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COMPARATIVE ANALYSIS AND SEISMIC ASSESMENT OF A TYPICAL SIX STORY RC STRUCTURE FOR THE SEISMIC CONDITIONS OF SKOPJE

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The need for building the "City Wall" building complex in Skopje, had arisen since the catastrophic earthquake in Skopje of 1963, which rendered more than 65% of the structures in Skopje inhabitable and around 150.000 people homeless. The construction of the "City Wall" building complex provided more than 1800 apartments which were meant to house around 7800 people. With that the "City Wall" has become an integral part of the Skopje city center.

Considering the fact that Macedonia is soon to appropriate the Eurocodes as it's national building codes, the authors of this paper have made a comparison between the design and assessment of RC structures according to the Eurocodes and the existing codes in Macedonia as well as the codes that have existed in the past in Macedonia i.e. the codes according to which the buildings of "City Wall" were designed.

In order to do so, one of the characteristic buildings from the "City Wall" was taken in consideration. The paper conducts a simulated design of the building, keeping the geometry and the dimensions of the elements in the building, according to the respective codes, and makes a comparison of the results. Furthermore, the paper contains an analysis of the capacity of the structure according to the Eurocodes.

Introduction

In the aftermath of the earthquake in 1963, the city of Skopje was left in a state of ruin, with more than 65% of its structures rendered uninhabitable and more than 150.000 people in need of housing. Considering the fact that at this time the population of Skopje was around 200.000 people, this was a major blow to the city. In the wake of such devastation, Skopje needed a new urban plan and major reconstruction. One of the greatest projects which were meant to solve the housing problem of Skopje in the aftermath of the Earthquake was the "City Wall" building complex composed of residential blocks (Gf + Me + 6; and Gf + Me + 4), and towers (Gf + Me + 12). With that, more than 1800 apartments were planned, with the capacity to house around 7800 residents. As such the Skopje "City Wall" has become an integral part of the city center and an important landmark.

Purpose of the paper

Considering the importance of the building complex, this paper will review one of the typical structures from the residential blocks and asses its capacity according to the current building codes in Macedonia as well as the Eurocodes, as codes which Macedonia strives to adopt as national standards. The reviewed structure is one of the annexes to the residential blocks which consists of six floors (Gf + Me + 4) and for which the original design and calculations have been obtained. In plan, the structure is symmetrical by its orthogonal axis. In the longitudinal direction it consists of 4 modules, each spanning 4.8 m and in the transversal direction, it consists of 3 modules, 2 with a span of 5.5 m and one middle module spanning 3.8 m. In terms of elevation the structure has six floors, with its ground floor being the highest at 4.4 meters, a mezzanine with a height of 2.45 meters and four floors with a height of 3.1 meters. The considered structures was built during the 1960s, and as a basis of this paper the original design documents of the structure

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shall be used. At this time, in the territory of Macedonia the provisional seismic design codes from 1964 were in effect (henceforth SDC64), which were adopted after the earthquake of 1963. Fifteen years later, namely after the earthquake in Montenegro of 1981, the national building codes were updated with a new seismic design code (henceforth SDC81). And as of writing this paper, it is expected that in the following few years the Eurocodes will be adopted as national building codes of Macedonia.

With that in mind, the following types of analysis were conducted in the scope of this paper.

- Analysis of the amount of reinforcement in the columns according to the separate codes (SC63, SDC81 and EC8) and their comparison;
- Push over analysis according to the requirements of the Eurocode 8.

Code specific reinforcement demands

All structural analyses the results of which are presented in this section are conducted under the following assumptions:

- Column proportions: as designed;
- Concrete type: МБ 30 (C 25/30);
- Reinforcement: Flat, GA 240/360; and,
- Ground type: III (SDC64 , SDC81), “C” (Ec8);
- Model geometry: same as in original design

The structural analyses are performed with licensed software packages:

- SAP2000 (SAP2000 Ultimate 16.0.0); and,
- TOWER (3D Model Builder 7.0 – x64 Edition [7422]).

TOWER is used to compute the SDC81, whereas, SAP2000 for computing the Ec8 seismic effects and design accordingly. The structure was not designed according to the SDC64 but for the purpose of this paper, the amount of reinforcement was assumed according to the original design.

Considering the cross section geometry of the building, (Figure 1) the original design uses an analytical model with ground floor height of 4.2 meters, that is quite different to mezzanine (2.45 meters) and typical story (3.1 meter) heights. According to SDC81, such vertical geometry would be treated as flexible story requiring the ductility and damping coefficient of Kp = 2.

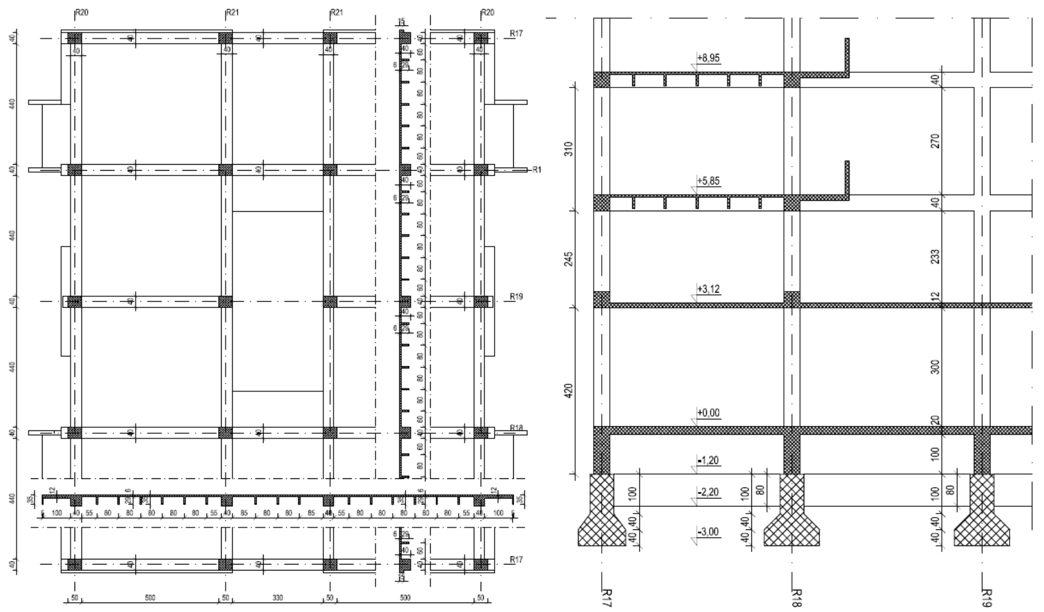


Figure 1: Plan and cross section of the building

However, the sanitary floor of height of 1.2 meters (top RC slab included), is bounded by circumferential RC beam system of thickness of 50 cm that together with strip foundation system in transverse direction, create RC box that reduce the ground floor height to 3.0 meters. For such a case – frame structure supported by box foundation - SDC81 allows the ductility and damping coefficient of Kp = 1.

Accordingly, two analytical models are formulated for TOWER analyses:

- Model with flexible story, Kp = 2, total height of 19.05 meters, referred in the following as SDC81f model; and,
- Model without flexible story, Kp = 1, total height of 17.85 meters, referred in the following as SDC81 model.

SAP2000 analyses have been carried out for two types of design spectra:

- Type 1, with referent ground acceleration of 0.25 g; and,
- Type 2, with referent ground acceleration of 0.15 g, calculated for local seismic sources, only.

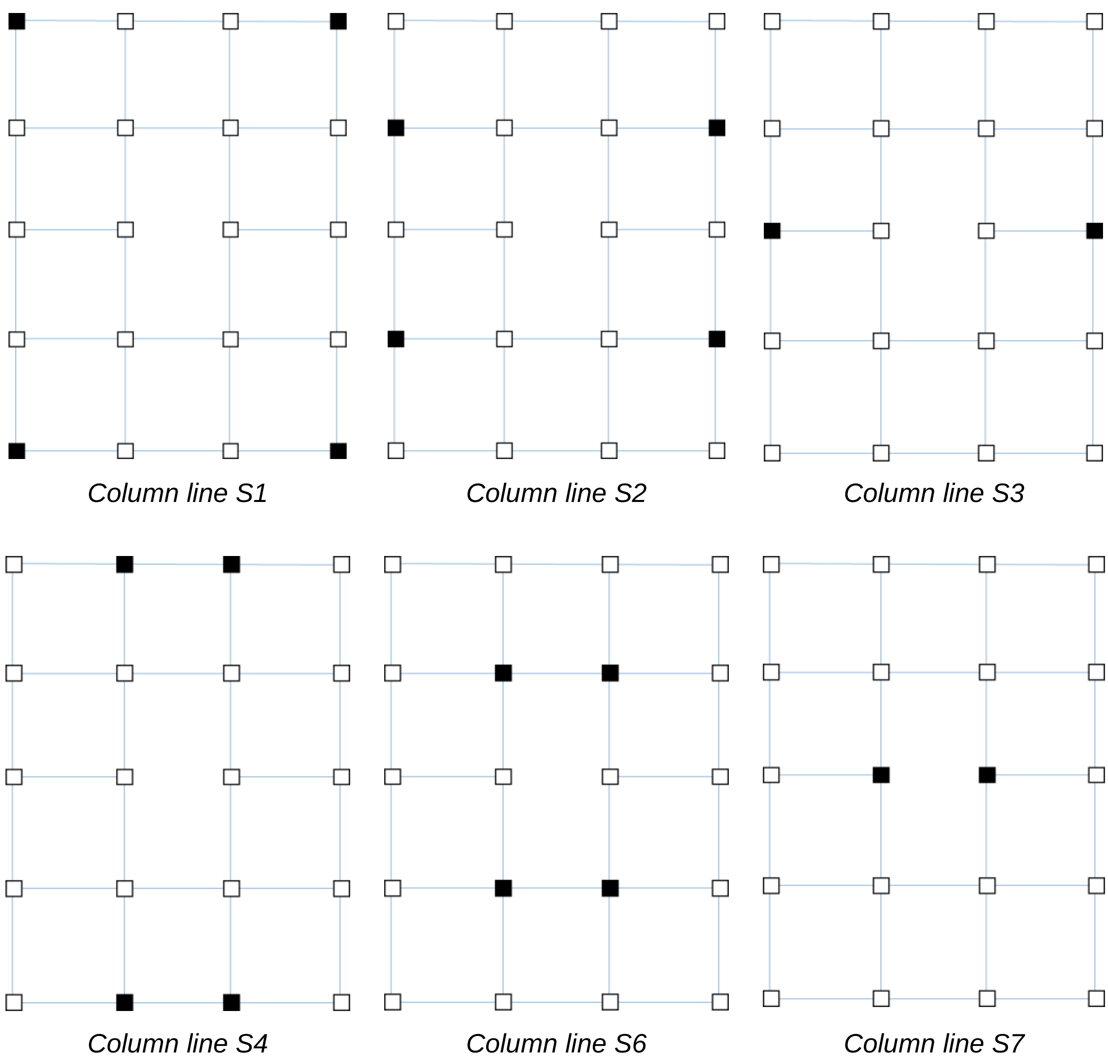


FIGURE 2: POSITION OF COLUMN LINES

The acquired results from all the analyses that were conducted according to the described assumed models are presented in table 1 in terms of the total mass of longitudinal reinforcement in each of the column lines, as well as the total mass of the longitudinal reinforcement required.

Model type	Column line S1	Column line S2	Column line S3	Column line S4	Column line S5	Column line S6	Total	
	W [t]	W [t]	W [t]	W [t]	W [t]	W [t]	W [t]	wD [%]
Number of columns	4	4	2	4	4	2	20	
SDC64	1.81	1.81	0.99	1.81	1.81	0.91	9.13	0
SDC81; TOWER	1.11	0.98	0.45	1.17	0.91	0.46	5.09	44.25
SDC81f; TOWER	2.93	3.52	1.7	3.71	3.39	1.61	16.85	-84.56
Ec8 SpT1; SAP2000	1.42	1.35	0.65	1.33	1.35	0.65	6.74	26.18
Ec8 SpT2; SAP2000	1.35	1.27	0.61	1.27	1.25	0.61	6.35	30.45

TABLE 1: Masses of the reinforcement calculated using different models

The built in mass of longitudinal reinforcement (SDC64 model) calculated at 9.12 tons, for 44.25% is larger than that adopted for SDC81 model, and for 26.18 to 30.45 % for Ec8SpT1 and Ec8SpT2 models, respectively.

However, if the same model used for calculation of SDC64 longitudinal reinforcement mass is implemented, which nowadays would correspond to flexible story model (PIOVS81f) the SDC64 adopted longitudinal reinforcement is insufficient, being underestimated for 84.56 %.

The presented quantifications refer to GA240/360 flat reinforcement that nowadays is not in use. Nowadays design would use steel 400/500 ribbed reinforcement resulting in reduced longitudinal reinforcement mass demand.

Depending on the code implemented, the longitudinal reinforcement mass, at building level, vary from 5.09 (SDC81 model) to 6.74 (Ec8SpT1 model) tons, which variation, relative to the construction cost of the entire building, is negligible.

Push over analysis

The push over analysis of the structure was conducted according to the Eurocode 8, using the software CSI SAP 2000 v19 in order to determine the capacity of the structure, and to assess its ability to withstand the demand determined by the eurocodes. Since the authors of the paper were not able to do the necessary survey of the building in order to define the geometry, material properties and detailing, the design parameters were adopted and a knowledge level 2 was assumed. The model obtained is shown in figure 3.

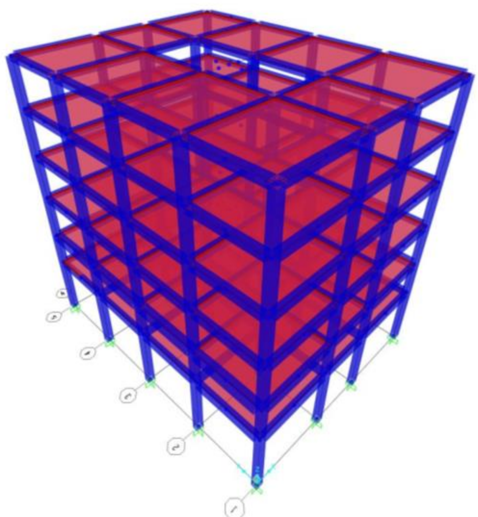


FIGURE 3: 3D Model of the structure

After the structure was modelled the loads were applied as determined in the original calculations. Using this, the axial loads in the columns were obtained which together with the details from the original design were used in order to calculate the behaviour of the plastic hinges in each column and beam joint. The calculated hinges were then applied to the model.

According to Eurocode 8, the pushover analysis needs to be conducted using two different lateral load patterns:

- uniform pattern, in this case mass proportional
- modal pattern, proportional to the first mode in X and Y direction

In the current case the load patterns shown on figure 4 were obtained.

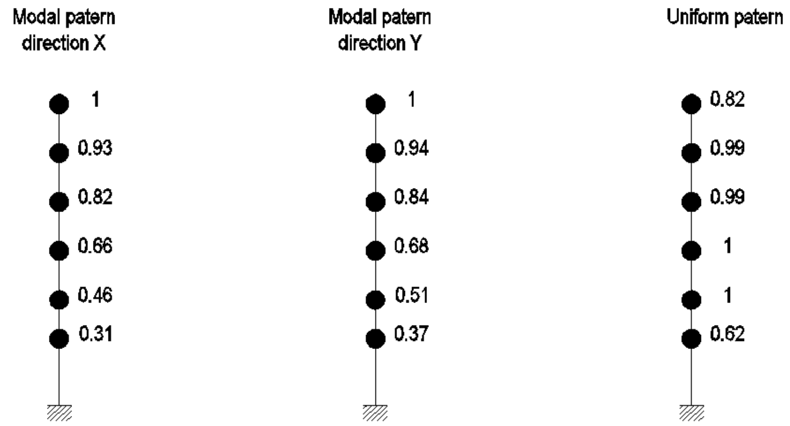


Figure 4: Calculated load patterns

Since the inelastic mechanisms which are likely to develop in existing buildings are, in general, unknown, the results obtained using the two standard lateral force patterns should be considered as an envelope of the actual response, which should lie between the two capacity curves. Therefore, the most unfavourable results of the two pushover analyses should be adopted. Denoting as X and Y the two principal horizontal orthogonal directions of the structure, sixteen different pushover analyses should be performed, eight in X-direction (“modal” towards positive X ± eccentricity, “modal” towards negative X ± eccentricity, “uniform” towards positive X ± eccentricity, “uniform” towards negative X ± eccentricity) and eight in Y-direction (“modal” towards positive Y ± eccentricity, “modal” towards negative Y ± eccentricity, “uniform” towards positive Y ± eccentricity, “uniform” towards negative Y ± eccentricity).However, due to the planar symmetry of the structure, the results are not dependant on the direction or the eccentricity of the loading pattern.

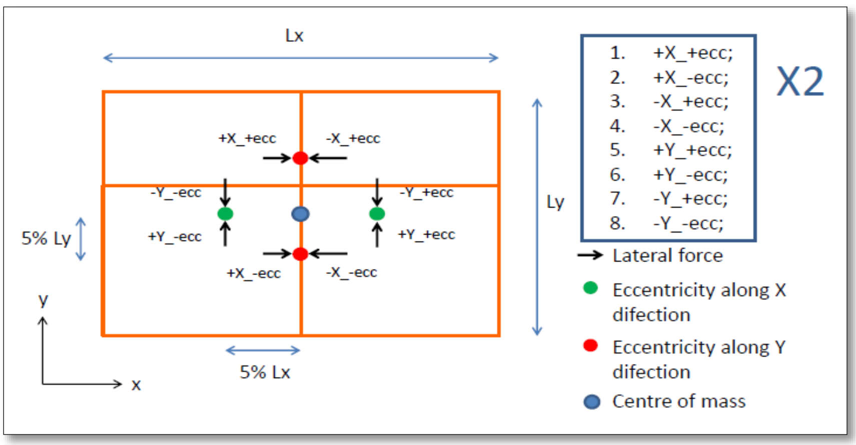


Figure 5: Pushover loading nodes

In the interest of making this paper concise only the worst case of the analysis (pushover in the X direction, using the uniform load pattern) shall be presented. In this case, the structure failed at step 93 with a displacement of 11.16 cm at the top due to the reaching of the ultimate rotation in one of the column hinges.

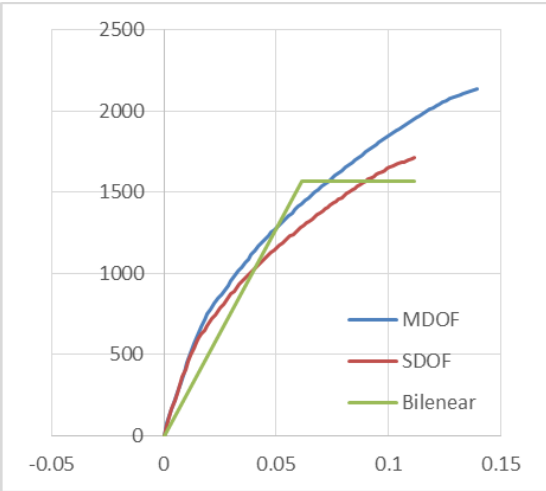


Figure 6: Capacity curve in Y direction, uniform load pattern

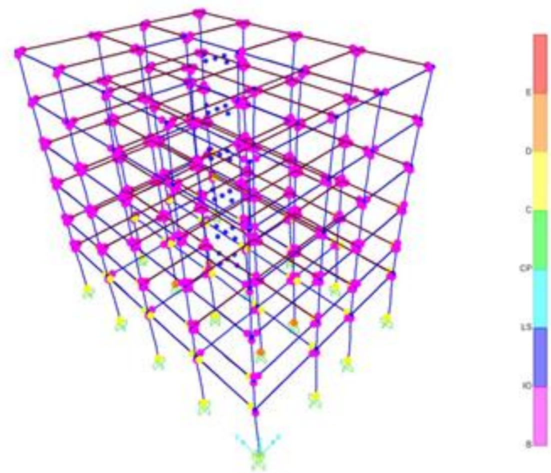
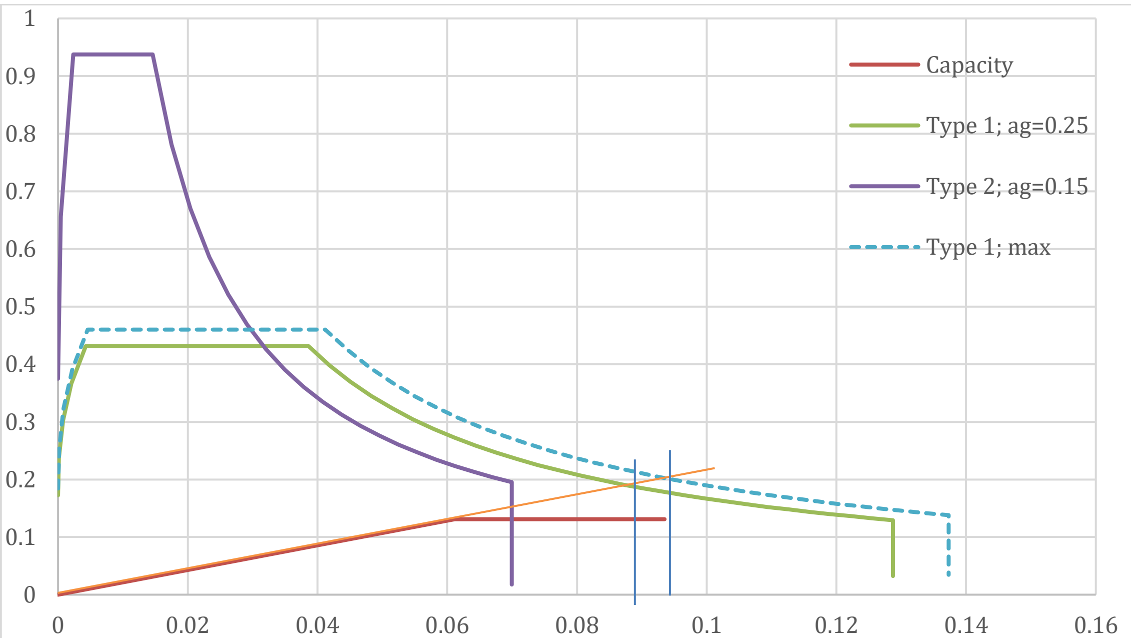


Figure 7: Step 93 of the push over analysis, Y direction , uniform load patern

The obtained push over curves shall be compared to the demand according to both types of spectra in the Eurocode. For spectra type 1, a peak ground acceleration of 0.15g, and for spectra type 2, a peak ground acceleration of 0.25g.



.Figure 8: Comparison with demand

From the comparison displayed in figure 8, it is clear that the structure satisfies the demand for the proposed spectra. Additionally we can conclude that the structure is more vulnerable to the spectra type 1, although it is calculated with a lower PGA. In addition, in figure 8 is shown the maximum spectra for which this structure satisfies the demand, a spectra type 1 with a PGA = 0.185g.

Conclusion

In conclusion, it is clear that the considered structure satisfies the demand of the Eurocode 8 in terms of its push over analysis. It should be mentioned that the input parameters of the structure were not obtained through surveying of the structure. In order to give a definitive answer to the vulnerability of the considered structure, proper survey must be conducted.

It is also interesting to mention that the original design of the structure predicts more longitudinal reinforcement in the columns then all the other considered analysis models with the exception of the analysis model according to the SDC81 and a Kp =2, which considerable increases the seismic forces in the structure.

References

BS EN 1998-1:2004+A1:2013, Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings, AMD 31st May 2013

Bubnov, S.A. (1981). Governmental Role in Mitigating the Impact of Earthquakes in Yugoslavia. In Jones, B.G. and Tomazevic, M. Social and Economic Aspects of Earthquakes. Proceedings of the Third International Conference: The Social and Economic Aspects of Earthquakes and Planning to Mitigate their Impacts. Bled, Yugoslavia, June 29 - July 2, 1981.

Chopra, A.K. (2012). Dynamics of structures – Theory and applications to earthquake engineering, fourth edition. University of California at Berkeley.

Петровски, Ј ., Ј уруковски, Д . и П ерчинков, С . (1971). Д инамички особини н а 6 спратна армирано бетонска зграда. Публикација ИЗИИС бр. 24. Скопје, Септември1971. Petrovski, J,D. Jurukovski and S. Percinkov. Dynamic properties of 6 story reinforced concrete building. Publication IZIIS no. 24 Skopje, September 1971.

Правилник за привремените технички прописи за градење во сеизмичките подрачја (ПТПС64). Сл. Лист на СФРЈ бр. 39/64 од 30 септември 1964 година.

Правилник за техничките нормативи за изградба на објекти на високоградба во сеизмички подрачја (ПИОВС81). Сл. Весник на СФРЈ бр. 31/81 од 5 јуни 1981 со измените бр. 49/82 од 13 август 1982, бр. 29/83 од 10 јуни 1983, бр. 21/88 од 1 април 1988 и бр. 52/90 од 7 септември 1990

Шелев, Ѓ., П. Гавриловиќ и Ј. Танасијевиќ (1968). Главен Проект за Блокови за Градски Зид, Скопје: Статика. Здружени проектни организации Бетон, Пелагонија и Македонијапроект. VI.1968 година.