I Младежка научни конференция с международно участие
„Проектиране и строителство на сгради и съоръжения“, 4-5 ноември 2021 г., София

I Youth Scientific Conference with international participation
„Design and Construction of Buildings and Facilities“, November 4-5, 2021, Sofia, Bulgaria
ISSN 2738-7887 (online); ISSN 2738-7879 (CD-ROM)

СРАВНИТЕЛЕН АНАЛИЗ НА СТОМАНОБЕТОННА КОНСТРУКЦИЯ НА ЖИЛИЩНА СГРАДА, ПРОЕКТИРАНА В ДВА ВАРИАНТА

Симеон-Атанас Стойков[1], Марина Трайкова[2]

COMPARATIVE STUDY OF A RC STRUCTURE OF RESIDENTIAL BUILDING, DESIGNED IN TWO VARIANTS

Simeon-Atanas Stoykov[1], Marina Traykova[2]

Abstract:
The purpose of the study is to provide a comparison between the actual Bulgarian regulations and Eurocodes, based on the structural project of a residential building, situated in the city of Plovdiv. The paper use some details and drawings prepared for the MSc diploma thesis of Simeon Stoykov and the real structural project prepared for the construction of the building. The main structural elements (slabs, beams, columns and shear walls) for both gravity and seismic actions are analyzed. The comparison is made in several aspects: actions, combinations of actions, design and detailing of the reinforcement. Special attention is carried out to the seismic design and the specific detailing of the reinforcement of the different structural elements. Some quantities of the reinforcement are provided in the presented analysis and comparison. Based on the above, the paper proposes some general conclusions concerning the application of the different standards.

Key Words:
Eurocodes, Bulgarian Regulations, Reinforced concrete structures

1. INTRODUCTION

The application of two groups of standards in the design of the structures is related to some qualitative and quantitative differences in the final parameters of the structure. The presented comparative analysis aims to emphasize some fundamental differences between the Eurocodes and the Bulgarian norms, given the fact that in Bulgaria it is still possible to apply both groups of standards for structural design.

Of course, the comparison made in this paper is rather illustrative and is based on the diploma thesis of Simeon Stoykov [1] and the real structural project for the residential building in the city of Plovdiv [2].

The aim of this comparison is to highlight some important topics/differences in both group of documents and to convince the designers to apply the Eurocode standards in the design practice.

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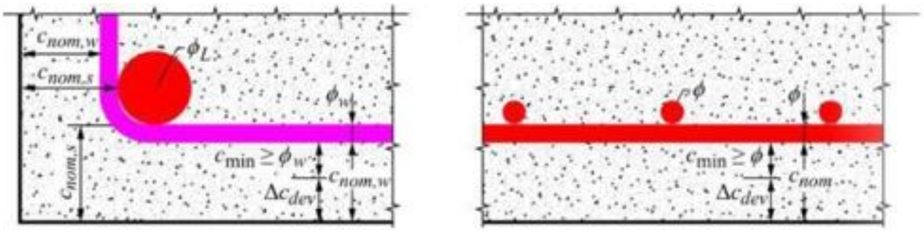
[1] Structural Engineer, MSc, University of Architecture, Civil Engineering and Geodesy,

[2] Professor, PhD, University of Architecture, Civil Engineering and Geodesy, Faculty of Structural Engineering, Department of Reinforced Concrete Structures

2. COMPARISON OF SOME BASIC PARAMETERS AND CONCEPTS IN THE DESIGN FOR GRAVITY LOADINGS

2.1. Choice of the concrete cover



$$c_{min} = \max\{\phi; c_{min,dur}\} \text{ [mm]}; \quad c_{nom} = c_{min} + \Delta c_{dev} \text{ [mm]}.$$

Figure 1. Concrete cover according to [3]

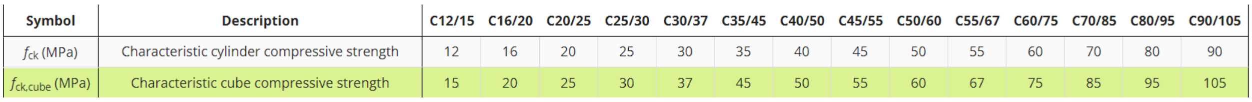
Concrete cover according to [3] $c_{min,dur}$ takes into account the environmental classes, the required fire protection and the required bond between the reinforcing bars and the concrete. [3] is giving the opportunity to take into account the deviation of the concrete cover adopted as 10 mm, but finally defined in the National Annexes.

In [4], the concrete cover is taken as a fixed value depending on the size of the reinforcement bars and the dimensions of the element. The surrounding environment is not taken into consideration with some specific requirements. For example: for slabs in [4], c_{min}= 10 mm for bottom and top reinforcement in case of thickness less than 10 cm, in all other cases it is 15 mm. When considering the minimal concrete cover, in both codes the concrete cover must not be smaller than the diameter of the reinforcement bar.

2.1. Characteristics of the construction materials

2.2.1. Concrete

Two main characteristics are considered: compressive strength and modulus of elasticity on Figure 2.



Symbol	Description	C12/15	C16/20	C20/25	C25/30	C30/37	C35/45	C40/50	C45/55	C50/60	C55/67	C60/75	C70/85	C80/95	C90/105
f_{ck} (MPa)	Characteristic cylinder compressive strength	12	16	20	25	30	35	40	45	50	55	60	70	80	90
$f_{ck,cube}$ (MPa)	Characteristic cube compressive strength	15	20	25	30	37	45	50	55	60	67	75	85	95	105

a)

Клас по якост на натиск	B 7,5	B 10	B 12,5	B 15	B 20	B 25	B 30	B 35	B 40	B 45	B 50	B 55	B 60
Минимална средна кубова якост на натиск, Rm N/mm2	9,63	12,84	16,05	19,26	25,68	32,1	38,53	44,95	51,37	57,79	64,21	70,63	77,06

b)

Figure 2. Comparison of compressive strength: Cubic compressive strength according to [3] (a) Minimal cubic compressive strength according to [4] (b)

The comparison shows that there is a more significant difference in the mean compressive cubic strength for concrete classes below B 20 (C16/20). After these classes there is still a difference however it is smaller in the ranges between 8-12%. It is important to note that when designing according to Eurocode the cylindrical compressive strength is accepted and when designing according to Bulgarian norms, the cubic compressive strength is taken into consideration. Furthermore, the characteristic design value for concrete compressive strength in both code must be divided by the partial factor of concrete. However, while the partial factor for concrete in [3] is 1,5 in [4] it is 1,3.

Concerning the modulus of elasticity of the concrete, a comparison is presented on Fig. 3. The modulus of elasticity in [3] is given with the formula: $E_{cm}=22*[(f_{cm})/10]^{0.3}$. According to [4] the modulus of elasticity of the concrete in compression and tension are given in Table 19 in [4] and they are dependent on the grade of compressive strength of the concrete. For concrete under perpetual freeze/thaw the values are multiplied by the coefficient $\gamma_{\text{bб}}$.

[3]		[4]	
Class of concrete	Ecm (Mpa)	Eb(Mpa)	Class of concrete
C 12/15	27000	25000	B 15
C 16/20	29000	27500	B 20
C 20/25	30000	30000	B 25
C 25/30	31000	31500	B 30
C 30/37	33000	33000	B 35
C 35/45	34000	36500	B45
C 40/50	35000	37500	B 50
C 45/55	36000	38500	B 55
C 50/60	37000	39500	B 60

Figure 3. Modulus of elasticity of concrete [3] [4]

2.2.2. Reinforcing Steel

It is important to note that according to [4], it is possible to use hot-rolled reinforcing steel smooth (AI) and with a ribbed profile (A-II, A-III, T-III, T -IY and A-IV). The reinforcement according to [3] must be ribbed and it cannot be smooth.

In [3] we have a fixed a fixed value for the partial factor for all types of reinforcing steel which is 1.15 (1) however, in the [4], depending on the class of steel, the partial value for reinforcing steel varies. For example, for A-I the value is 1.05, for A-III and T-III the value is 1.10, for B-I the value is 1.27 etc.

$$f_{yd}=\frac{f_{yk}}{\gamma_s}=\frac{f_{yk}}{1{,}15}\quad[N/mm^2], \tag{1}$$

f_{yk} - characteristic yield strength of reinforcement;
γ_s - partial factor for reinforcing steel.

2.3. Combinations of actions

2.3.1. Safety factors for the actions

Partial safety factors for permanent load actions are accepted as:

No	Type of structure	Partial coefficients for permanent load actions - γG	
		EN1991	Ordinance No-03
1	Reinforced concrete structure	1,35	1,20
2	Masonry	1,35	1,20
3	Isolated and finishing works, implementation of construction	1,35	1,35

Figure 4. Partial safety factors [10], [8]

For the variable loadings the following safety factors are adopted:
[10]: $\gamma_Q=1.5$; [8]: $\gamma_Q=1.3*(1.1)\approx 1.43$

It is notable that in Eurocodes the design values are greater than in the Bulgarian norms. Furthermore, it must be noted that in [3] we only multiply the safety factor by 1.1 for some structures depending on the importance class.

2.3.2. Comparison of load combinations

Type of load action	Characteristic values		Design values -	
	[2]	[1]	[2]	[1]
Area loads on floor slab (kN/m²)				
Permanent loads	6,44	6,44	7,73	8,70
Variable - floor	1,50	2,00	2,15	3,00
Variable - stairs	3,00	3,00	4,29	4,50
Linear loads on floor slab at a height of +5,44 (kN/m')				
Inner masonry	12,70	12,70	15,24	17,15
Partition walls	7,10	7,10	8,52	9,59
Outer masonry	12,70	12,70	15,24	17,15

Figure 5. Load combinations [2], [1]

The Fig. 5 shows the comparison between the fundamental combination for ULS according to [1] and [2].

2.4. Ultimate Limit States (ULS) Comparison

Most of the steps when designing in ULS for the main structural elements are similar in both codes, however when it comes to the design of the shear forces, they have a few discrepancies. The paper presents the main differences in the design for shear.

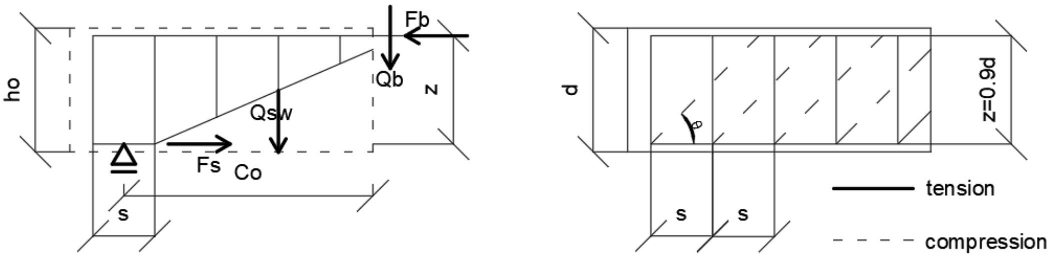


Figure 6. Design for shear (left image) a) [4], (right image) b) [3]

In [3] (image on the right) we can be flexible when choosing the angle of compression:

$$1,0 \le \cot\theta \le 2,5 \;\; (45^o \ge \theta \ge 22^o). \qquad (2)$$

The shear force must meet the following requirements:

$$V_{Ed} \le V_{Rd,s} = q_w.z.\cot\theta , \qquad (3)$$

$$q_w = A_{sw} f_{ywd} / s = \rho_w b_w f_{ywd} \qquad (4)$$

However in [4] (image on the left), the angle of compression is fixed as 45 and the projection for the dangerous zone of cracking of concrete is accepted using the following formula:

$$Q \le Q_{b,sw} = Q_{sw} + Q_b =$$

$$= q_{sw}.c + 1{,}5 R_{bt} b h_o^2 / c \qquad (5)$$

2.5. Comparison of the minimal steel ratio

Element	Minimal reinforcement ratio	
	[4]	[3]
Beam	0,05	A s, min = 0.26*f ctm/f yk*bt*d > 0.0013*bt*d
Slab	0,05	A s, min = 0.26*f ctm/f yk*bt*d > 0.0013*bt*d
Column	a) lo/l <17 -> 0,05	As,min = 0.10 NEd/fyd > 0.002Ac
	b) l0/l = 35 -> 0,1	
	b) l0/l = 83 -> 0,2	
	b) l0/l = 104 -> 0,25	

Figure 7. Comparison of steel ratio

3. COMPARISON OF SOME BASIC PARAMETERS AND CONCEPTS IN THE DESIGN FOR SEISMIC ACTIONS

3.1. Map of seismic regions according to EN 1998-1[8] and Ordinance РД-02-20-2 [8]

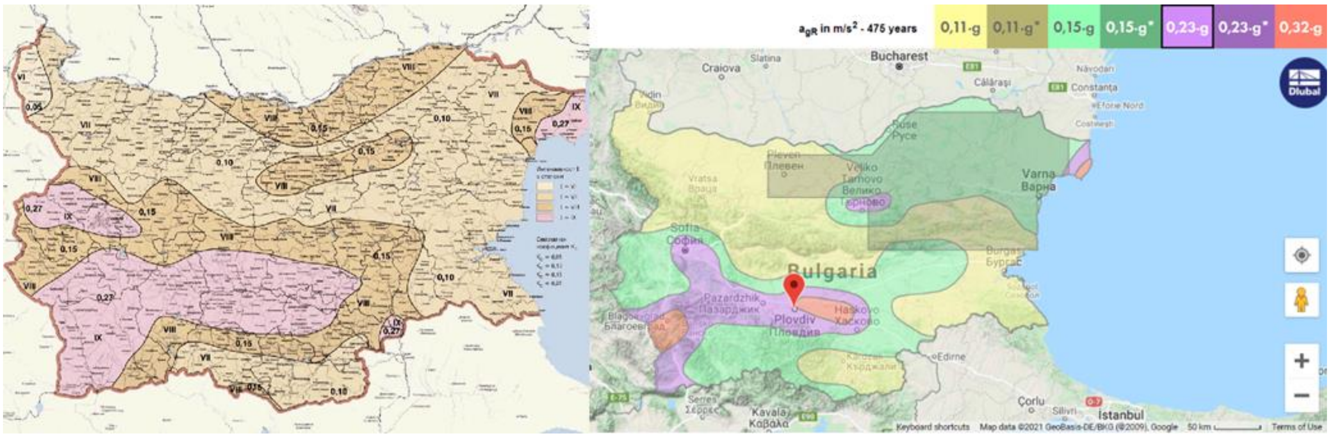
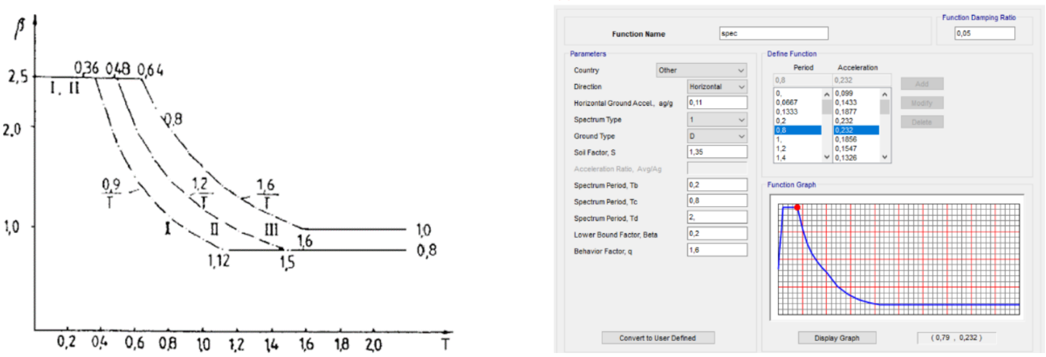


Figure 8. Map of seismic regions according to Ordinance РД-02-20-2 from 2012 (a) [8] according to National Annex in regards to EN 1998-1 (b) [11]

While In the Bulgarian Ordinance there is a return period of 1000years in Eurocodes there are return periods of 495 years for no collapse requirements (ULS) and 95 years for the damage limitation requirements (SLS).

3.2. Spectral Curve



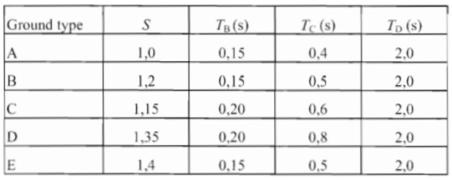
Function Name: spec
Function Damping Ratio: 0,05
Country: Other
Direction: Horizontal
Horizontal Ground Accel., ag/g: 0,11
Spectrum Type: 1
Ground Type: D
Soil Factor, S: 1,35
Acceleration Ratio, Avg/Ag:
Spectrum Period, Tb: 0,2
Spectrum Period, Tc: 0,8
Spectrum Period, Td: 2,
Lower Bound Factor, Beta: 0,2
Behavior Factor, q: 1,6

Period	Acceleration
0,8	0,232
0,	0,099
0,0667	0,1433
0,1333	0,1877
0,2	0,232
0,8	0,232
1,	0,1856
1,2	0,1547
1,4	0,1326

(0,79 , 0,232)

Figure 9. Spectral curves “a” (left image) according to [4] and “b” (right image) according [1]

Ground Type	S	T c	T d
A, B-I	0,90	0,36	1,125
C-II	1,20	0,48	1,500
D-III	1,60	0,64	1,600



Ground type	S	T_B (s)	T_C (s)	T_D (s)
A	1,0	0,15	0,4	2,0
B	1,2	0,15	0,5	2,0
C	1,15	0,20	0,6	2,0
D	1,35	0,20	0,8	2,0
E	1,4	0,15	0,5	2,0

Figure 10. Spectral values according to (a) (left image) [4] (b) (right image) [11]

It is clear that this difference in the response spectrum appears from the fact that in the Eurocode, all the values and coefficients for the spectral curve are more conservative. [11] and [7] have the same concept for forming the spectral curve, as the connection between the behavior factor and the reaction coefficient is R=1/q. It is interesting to note that we have a plateau for the period between 0,2 and 0,8 in the design according to [1] which is shorter than the design according to [7].

3.2. Comparisons of forces and moments

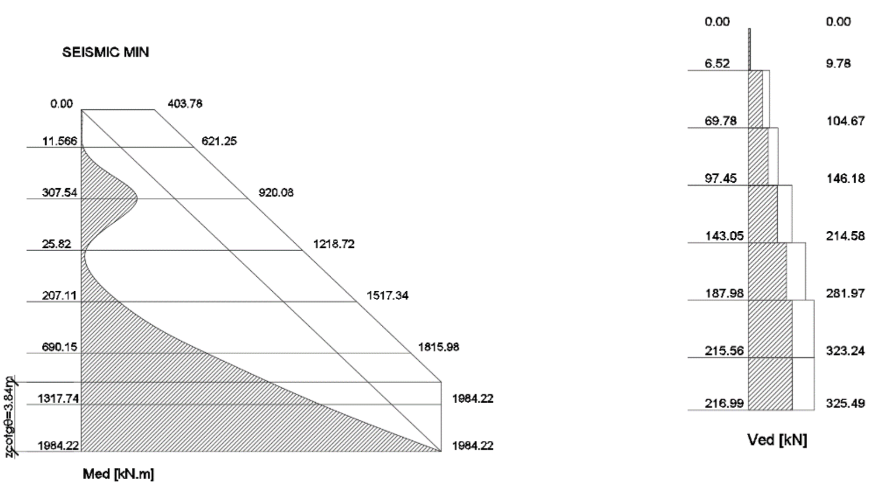


Figure 11. Capacity corrected moments and shear forces according to project design by S. Stoykov [1]

We can see the original moments for which the building is designed. The capacity correction is done to ensure plasticity at the base of the structure. In the Bulgarian norms, the design for seismicity is calculated with the greatest value of the moments and shear forces whereas in [11] we use the capacity corrected moments.

4. FUNDAMENTAL DIFFERENCES IN DETAILING

Shear wall detailing according to РД-02-20 code:

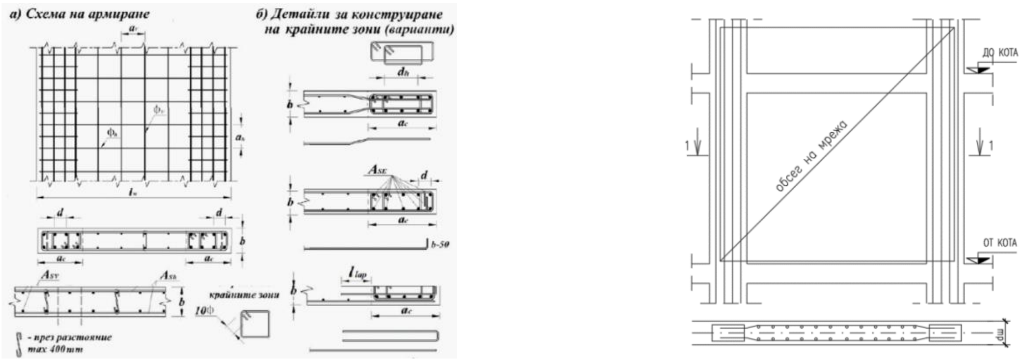


Figure 12. Shear wall detailing from РД-02 (left image) (a) [8] detailing given by E. Boychev (right image) (b) [2]

While there are hidden columns in the Bulgarian norms, they are not calculated. They are a taken as a fixed valued depending on the length of the shear wall. Furthermore, due to the uniformity of the wall, exact detailing in the middle of the shear wall is not necessary.

Shear wall detailing according to [11]:

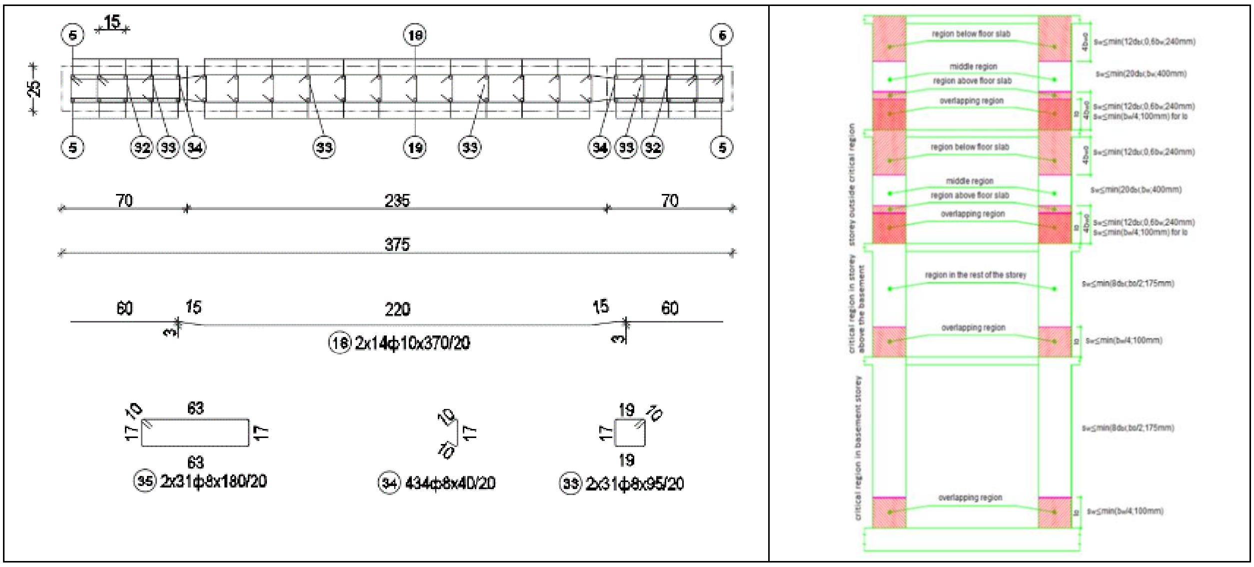


Figure 13. Shear wall section detail from project design of S. Stoykov (left image) (a) [1], shear wall detailing according to [7] (right image) (b)

A boundary element must be defined. Within the boundary of the shear wall there are two hidden columns on both sides of the walls. The boundary element is calculated by considering many different factors. Exact detailing must be given due to the change in geometry of the hidden columns.

5. SOME QUANTITATIVE COMPARISONS IN PROVIDED REINFORCEMENT

Type of Element	Weight (kg) according to the	Weight (kg) according to design by Eurocode	Difference (%)
Slab (Level -0,04)	2623	2685,55	2,3
Shear Wall 3	2572,84	3702,4	30,5
Column 5	350,57	412,2	14,9

Figure 14. Reinforcement comparison according to [1]

While the design is similar in the slabs, the ideology behind the design of the vertical elements differs greatly and we expect around 30% more reinforcement in the design of vertical elements according to Eurocodes.

CONCLUSIONS

After the comparative analysis it was found that:

1) The design method, actions, construction materials, models for calculating and verifying boundary conditions, as well as the principles for detailing in [3] and the Bulgarian standard

for the design of RC structures [4] are harmonized with a sufficient degree for the practical application. Of course, some differences could be found when designing for some specific situations e.g. shear, punching, etc.

2) Concerning the seismic design: the implementation of the capacity design in [11] provides a different level of safety by introducing new philosophy of design and detailing in comparison with the Ordinance 02-20-2 [7].
3) Eurocodes standards take more factors into consideration in different aspects such as safety and combination factors, choice of concrete cover, determining the behavior factor, etc. In some cases, the difference between the two group of regulations (Eurocodes and the Bulgarian standards) can result in higher amount of the provided reinforcement. This fact very often leads to skepticism when it comes to choosing Eurocodes in the structural design, especially in the provision of buildings for seismic actions.

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