anul 2010.

Analize comparative privind variaţiile consumului de armătură sunt incluse şi unele avantaje ale normativului European sunt evidenţiate.