1st Croatian Conference on Earthquake Engineering
1CroCEE
22-24 March 2021 Zagreb, Croatia

DOI: https://doi.org/10.5592/CO/1CroCEE.2021.107

The role of masonry infill on seismic behaviour of RC buildings

Zoran Trajchevski[1], Golubka Nechevska-Cvetanovska[2]

[1] *Graduated civil engineer*, Chakar & Partners – Skopje, *trajcevskizoran92@gmail.com*

[2] *Proffesor*, Institute of Earthquake Engineering and Engineering Seismology St. Cyril and Methodius University, Skopje, *golubka@pluto.iziis.ukim.edu.mk*

Abstract

In a large number of seismic-prone regions, the reinforced concrete frames of the buildings are filled with masonry and in this way, a composite constructive composition is created whose behaviour can be hardly predicted and modelled, which leads to flaws in the design regulations. Masonry infill is often presented as a non-constructive element and often is not included in the analyses, which creates a problem, a constructed building, in reality, can have different dynamic characteristics from the project ones, and thus different seismic behaviour than predicted. Therefore, the aim of this paper is to investigate how buildings behave in seismic activities when the masonry infill is included in the model and calculations. A comprehensive comparative analysis has been performed involving linear and nonlinear-Pushover static analyses and the obtained results from hypothetical models with 5 and 8 floors, with and without modelling the infill, according to the Macedonian regulations and according to Eurocodes were compared. For modelling the infill, the recommendations according to FEMA 356 for macro-modelling were used, where the masonry is modelled with an equivalent diagonal strut. From the conducted analyses, it can be generally concluded that the masonry infill has a very favourable effect on the behaviour of the buildings when it is evenly distributed. Although the ductility of the building decreased, however, the initial rigidity is substantially increased (almost 2 times in the presented paper). It can be freely recommended that when we have such a case of evenly and regularly distributed masonry infill, it should be included in the analysis as the first line of defence in overcoming seismic forces. In the model Ekopen 1-st story, it can be seen that the infill has a negative impact on the overall behaviour with a tendency to form a soft story on the ground floor.

Key words: Masonry infill, Soft story, Non-linear static analysis - Pushover

1 Introduction

With the development and globalization of reinforced concrete, building norms and regulations have evolved, improving the safety and stability of structures as well as a better understanding of phenomena such as earthquakes and finding solutions to deal with them. However, the development of standards is generally aimed at improving the construction of structural elements, while largely neglecting non-constructive ones such as masonry. It is still the most common solution in high-rise construction where the masonry infill is used to form partition walls or a facade. These elements have been upgraded over time as well as the standards and regulations for them, but still usually referred only to the improvement of their insulation characteristics, while forgetting the rigidity and the ability to take part of the loads. Non-constructive elements, by definition, are not designed to carry any forces other than those arising from their own mass. They are also, in principle, elements that construction designers do not design and for which architects and mechanical or electrical engineers take responsibility. Non-structural elements transform the construction into a habitable and functional building. Tenants, building materials and the contents of buildings and the activities that take place in them are the lifeblood of society. Therefore, non-structural elements should behave well during an earthquake, as they pose a serious risk to human safety. The description of most of the infill walls as “unconstructive” is the least misinterpreted. Any rigid and strong element of a building, whether designed by a builder or not, attracts forces to itself. In the process of accepting seismic forces, the infill walls can cause serious structural damage to the building. Therefore, the problems they create and the solutions to overcome them require careful consideration. Our territory, which belongs to seismically active areas, has requirements for design and construction of seismically resistant structures. In the world, modern construction tends to adequately respond to such requirements, in order to obtain safe, durable, economical and functional facilities. European and world regulations for seismic design recognize this problem and pay great attention to the masonry infill through appropriate criteria and constraints that reduce the negative and undesirable impacts of local and global character in terms of construction. In contrast, our current regulations do not take into account the performance of masonry, nor are there any guidelines for its proper design. Therefore, the purpose of this paper will be to find out what and how much impact the masonry infill has when it is included in the analysis, in the overall behaviour of the buildings.

Extensive analytical linear analyses have been performed. First, an 8-storey building with and without modelling the infill, according to MK regulations was analysed. Furthermore, several linear analyses of a 5-storey building with and without modelled infill, were performed according to MK [1, 2] and EC [4, 5] regulations. A case of the same building with 5 storeys was presented, only without infill on the ground floor (bare 1st storey).

A comparison of the results obtained from the performed linear analyses was made. The dynamic characteristics, design seismic forces, displacements and storey stiffness of all models are considered. In the next chapter, a static nonlinear (Pushover) analysis of 3 models with 5 storeys designed according to EC regulations was performed. The analyses were performed in both orthogonal directions with two loading schemes and the load-bearing capacities were obtained, as well as the development of the plastic joints and the fracture mechanisms of all 3 analysed models. The obtained results justify the purpose of the research in this paper.

2 Characteristics of the models

In order to show the differences in RC buildings with infill and without, and designed according to different regulations (MK regulations [1, 2] and Eurocode [4, 5]), linear static analyses of regular RC building with 5 and 8 storeys are made Table 1:

Table 1. Tabular overview of all analysed models

MK regulations	8-storeys	5-storeys	description	EC regulations	5-storeys	description
	Model A	$MK_{no\ infill}$	-no infill		$EC_{no\ infill}$	-no infill
	Model B	MK_{infill}	-with infill		EC_{infill}	-with infill
					$EC_{bare\ 1st\ storey}$	-bare 1st storey

The construction is a residential building with a ground floor and seven floors (Gr + 7). In the base is with dimensions 15 x 12 m with a storey height of 3 m. Structurally, the building is a reinforced concrete skeletal frame system consisting of beams and columns. The building is symmetrical along the two orthogonal axes with spans 6m-3m-6 m in X-direction and 3 x 4 m in Y-direction. In the first two storeys, the columns have dimensions of 85/85 cm, and the beams with 40/50 cm, while in the other floors, the columns are reduced by 10 cm every two floors, so that the upper two floors have dimensions of 55/55 cm, and the slab is RC with a thickness of 14 cm.

As for the 5-storey models, Figure 1, Figure 2 and Figure 3, they have exactly the same dimensions and the same layout of the masonry, the number of storeys is different and of course the dimensions of the columns and beams. Thus, in the first two storeys the columns are with dimensions 60/60 cm, and the beams with 40/50 cm, while in the other floors upwards the columns are with dimensions 50/50 cm, and the beams 30/50 cm, and the slab is 14 cm.

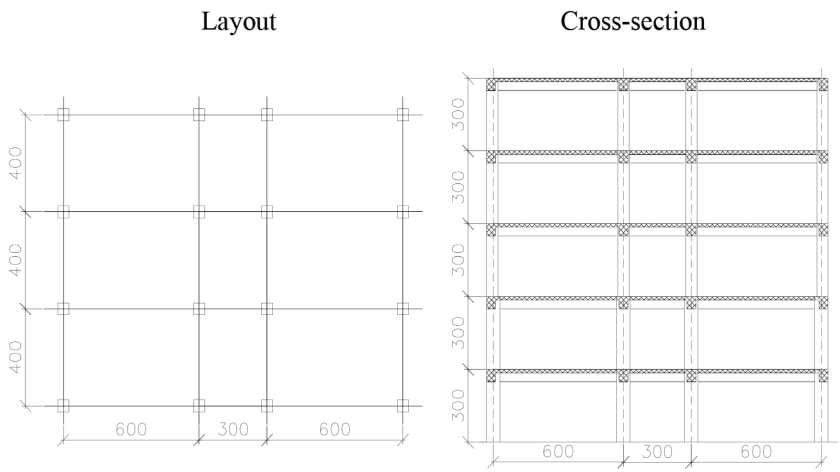

Figure 1. Geometric features of 5-storey models

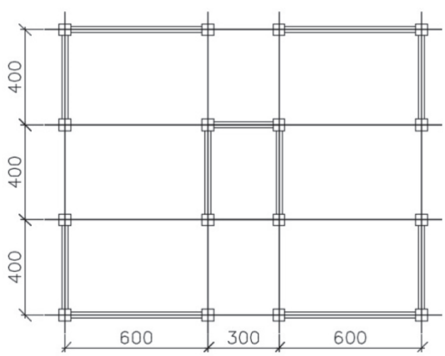

Figure 2. Layout of masonry-infill

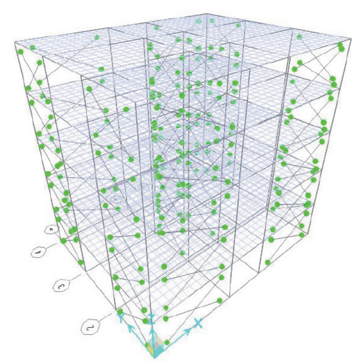

Figure 3. 3D view of a mathematical model in SAP 2000

2.1 Modelling of the masonry infill

There are generally two approaches to modelling the infill, micro and macro modelling. In micro modelling it is necessary to define a number of parameters, because the wall is modelled as a discontinuous set of blocks that are interconnected by discrete nodes. Because it is complex, micro modelling is often used experimentally. In macro modelling, homogenization is performed, the mortar and bricks are not modelled separately, but the infill is a homogeneous material. This method is much simpler than the previous one and is often used. In this approach, two methods are most common: MKE and the method with equivalent diagonal strut, which will be used in further analyses. The rules for modelling the equivalent diagonal strut are same in FEMA 356 and ASCE/SEI 41-17. Namely, in these codes, the masonry infill is elaborated in much more detail than in the Eurocodes.

$$a = 0.175(\lambda_1 h_{col})^{-0.4} r_{inf};\ \lambda_1 = [\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}]^{\frac{1}{4}} \quad (1)$$

In addition to the irregularities in the base and height, the openings are taken into account, the stability of the infill is checked, cases of damage are given, etc. Since they are most appropriate, the following Equation 1 will be used to define the equivalent diagonal strut given in FEMA 356 (7.5.2.1) codes [3]: (2). Figure 4 is an explanation to the aforementioned equation.

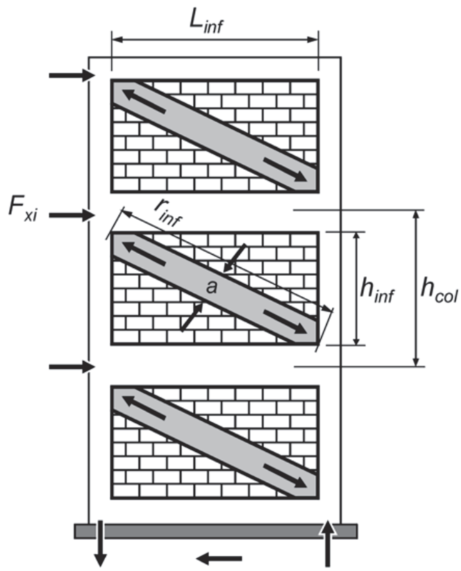

Figure 4. Excerpt from FEMA 356 [3] to explain the parameters in Equation (1)

There are three masonry infill panels in the presented building, so according to that, there will be three different widths of the diagonal strut which are presented in Table 2.

Table 2. Widths of the diagonal struts

3 x 6 m	
λ1	0.6641
a [m]	**0.80**

3 x 3 m	
λ1	0.7128
a [m]	**0.46**

3 x 4 m	
λ1	0.7030
a [m]	**0.56**

3 Comparison of the results obtained from linear analysis

3.1 Comparison of the 8-storey models

The first mode shape of the model without infill A) is 0.912 sec and represents an X-direction translation, while the first mode shape of the model with infill B) is 0.628sec or 31 % less than the model without masonry and represents a Y-direction translation. Because the stiffness of the infill is greater in the X-direction, the orthogonal direction of the first mode shape changes, and therefore the first mode shape of model B) has a Y-direction translation. Due to the increased rigidity, there is a lower value of the first period of the model B), so on the other hand the total seismic force is higher than the model without infill A). See Figure 5. From Figure 6 and Figure 7. it can be seen that the model with infill B) has almost twice the rigidity of the model without infill A).

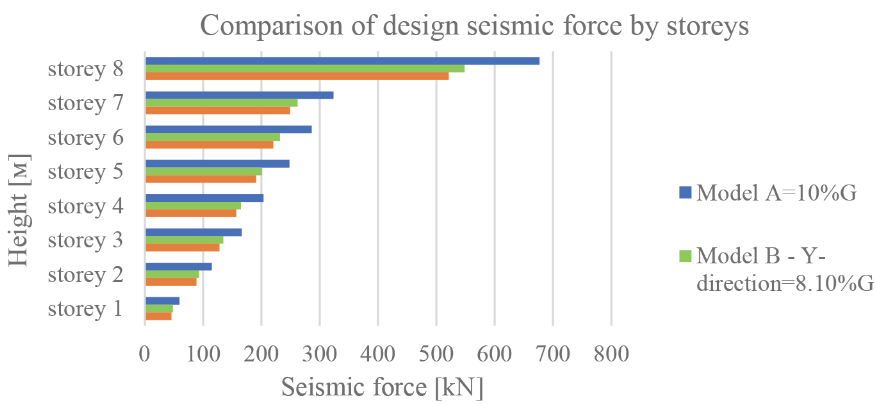

Figure 5. Comparison of design seismic force

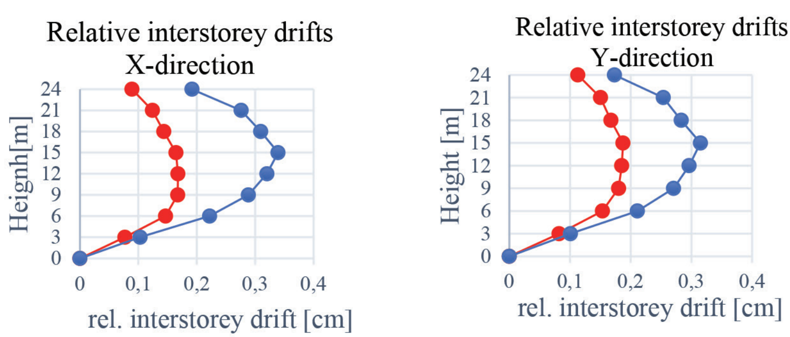

Figure 6. Comparison of interstorey drifts (red line-model with infill); (blue line-model without infill

Figure 7. Comparison of stiffnesses

3.2 Comparison of the 5-storey models

Table 3 presents a comparison of the first two periods for all analysed 5-storey models. There is a difference between MK regulation and the Eurocode for the calculation of the effective mass. The main difference is in determining the effective mass that is activated. The MK regulations use the full value of the gravitational loads and the snow plus half of the value of the variable ones.

Table 3. Tabular overview of the values of the first periods of the compared models

Model	**1-st period** [s]	**2-nd period** [s]
$MK_{no\ infill}$	0.533	0.505
MK_{infill}	0.397	0.391
$EC_{no\ infill}$	0.524	0.497
EC_{infill}	0.385	0.384
$EC_{bare\ 1st\ storey}$	0.342	0.337

In the Eurocodes it is given with the following Equation 2:

$$M = \Sigma Gk,i\text{"+"}\ \Sigma \Psi E,i \times Qk,j \tag{2}$$

Although the model MK_{infill}, in this case has 26 % less period than $MK_{no\ infill}$, so it is stiffer, still the seismic force will be the same for both cases, because Kd - dynamic coefficient remains the same with a value of 1.0.

Table 4. Tabular overview of the values of design seismic forces

X-direction [kN]						
Level	Z [m]	$MK_{no\ infill}$	MK_{infill}	$EC_{no\ infill}$	EC_{infill}	$EC_{bare\ 1st\ storey}$
Storey 5	15	483.44	483.44	362.64	387.31	372.78
Storey 4	12	856.58	856.58	872.28	947.79	998.34
Storey 3	9	1139.18	1139.18	1246.04	1383.71	1488.17
Storey 2	6	1338.48	1338.48	1492.48	1550.71	1946.95
Storey 1	3	1442.04	1442.04	1607.92	1678.58	2251.60

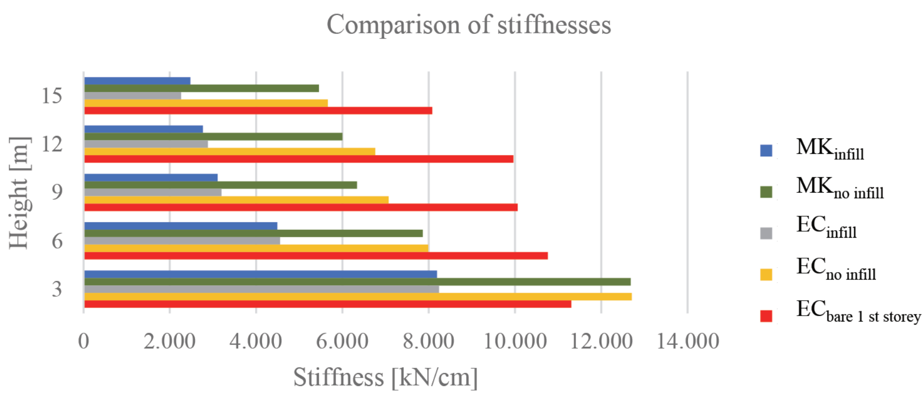

Figure 8. Comparison of stiffnesses for 5-storeys models

The first thing that can be noticed from Table 4 and Figure 8, is that the masonry infill does not play any role at all in generating seismic forces in the models designed according to Macedonian standards. It can be noticed that the design seismic forces in the model EC_{infill} are about 5 % higher than the model $EC_{no\ infill}$. Although the infill model is stiffer, it has a shorter period than the non-infill model, the design seismic forces are almost the same because the first periods of both models are on the horizontal part, between the TB and TC points of the design spectrum. Another thing that can be noticed is that in the buildings designed according to the European regulations, are dimensioned with higher seismic force compared to MK regulations, so the total seismic force in the $EC_{no\ infill}$ model is 10 % higher than that $MK_{no\ infill}$ model, and if we compare the models with the infill, difference is about 14 %. Also it should be taken into account that buildings are calculated with high ductility class (DCH) and a large behaviour factor q-5.85, which greatly reduces the design seismic forces. The difference of the total seismic force between the model $EC_{bare\ 1st\ storey}$, and the EC_{infill} is 25 % and is mostly due to the rules in the EC to reduce the factor of behaviour by 20 % (q = 4.68), in this type of buildings where which has a sharp change in stiffness. The displacements are almost 2 times larger in objects without modelled infill than those with.

Models without modelled infill have almost 2 times less rigidity than those with. In the last model, although we did not get a classic "soft storey", the behaviour still goes in that direction, especially when comparing the rigidity of the models with infill in the first floor. It should be noted that such a case with a bare 1st storey, in reality, very often occurs due to architectural requirements, and even the storey height is higher than the other storeys of the building. Despite the observed differences and anomalies of the structures, such an analysis cannot draw a detailed conclusion. In order not to base all further comments on estimates and assumptions, we will continue with the analysis to see what happens in the nonlinear area.

4 Comparison of the results obtained from nonlinear pushover analysis

A non-linear static analysis (pushover) of the previously presented models was made, EC_{infill}, $EC_{no\ infill}$, and $EC_{bare\ 1st\ storey}$. The obtained results are shown in Table 5.

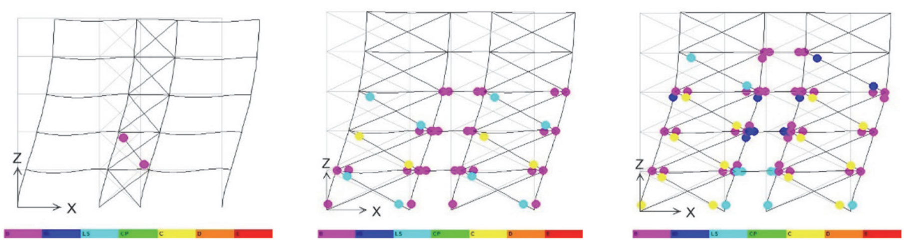

Figure 9. Development of plastic hinges (EC_{infill} model)

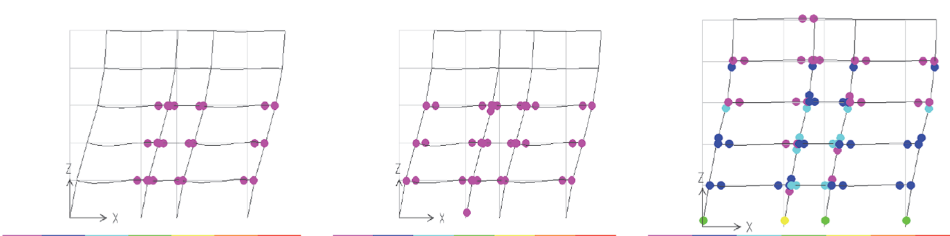

Figure 10. Development of plastic hinges ($EC_{no\ infill}$ model)

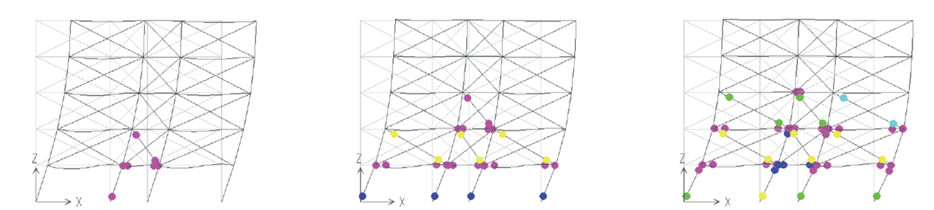

Figure 11. Development of plastic hinges ($EC_{bare\ 1st\ storey}$ model)

Table 5. Tabular Comparison of the values of obtained capacity curves

X-direction	EC_{infill}		$EC_{no\ infill}$		$EC_{bare\ 1st\ storey}$	
	[cm]	[kN]	[cm]	[kN]	[cm]	[kN]
yelding	2.74	4837.85	2.50	5345.20	3.50	3234.51
ultimative	14.44	11716.39	10.77	11313.96	23.54	9447.95
ductility	**5.26**	**2.42**	**4.31**	**2.12**	**6.73**	**2.92**

In the $EC_{no\ infill}$ model, the first plastic joint appears at a displacement of 3.5 cm at 3234 kN force, while the maximum force is 9447 kN at a displacement of 23.54 cm, Figure 9. In the EC_{infill} model, the first plastic joint appears at a displacement of 2.74 cm at 4838 kN force. Furthermore, the diagonals on the lower three floors lose their bearing capacity without any major damage to the 4th or 5th floor. The failure is through the columns on the ground floor with a maximum force of 11716 kN and a maximum displacement of 14.44 cm, Figure 10.

In the model $EC_{bare\ 1st\ storey}$, the first plastic joint appears at a displacement of 2.50 cm. The value of displacement ductility is the lowest compared to other analysed models. The capacity of the building is unused. The 4th and 5th floors are in a linear area and the infill is undamaged Figure 11. Comparison of capacity curve for all 3 models are shown on Figure 12.

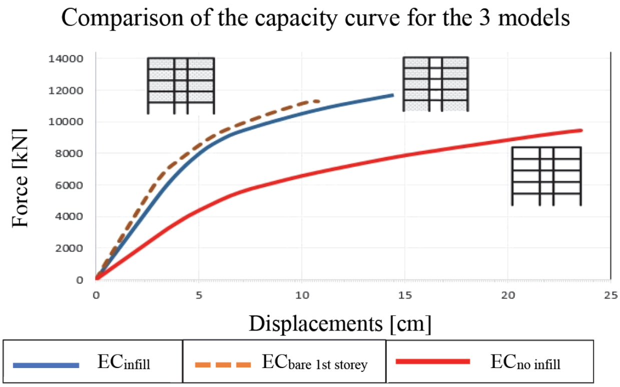

Figure 12. Comparison of capacity curve for all 3 models

5 Conclusion

The purpose of this paper was to investigate the impact of masonry infill on the behaviour of an RC buildings. From the linear static analyses and the performed comparisons it can be concluded that the masonry significantly hardens the construction. In the presented examples, the stiffness of the models with included infill was twice as high as those without. In the $EC_{bare\ 1st\ storey}$ model. We see that the infill has a negative impact on the overall behaviour, which results in increased values of displacement and internal static values in the columns of the first storey. From the performed nonlinear analyses Figure 12, it can be best concluded that the masonry infill has a favourable effect on the behaviour when it is evenly distributed. Although the ductility of the building decreases, the initial stiffness is significantly increased. If we want to know how the buildings will behave during the earthquake when we have masonry infill, it is necessary to model it and make a nonlinear analysis. The most common case in reality is when there is a need for an open first floor. From the nonlinear analyses we saw that this type behaves unfavorably, because the capacity of the structure is not fully utilized. Although in our case the building was in a linear area at the design seismic forces, it can still be concluded and recommended when we have such a case, to design the building with the recommendations for "soft storey", or at least to add additional reinforcement against shear of the columns of that floor, whether the storey height of the bare floor is the same or greater than the others. Based on these analyses, it can be generally concluded that we should not neglect the masonry infill, both because of the positive and because of the negative effects.

References

[1] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima - PIOVS '81 (Službeni glasnik 31/81)

[2] Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima - Pravilnik o tehničkim normativima za beton i armirani beton PBAB "87 (Službeni glasnik 11/87)

[3] FEMA 356 (Federal Emergency Management Agency) (2000): Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Federal Emergency Management Agency, FEMA

[4] Eurocode 8: Design of structures for earthquake resistance – (2004)

[5] Trajchevski, Z. (2019) - Comparative analysis of the influence of masonry infill in seismic behaviour of RC buildings, Master thesis mentor Prof. D-r Golubka Nechevska-Cvetanovska