Comparative analysis of eurocodes and macedonian codes – In terms of an example RC frame structure

Abdiu, Besar; Nechevska Cvetanovska, Golubka

Source / Izvornik: **1st Croatian Conference on Earthquake Engineering 1CroCEE, 2021, 1039 - 1048**

Conference paper / Rad u zborniku

Publication status / Verzija rada: **Published version / Objavljena verzija rada (izdavačev PDF)**

https://doi.org/10.5592/CO/1CroCEE.2021.112

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.112

Comparative analysis of eurocodes and macedonian codes – In terms of an example RC frame structure

Besar Abdiu[1], Golubka Nechevska-Cvetanovska[2]

[1] *Teaching Assistant*, Mother Teresa University, *besar.abdiu@unt.edu.mk*

[2] *Professor*, Institute of Earthquake Engineering and Engineering Seismology, *golubka@iziis.ukim.edu.mk*

Abstract

Earthquake resistance of structures is guaranteed through their proper design according to the seismic codes in power. In the Republic of North Macedonia, since 1981, the regulative for construction of high-rise buildings in seismic locations together with the regulative for concrete and reinforced concrete (1987) are applied, herein called Macedonian Codes. On the other hand, for seismic design of structures, in member states of European Union, Eurocode 8 (accompanied with other parts of Eurocodes) is implemented. In this paper the differences and similarities in concepts as well as in requirements between Macedonian Codes and Eurocodes are highlighted. Then, an example RC frame building is analyzed and designed separately in accordance with Macedonian Codes and Eurocodes, so that to satisfy the minimal requirements. The structural dimensions of both buildings (in terms of stories, bays, slab thickness and beams' cross-sections) are intentionally taken to be the same, in order to simplify and clarify the comparison, but because codes have different strictness for certain criteria, i.e. interstorey drifts and normalized axial load, there are some differences in reinforcement quantities or even in column cross-sections. Because the elastic analysis of the building does not give a clear picture about the building behaviour after its yielding point, another type of analysis was performed, namely, nonlinear static (pushover) analysis. Performing this analysis, it is confirmed whether the calculated levels of strength and deformation (in terms of base shear force and top-storey displacement, respectively) based on codes are achieved.

Key words: analysis, design, RC structure, capacity, ductility, Macedonian Codes, Eurocodes

1 Introduction

In North Macedonia, seismic design of structures is performed through the application of Macedonian Codes. Starting from the last year, in North Macedonia, among Macedonian Codes, the designers can also follow the procedures of Eurocodes for structural design, and after three years, only Eurocodes will apply. This paper is mainly focused on seismic design of structures, which is covered by Eurocode 8 (EC8) [1] in Eurocodes (EC), and by the Regulative of technical normatives for construction of high-rise buildings in seismic locations [2] in Macedonian Codes (MC).
The development of materials, construction technologies or methods of construction are some of many reasons why codes are upgraded in certain periods of time. The last upgrades of Eurocodes were made in less than twenty years, whereas no significant development was done in case of Macedonian Codes since 1981 [3]. Taking into consideration this difference in time between the last upgrades of these codes, it is important to recognise their approaches, differences and similarities. However, in this paper, general concepts rather than detailed design procedures are discussed, which then are applied in designing of an example RC frame building structure. Normally, the quantitative parameters of the codes may differ, but they are represented so that the comparison of the results to be easier. The result shown indicate the required reinforcement contents in beams and columns, which are then adopted as a provided reinforcement in order to ensure the compliance with the corresponding code.
Finally, a nonlinear static (pushover) analysis was performed to estimate the strength and the deformation capacity of the same structure designed according to MC as well as EC.

2 Building description and input data

The example building is a 5-storey regular and symmetric building with 3 bays of in both directions and storey height of . Its 3D model representation, generated from software *Robot Structural Analysis Profesional 2021* [3] with whom the elastic analysis was performed, are shown in Fig. 1. It is important to highlight that, in EC8, there are quantitative parameters through which the regularity and/or the symmetry of the building can be verified. There are no such criteria in MC. The concrete class is C25/30 and the steel grade is B500. For the model designed to MC, concrete and steel grades are MB30 and DR 400/500-2, respectively. The building is assumed to be located in Skopje - capital of North Macedonia, where the reference peak ground acceleration is, or seismic zone X [5] - according to MC.

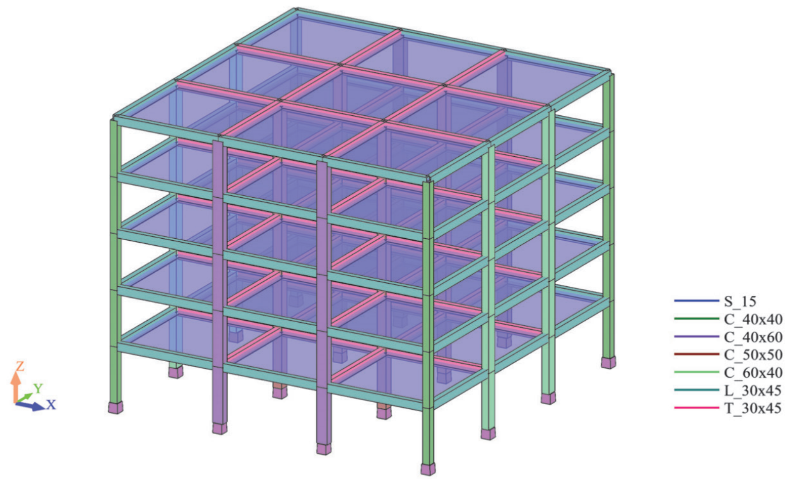


Figure 1. 3D represantation of the building and member sections

3 Structural analysis of the example building

3.1 Structural modeling

Due to the identical geometry in X and Y direction, in the following discussion, only the X - direction of the building will be considered. Beams and columns are idealized as line elements, whereas slabs are idealized as plate elements. Cracked sections were considered as required by [1].

3.2 Dynamic characteristics and seismic forces

When determinig the mass of the structure, besides full permanent load, 30 % of the variable load has to be taken into account according to EC8 [1]. However, in accordance with MC, the mass of the structure consists of full permanent load and half the variable load [2]. This difference will, normally, lead to different fundamental periods. The distribution of masses (in tons) through the building height are shown in Table 1. It is clear that the difference in mass is less than 5 %. So, it is expected that the dynamic characteristics of the structures to be very close. Their natural periods and frequencies, are shown in the Table 2. As expected, these quantities are almost identical.

Table 1. Distribution of mass through the height of the building

Storey	EC8	MC
5	299.33	312.54
4	299.33	312.54
3	299.33	312.54
2	299.33	312.54
1	299.33	312.54

Table 2. Natural fundamental periods and frequencies of structures

	EC8	MC
Period [sec]	0.86	0.87
Frequency [Hz]	1.17	1.149

According to EC8 [1], it is possible to design earthquake resistant structures with different ductility classes (DCM or DCH), while in MC [2] there are no options for ductility classes. The example structures is designed for medium ductility (DCM), for which the value of the behaviour factor is. Using the expressions of lateral force method of analysis given by the codes, the seismic base shear forces can be obtained. These forces and their distribution along the height of the structure are shown in Fig. 2. Expressed as a percentage of the building weight, these forces amount to 9.52 % (EC8) [1] and 8.04 % (MC) [2]. Note that the base shear obtained in accordance with EC8 [1] is 13.4 % larger.

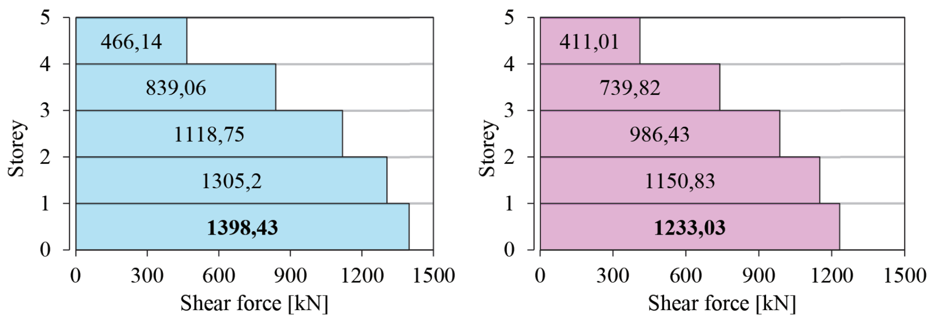


Figure 2. Distribution of seismic shear forces along the height of structure according to Eurocode 8 (left) and Macedonian Regulations (right)

3.3 Safety verification

Before proceeding to the design of members, some criteria related to geometry and stiffness of the structure and of its members should be checked. Only some criteria which are common for both codes are shown. Even though these criteria are common, the way they are expressed in codes is different. For example, lateral displacements obtained from elastic analysis are multiplied by the behaviour factor in EC8, which is not the case in MC [3]. EC8 also takes into account torsional effects when checking displacements, interstorey drift, or interstorey drift sensitivity coefficient. On the other hand, when the structure is symmetric, no accidental torsion is taken into account in the MC [2].

Interstorey drift limit obtained from EC8 [1] (for the case of brittle nonstructural elements and storey height of) amounts to , whereas its counterpart from MC [2] is . As discussed in the previous paragraph, the former is multiplied by the behaviour factor and the latter is taken directly from linear analysis. If the former was taken directly from linear analysis, its value would have been , which is not too far from . The difference is . EC8 [1] also gives other drift limits for buildings having ductile nonstructural elements or nonstructural elements not influenced by structural displacements.
In Fig. 3, the interstorey drifts obtained from the seismic actions are shown. The largest values of drifts were obtained in the second story in both cases. But, in case of EC8, the drift is closer to the limit. On the right-hand side of the figure, with dotted line are shown the same drifts of left-hand side, and with the dashed line, its corresponding limit is shown. Both divided by the behaviour factor in order to be comparable with the drift obtained from the MC. Clearly, it is not only the drift limit which is stricter in EC8, but also the values of drifts caused by the design seismic forces. This criterion governed the preliminary design of members as well.

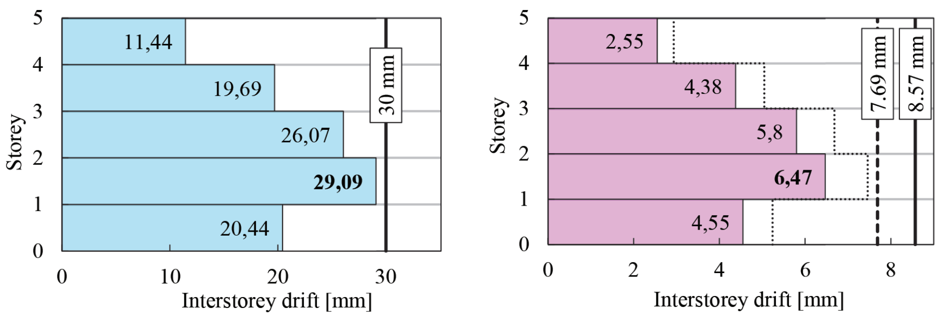


Figure 3. Interstorey drifts. Eurocode 8 (left) and Macedonian Code (right)

Except interstorey drifts, the top-storey displacement of the building is also limited in MC. The top-storey displacement of the building must not exceed the quotient of building height and 600 [6]. So, the limit is equal to 25 mm. The addition of story drifts from right-hand side of Fig. 3 gives the value of top-storey displacement (23.75 mm), which is smaller than the limit. Apparently, this criterion would have not been fulfilled by the building designed to EC8. Interstorey drift sensitivity coefficient is another important parameter related to the displacement, or, more precisely, to the second-order effects, in EC8 [1]. However, since this criterion is not directly applicable in MC [2], it will not be compared here.
When designing structures in accordance with MC, it is usual practice to check the so-called S-factor in columns. In many cases, it is also used for the preliminary design of columns. The reasons are two: first, it is the most critical criterion, and second, the corresponding load combination is due only to gravity, which means that it can be hand-calculated. S-factor is an utilization factor, which presents the ratio of axial stress and of concrete design compressive strength in columns, similar to normalized axial

load in EC8 [1]. They differ not only in numerical values, but also in the governing load combinations. Normalized axial load is checked under the seismic design situation [6]. The levels of normalized axial load and S-factor for all (80) columns of the structure, are shown in Fig. 4. The horizontal lines represent their limits. Note that in case of normalized axial load there are two limits, depending on the ductility class. It means that for larger ductility classes, smaller axial loads are allowed in columns, or vice versa.

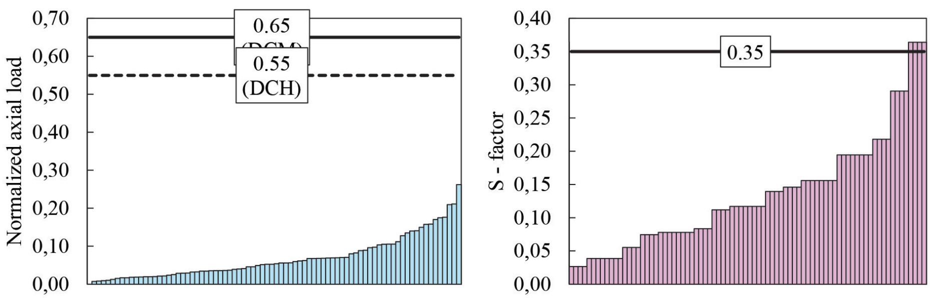


Figure 4. Normalized axial load (left) and S-factor (right)

Although axial loads are somewhat larger in case of S-factor, its strictness seems to be considerably larger than that of normalized axial load. That is why this factor is used since the preliminary design of columns. Some columns exceeded the limit by about , but it is estimated to be negligible. Moreover, it can be covered by an increase in strength of the concrete core due to its confinement, which is also neglected in this code. Comparing the graphs, it is noted that for almost every single column, different levels of normalized axial load have been obtained. On the other hand, there are several groups of columns having the same level of S-factor. This difference is due to the different load combinations.

4 Design of members

Once the confirmation that the member sections are chosen so that the building satisfies all the previous checks, one can continue to the design phase. The design of members in Macedonian Codes is straightforward, for example, the design of a column does not depend on the capacity of adjoining beams, but rather, it is designed directly, based on the action effects from static analysis of the structure. On the other hand, in Eurocodes, the design phase should pass through capacity design checks [1]. The application of these checks provides failure mechanism, which is capable to develop considerable plastic deformations.

4.1 Provided reinforcement

The critical sections of characteristic members designed in accordance with Eurocodes and Macedonian Codes are shown in Figures 5.a and 5.b, respectively. Note the relatively low reinforcement content in members. In fact, almost all members were designed with minimal reinforcement requirement, since the required reinforcement percentage was low. The minimal reinforcement contents according to Eurocode 8 and Macedonian Codes are 1 %, and 0.6 %, respectively [1, 2]. However, in beams, the situation seems to be different: larger reinforcement content was provided in case of beams designed to Macedonian Code. One of the reasons is the smaller design yield strength of the steel, and the other is the dominance of gravity load combination over the seismic load combination. The load factors for dead and live loads, for the gravity combination, according to this code are 1.6 and 1.8, respectively [6].

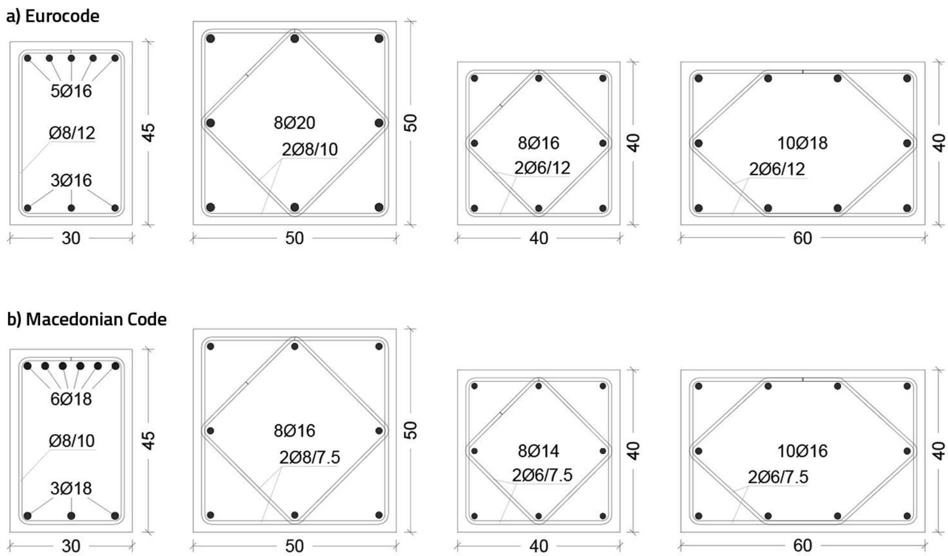
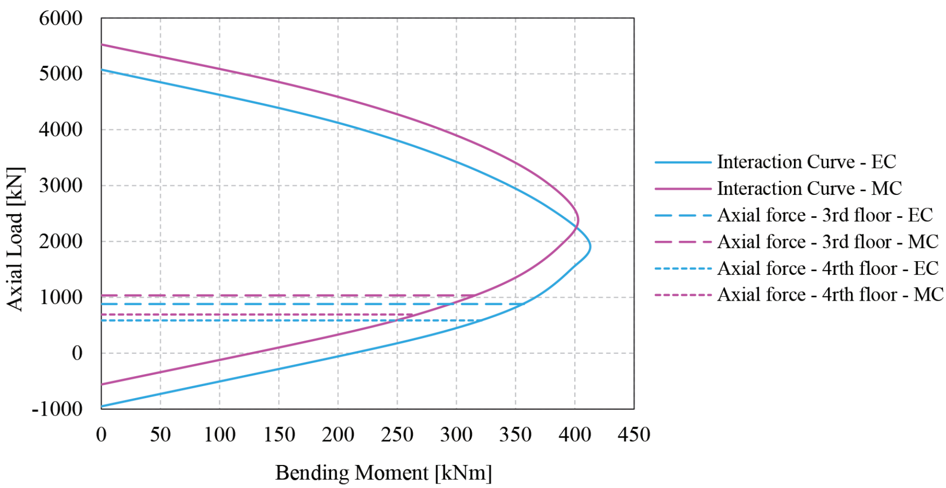


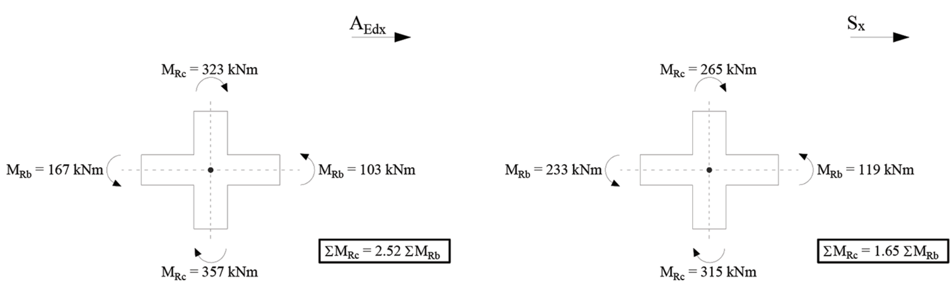
Figure 5. Provided member reinforcement in accordance with: a). Eurocodes, and b). Macedonian Codes

4.2 Capacity design

Analysing the sections designed to Macedonian Codes, and comparing them with their counterparts of Eurocodes, it can be said that, even not checked, sections designed to Macedonian Code, due to the more congested transverse reinforcement, probably fulfil the capacity design requirement related to the failure mode, namely, it is ensured that the member will fail in flexural rather than shear manner. This is valid for both beam and column sections. However, it is not clear whether the soft beam-strong column requirement is satisfied.

While in Eurocode 8 it is clearly defined the minimal required ratio of colum-to-beam flexural resistances [1], in MC, this requirement is deemed to be satisfied if the column stiffness is larger than the beam stiffness [2]. Based on Fig. 1, the most critical to this requirement are the central joints. Since, toward the upper stories, the axial force reduces and the requirement is waived, an internal joint of third floor was decided to be checked. In Fig. 6, the axial load-bending moment interaction diagrams are shown, for columns designed to both codes. Also, shown in the figure are the levels of axial forces from the most unfavourable combinations of seismic design combinations on third and four floor columns. Because, in EC, the design strength of concrete is smaller and, both the amount as well as the design yield strength of the reinforcing steel are larger, there is a "shift" of the corresponding interaction curve downwards. In the tension failure zone, this shift increases the bending moment capacity of columns designed to EC, as compared with those designed to MC.





a) Eurocode **b) Macedonian Code**

Figure 6. Axial force – bending moment interaction diagrams

The calculated bending capacities of beams and columns connected in the third floor of an internal joint are given in Fig. 7. Although this criterion is required only by EC8, it is also satisfied by the MC. However, due to larger reinforcement percentage on beams and smaller reinforcement percentage in columns, the value obtained in case of Macedonian Code is smaller.

5 Nonlinear static analysis results

So far, only the results from the linear analysis have been presented, and their compliance to corresponding codes was discussed. In some cases, the members designed to EC showed better performance, whereas in other cases their counterparts to MC were in the safe side. However, to obtain a better view on general performance of structures, a nonlinear static (pushover) analysis was performed for both cases, using the comercial software SAP2000 [8]. The results of pushover analysis, namely, the capacity curves and their characteristic points, are shown in Fig. 7.

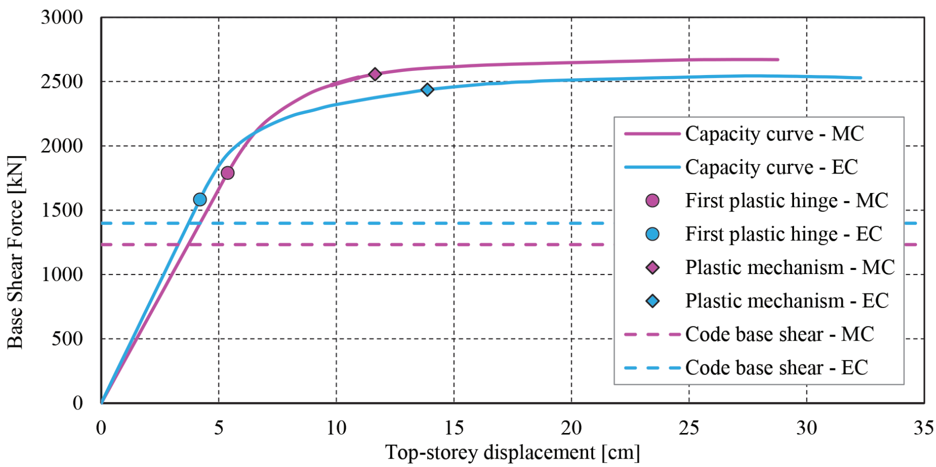


Figure 7. Capacity curves

Although in some cases, there was a considerably discrepancy, the general results show that both structures performed well and very similarly. However, there are some small differences in pushover curves. The building designed to EC has both larger initial stiffness and larger ultimate deformation capacity. On ther other hand, the building designed to MC has slightly larger strength. Also, it is noted the difference between base shear forces obtained from code expressions and pushover analysis. This difference is smaller in case of EC. Expressed in numerical values, the differences are 1.81 and 2.17, for EC and MC, respectively.

6 Conclusions

The comparative analysis between Eurocodes and Macedonian Codes through an example building showed that in Eurocodes many aspects are given quantitatively and the design procedure is continuous. On the other hand, Macedonian Codes are implicit, with some criteria being overconservative. However, taking into account that Macedonian Codes were formulated relatively long time before Eurocodes, for simple, regular buildings, their results are quite satisfactory.

References

[1] CEN (2004): Eurocode 8: Design of structures for earthquake resistance — Part 1: General rules, seismic actions and rules for buildings, European committee for standardization, Brussels.

[2] Službeni list SFRJ (1981): Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima.

[3] Abdiu, B. (2018): Analysis and design of optimal earthquake resistant RC frame building structures according to Eurocodes and Macedonian regulations - master thesis (mentor: Nechevska-Cvetanovska G.), Skopje.

[4] Robot Structural Analysis Professional , 2021.

[5] Dumurdjanov, N., Milutinovic, Z., Salic, R. (2020): "Seismotectonic model backing the PSHA and seismic zoning of Republic of Macedonia for National Annex to MKS EN 1998-1:2012 Eurocode 8," Jounal of Seismology, pp. 319-341.

[6] (1987): Pravilnik o tehnickim normativima za beton i armiran beton

[7] CEN (1994): Eurocode - Basis of structural design, European committee for standardization, Brussels.

[8] Sap2000 v21, Computers & Structures, Inc..

[9] CEN (2004): Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings, European committee for standardization, Brussels.