Comparative Analysis of Reinforced Concrete Structure with Traditional and Decoupled Masonry Infill Under Earthquake

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Abstract: ***Reinforced concrete (RC) frame structures with masonry infill are a popular form of construction in many earthquake-prone regions all over the world. Throughout the Balkans, but especially in Serbia, there is a substantial number of school buildings with this structural system, which are located in high seismic hazard areas. Although infill walls are considered non-structural elements and are usually neglected in the design process, field observations after past earthquakes have shown that they interact with the structural system and experience severe damage or total collapse when subjected to seismic loads.***

This paper presents the results of comparative numerical analyses on three models, i.e. bare frame model (model 1) and bare frame models with traditional and decoupled masonry infill (models 2 and 3). First, a modal response spectrum analysis was performed on the elastic model, followed by non-linear "Pushover" and "Time history" analyses. The most common damage configurations caused by the irregular distribution of infill walls, such as the "short" column effect and the "soft-storey" mechanism, were avoided using the INODIS system that decouples masonry infills from the surrounding frame. The main aim of this paper is to investigate the effect of decoupling masonry infill using the INODIS system and then compare with the results of the bare frame and traditionally infilled frame models. The results of nonlinear analyses show that the model's behaviour with isolated infill walls is similar to the bare frame model. In contrast, the behaviour of the model with traditional infill is significantly different and requires a complex numerical model. The practically negligible difference in the behaviour of models 1 and 3 led us to conclude that there is a large potential for using the bare frame model in the design of RC frame buildings with masonry infill with the proper use of the INODIS system.

Index Terms: Earthquake, Pushover, Time history, Traditional masonry infill, Decoupled masonry infill

1. INTRODUCTION

EARTHQUAKES are one of the most destructive and widespread natural disasters a person can experience. Observations after major earthquakes in our immediate environment, e.g., the 1963 Skopje earthquake (M 6.1), the 1979 Montenegro earthquake (M 6.9), the 1977 Vrancea, Romania earthquake (M 7.2), and most recently, the November 26, 2019 Durrës, Albania earthquake (M 6.4) and the December 2020 Petrinja, Croatia earthquakes (M 6.4) have shown that the territory of Serbia is close to an area of high seismic hazard. In the last 100 years, more than 10 earthquakes with a magnitude of 5.0 and higher have occurred within the Serbian territory [1].

The fact that the territory of Serbia is located in a region characterized by a moderate seismic hazard is not so socially represented. It is very quickly forgotten after an earthquake occurs in our environment. Social awareness of the consequences of an earthquake in the community was suddenly awakened after the devastating earthquake in Skopje in 1963. Serbia experienced a construction boom after the first National Code for seismic design was introduced in 1964., and until 1980 numerous RC buildings with masonry infill had been constructed.

Reinforced concrete (RC) structures with masonry infill walls constitute a significant portion of the building stock since their use is common in many countries due to the excellent performance of infills in terms of durability, noise, temperature, fire, etc. Although infill walls are considered as non-structural elements and often ignored in the design process, they significantly changed dynamic characteristics of RC frame buildings when subjected to an earthquake event [2,3]. Field observations after the 2015 M 7.8 Gorkha, Nepal earthquake have shown that the infills produced a significant increase in stiffness that affected the natural frequencies of the structure [4]. Infill walls are characterized by a low drift capacity of 0.2–0.3% [5] and a rather stiff and

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brittle in-plane response. In some cases, due to the sudden drop in stiffness and strength of infill walls, their brittle behaviour can also cause the formation of a soft-story mechanism [6,7,8]. In addition to weak and/or soft stories, the damage configurations mostly observed in RC buildings caused by the irregular distribution of infill walls are torsion and "short" column effects.

After the cyclic movements of the structure caused by the earthquake excitation, cracks in the shape of the letter X appear in the infill walls. It also represents one of the most common types of damage in the infills under in-plane seismic loading. Many reports by various authors [9,10,11] have shown that stiff masonry infills cannot withstand the high deformability of RC frames without experiencing a rather brittle response causing severe damage under in-plane (IP) loading. Besides IP loading, infills are subjected to out-of-plane (OOP) forces acting perpendicular to the wall panel. Although OOP collapse of masonry infills is mainly expected to occur on upper storeys, masonry infills can also suffer substantial damage or complete failure due to interaction of in-plane and out-of-plane actions in lower storeys of buildings [10].

The recent earthquakes that hit the Western Balkan region had a devastating impact on the affected populations of these countries. In addition to significant structural damage to residential and industrial buildings, these earthquakes also caused extensive damage to educational facilities. Therefore, in future earthquake events, these school buildings may suffer severe material damage and, more importantly, endanger the users' lives of these educational institutions. For this reason, this paper is based on the comparative numerical analysis of a school building in Serbia.

This study has developed three numerical models: the “bare frame” model and the models with traditional and decoupled infill. Emphasis is placed on comparing models’ behaviour through the results of nonlinear analyses related to the displacements and inter-storey drift along the height of the school building. One of the main goals of this study is to draw certain conclusions and define the causes that could lead to significant damage to the school building and other school buildings of this structural system during future earthquake events.

2. PROBLEM STATEMENT

Post-earthquake reports have pointed out that one of the most common reasons for poor structural behaviour of RC structures is that stiff infills increase the stiffness of the “bare” frame RC buildings by several times, thereby changing their dynamic characteristics. However, in everyday design, infill walls were neglected and their effects on the global structure behaviour were not considered.

Depending on the predominant periods of the earthquake, decrease the natural period due to infill may produce an increase or decrease in the expected seismic response [2]. Due to certain torsional effects that are the product of the presence of the infills, the main mode shapes in the structure also change. During the earthquake action, when the infills are wholly or partially damaged, the natural period of the structure changes. This means that in a certain period of earthquake action, the higher level of forces that previously attracted and carried the infilled frame will be transferred to the more flexible and weaker bare frame.

In most cases, the presence of masonry infill walls changes the intended behaviour of low- to mid-rise buildings. It contributes to significant damage or collapse of the structure. Therefore, this paper presents an efficient decoupling system that has shown promising results and is described in [2]. This system, called INODIS (Innovative Decoupled Infill System), is able to effectively decouple and delay the activation of infill walls, thereby reducing infill/frame interaction and its side effects.

Another potential problem in future seismic activities in this territory is the fact that educational facilities in the Republic of Serbia are primarily older facilities built in the second half of the 20th century and were not designed according to the latest seismic regulations and rules of European standards.

3. THE BEST EXISTING SOLUTIONS

Firstly, at the beginning of this chapter, a brief description of the RC structure of the school building will be given. After that, emphasis will be placed on the existing solutions modelling buildings in daily engineering practice.

The representative school that is the subject of this paper is located in Mladenovac in Central Serbia. The school building was built in 1964. According to the provisions of Eurocode 8 [12], the base of the school building is irregular (T-shaped). The structure has one floor that is partially underground for the depth of the foundation - a basement with a height of 3.4 m and three above-ground floors with a height of 4.0 m. The total height of the building is 12.5 m, measured from the lowest elevation of the landscaped grounds to the highest point of the parapet of the school's flat roof. The total gross area of the school building is 1900 m^2. There are no RC shear walls on the entire structure to resist both horizontal and vertical loads. The predominant vertical structure is the RC structure, while the horizontal structure is a rigid diaphragm (RC slabs). The structural system of the school building is a RC frame structure with masonry infill. This building has rigid diaphragms (RC slabs). The slab is a fine-ribbed semi-prefabricated slab of the "Avramenko" system, which is formed from ready-made reinforced concrete beams. The thickness of the slab is 5 cm, including the roof-top slab. The ready-made RC beams that are part of the “Avramenko” system have dimensions of 25x5.5 cm and are defined at equal equidistant distances of 40 cm. These beams transfer the load in one direction from the slab to the RC beams that are an integral part of the longitudinal and transverse frames. According to the existing architectural drawings of the school building, the RC columns have the following cross-sections of 38x38 cm, 38x25 cm, 32x32 cm, 50x32 cm and ϕ30 cm. Given the lack of a data in design documentation, the dimensions of the beam are adopted as the width of the corresponding wall panel and the height of 45 cm.

The “bare” frame model is the first numerical model used and described in this paper. The design of structural elements (beams and columns) was performed on the initial model (model 1), following the usual engineering practice of ignoring the infills in the calculation. It should be noted that Eurocode 8 [12], unlike the regulations of other countries that do not use these extremely advanced European standards, also requires computational proof of providing the required level of local ductility in the critical area. In addition to the self-weight of the structure and the imposed load of 2.5 kN/m^2, the seismic load in two orthogonal directions is defined using the design spectrum of Eurocode 8 with soil condition C. The acceleration was adopted based on the seismological hazard map of Serbia, specifically for the city of Mladenovac and amounts a_g=0.1g. Considering that Eurocode 8 [12] classifies school buildings in the building importance class III, the a_g/g ratio is multiplied by the importance factor γ_I=1.2. The behaviour factor was adopted based on the recommendations given by Eurocode 8 [12] for a frame construction whose tops are connected by beams in both directions and is q = 3.45.

The class of concrete used is C 25/30 and the reinforcement steel is GA 240/360. The class of exposure of concrete to the external environment is XC 1. According to all relevant requirements of Eurocode 8 [12] and Eurocode 2 [13], the relevant RC column and RC beam are designed especially for bending moments and especially for shear forces. This is not presented in the paper, nor is the general design concept.

In the initial model, it was necessary to define the behaviour and position of the plastic hinges for the “Pushover” analysis that will be carried out in the following. The length of the critical zone of 70 cm (start and end parts) was adopted in RC elements. “Fibre” hinges were defined in “middle” sections of RC elements at a relative distance of 0.05 and 0.95. The location of the hinges is the same for the other two models and will not be described in the following models.

Due to all the aforementioned problems that may arise in the case of neglecting the infill walls during the design of a building, the first model was upgraded by adding infill walls, obtaining numerical model 2 (frame with traditional masonry infill). In order to model the in-plane behaviour of the infill walls, a macro-modelling approach was employed, using “link” elements available in SAP 2000 [14] to model equivalent strut. This type of element is used because it can connect two joints (RC frame and infills) and they are able to capture a nonlinear behaviour. Therefore, they are a suitable choice for modelling in-plane behaviour of infill panel. A link element is assumed that is made of six springs for each of the six degrees of freedom.

Due to the different thicknesses of the walls, the height of the frames and the height of the infill walls, "link" elements are defined individually for each floor (basement, ground floor and first floor). It should be noted that for walls with openings, there was no reduction in the bearing capacity of the infill walls depending on the size of the openings, but a much more complex and accurate calculation method was used. In those calculations, the height of the wall is taken as the height of the parapet wall, and much more realistic values were obtained with which the characteristics of the "link" element were further defined. The infill walls made from hollow clay blocks (nominal dimensions of the unit are 190 x 190 x 250 mm) with thin-layer mortar connection. The modulus of elasticity of the wall is E=5000 MPa, while the compressive strength is fc=5 MPa.

Figure 1 shows a 3D model of the school building with "link" elements that simulate a traditional masonry infills.

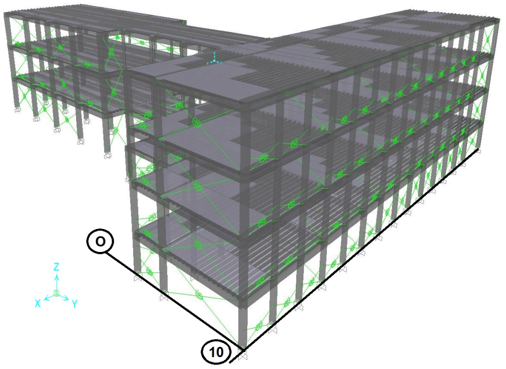


Figure 1: 3D model of the building with “link” elements [14].

4. THE PROPOSED SOLUTION

The previously described numerical model 2 was used to create numerical model 3 in the software package SAP2000 [14]. The masonry infill is defined using "link" elements in the same way as in model 2 (see chapter 3). The INODIS (Innovative Decoupled Infill System) system developed in [2] is a proposed innovative system made of elastomer, which is applied in the modelling of infill walls in numerical model 3. The basic idea of the system is decoupling of infill masonry walls and RC frame in in-plane direction combined with the out-of-plane connection measures along the edges of the wall panel. This innovative system takes a different approach than other existing systems. Instead of increasing the load-bearing capacity by adding additional reinforcement, and it is able to effectively decouple and delay the activation of the infill walls. In this way, a relative displacement can occur between the surrounding frame and the infill panel [2]. Also, this is an effective solution to avoid the brittle behaviour of the structure during frame-infill interaction under earthquake excitations.

Several essential things that make it stand out compared to existing solutions were highlighted. The INODIS system allows us to reach large drift values without developing significant damage in the masonry infill walls. In the case of buildings that have a lack of structural elements on the ground floor level due to functional demands such as parking and shops, this innovative system can reduce widespread configuration problems caused by the absence of infill walls or the presence of many fewer infill walls than the story above and/or below, such as "soft storey" mechanism", as well as torsional effects. Also, by using the INODIS system, we can avoid the effect of a "short" column, which is especially pronounced in walls with openings in this structural system. The details of the modelling approach using the proposed system will be presented in Chapter 6.

5. CONDITIONS OF THE ANALYSIS TO FOLLOW

For the comparative numerical analysis of the RC frame structure with traditional and decoupled masonry infill designed in according to the relevant requirements of Eurocode 8 [12] and Eurocode 2 [13] under the seismic loading, a 3D numerical model built in SAP2000 [14] was used. In this study, macro-modelling approach was employed, i.e. Equivalent Diagonal Strut model (ESM) using available “link” elements in software. Between several types of link elements available in SAP 2000 the multi-linear plastic link element was chosen due to its ability to present nonlinear behaviour of infill wall. Two link elements are placed inside the frame connecting diagonal opposite corners (see Figure 1).

Only the properties in the axial direction were defined because the equivalent diagonal strut “works” only in compression. The non-linear properties assigned to the "link" element are a) force-displacement curve and b) hysteresis type and parameters that describe it. To define the hysteresis model of the masonry infill, the "Pivot" model was chosen. For the definition of this curve approach proposed by [15] was used. The detailed calculation procedure of the force-displacement curve is beyond the scope of the paper, so only the final curve is shown in the following Figure 2.

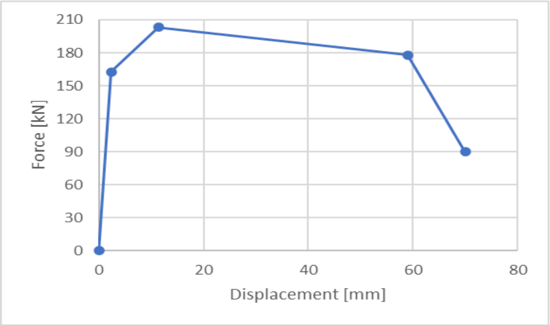


Figure 2: The force-displacement curve for the "link" element.

In the nonlinear analyses performed on the 3D models of the school building, the main parameters used to show the analysis results were inter-storey drift and absolute displacements. Inter-storey drift is one of the best indicators of damage levels and can give us a clear picture of how models behave under seismic loading. Based on the diagram of inter-storey drift and absolute displacements by the height of the school, the significant advantages of the proposed system developed in [2] compared to the model with traditional masonry infill will be highlighted.

6. DETAILES OF THE PROPOSED SOLUTION

Previously described umerical model 2 was used to create numerical model 3 by adding an elastomer material, which is used for decoupling infill wall from the RC frame. Elastomer is a rubber-based material with hyperelastic behaviour characterized by low stiffness and elastic response up to large strains. In order to take into account decoupling with the elastomers that are applied in the INODIS system, nonlinear “link” elements are also employed. Two approaches were used when modelling elastomers in the SAP2000 software [14]. The first approach was used when there was a wall without an opening in a building, adding two "link" elements in the corners of each compression diagonal (see Figure 3). The second approach was related to the wall with an opening, where there was no vertical "link" element on the upper side of the wall but only a horizontal "link" element that connected the traditional infill wall and the RC column (see Figure 4).

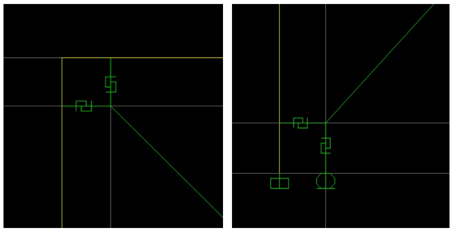


Figure 3: Corner detail with vertical and horizontal "link" elements simulating decoupled infill walls [14].

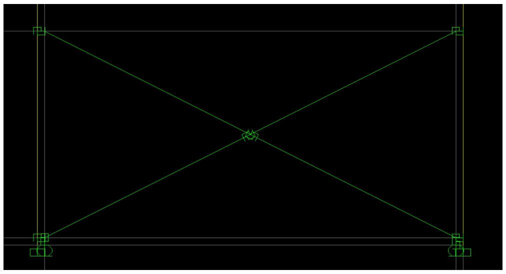


Figure 4: Modelling of decoupled infill walls with horizontal “link” element for a wall with an opening [14].

Based on the experiment [2], RF 400 was used as a system for decoupling the RC frame from the traditional masonry infill walls. Thickness of the column elastomers is of 37.5 mm and for the beams 25 mm. Using this data and the results of the force-displacement curve shown in Figure 5, the characteristics of the "link" elements representing the elastomers were defined. The “Takeda” model was used for the definition of the hysteretic model for the elastomers. This is the simplest model as it does not require definition of any parameter.

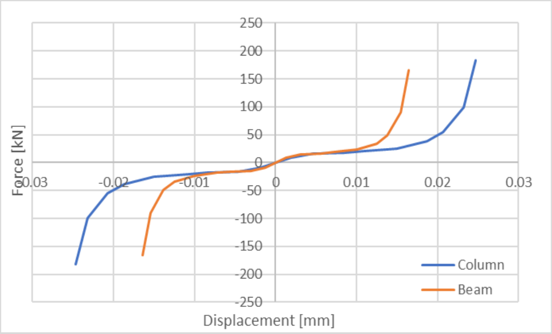


Figure 5: The force-displacement curves applied to the “links” presenting elastomers [2].

7. ANALYSIS

The reference method for determining the seismic effects is the modal response spectrum analysis, using a linear-elastic model of the structure and the design spectrum given in Eurocode 8 [12]. In this paper, the modal response spectrum analysis was first conducted on the elastic model, and then the nonlinear parameters were introduced into the models. By defining the nonlinear characteristics of the materials, the following nonlinear analyses were performed on the models, such as a) nonlinear static ("Pushover") analysis and b) nonlinear dynamic ("Time History") analysis. The following subchapters will describe the analyses used to obtain the results in the SAP 2000 software package [14].

7.1 Modal Analysis

Firstly, a modal analysis was performed to compare the dynamic characteristics of different models and check the influence of the traditional and decoupled infill walls on the behaviour of RC frame structure. By using this relatively simple and effective analysis, the natural periods of the structure and the main mode shapes are obtained. Mode shapes are typically calculated from undamped free vibration, where the effects of damping are not considered. In these analyses, the focus is on the inherent characteristics of the system, such as mass distribution and stiffness, which primarily influence the mode shapes. Mode shapes and values of natural periods of structure depend on the basic characteristics of the system: mass and stiffness. With the increase in stiffness of the structure and constant mass, the periods of oscillation will progressively decrease.

The results of the modal analysis for the first three modes for each model are presented in the following Figure 6. It can be seen that Model 1 ("bare” frame) represents a flexible structure (T_1=0.58 s), while Model 2, by adding the traditional masonry infill, has become a more rigid structure (T_1=0.325 s). On the other hand, the reduction on the natural period of the model with decoupled infills with respect to the “bare” frame model is much lower. The fully infilled frame structure with decoupling system gave a natural period of 0.55 s. This represents a reduction of about 5%.

Another interesting fact is that models 1 and 3 in the first vibration mode had pure translation in the Y-direction, while the second mode was the torsional mode. The difference is again visible in model 2, where the first vibration mode represents pure torsion, while the second mode is a combination of translation in the Y-direction and torsion.

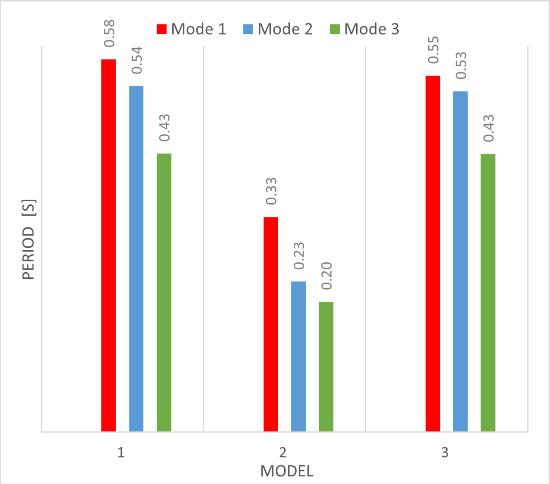
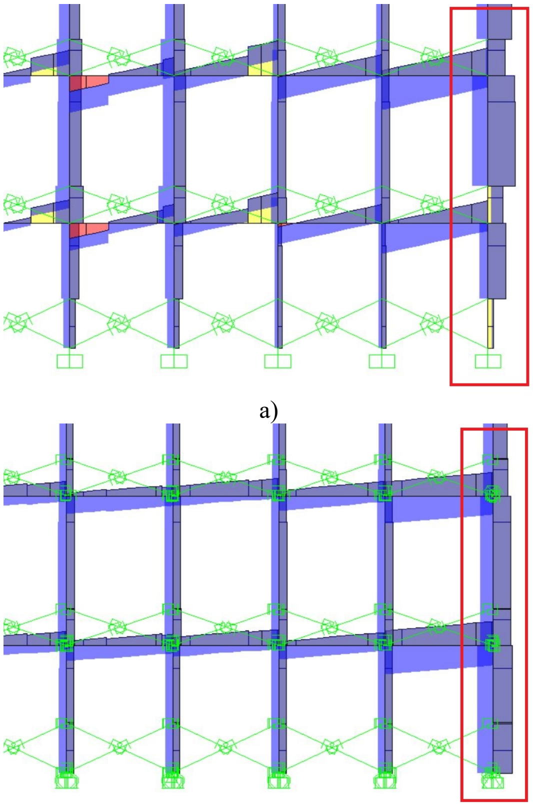


Figure 6: Natural periods of the first, second and third mode for different models (Model 1-red; Model 2-blue; Model 3-green).

7.2 *Response Spectrum Analysis*

Response spectrum analysis is based on the analysis of the structure using the given response spectra of assumed earthquakes or the designed spectrum given in Eurocode 8 [12]. The effects of this analysis will be observed within the load combinations used in the calculation to determine the maximum values of forces and bending moments in RC structural elements.

The relevant longitudinal frame in axis 10 (see Figure 1) and the transverse frame in axis O (see Figure 1) were chosen as the facade frames because they were the farthest from the centre of stiffness and had the largest displacements. The centre of stiffness and mass were mismatched when adding traditional masonry infill, creating torsional effects in our models. It can be seen from the diagrams of shear forces (Figure 7a) that there was a sudden rise of influence in the RC columns at the points of input forces from the infill walls (parapet walls). It is worth noting that the bending moments and shear forces were significantly higher in the case of the model with traditional infill (Model 2), especially when we had a parapet infill wall panel due to the appearance of the "short" column effect. By increasing the influence of shear forces in the RC columns, the steel reinforcement for receiving these forces should also be increased, which is undoubtedly higher than the amount calculated in the "bare" frame model. Given that the INODIS system was used in modelling infill walls in model 3, it was expected that the structure would behave similarly as in model 1 and that relative displacements of the frame in relation to the infill would be enabled. In particular, this solution avoided the appearance of a "short" column effect in Model 2 (see Figure 7b).


a)

b)

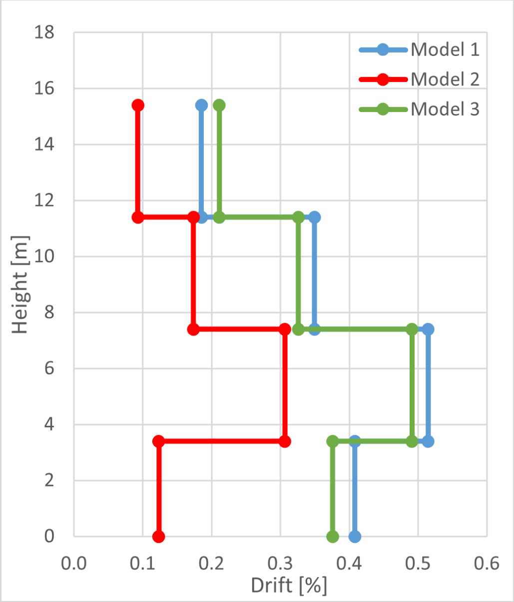
Figure 7: Diagram of shear forces V_{22} (envelope) for part of the frame in axis 10 in a) Model 2 and b) Model 3.

7.3 *Nonlinear Static (“Pushover”) Analysis*

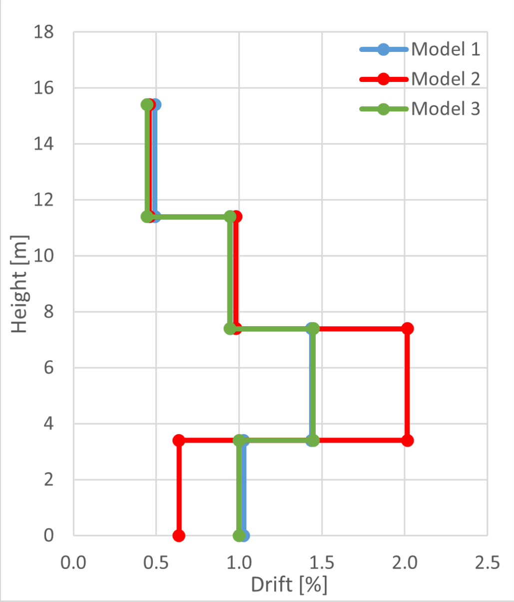
Static nonlinear (“Pushover”) analysis is used to check force-displacement capacity and base shear forces in these models.

Project designers use this analysis to design the structure's behaviour and to determine whether the cross-sections and reinforcement have been appropriately adopted. In some structural elements, it is necessary to design zones with a large absorbent capacity in which plastic hinges are formed. Conversely, the vertical bearing capacity of the structure must not be compromised. In other structural elements where it is more difficult to achieve high ductility, a sufficiently large load capacity is ensured so that plasticisation does not occur. These are elements in which shear and dominant axial forces occur.

The maximal horizontal force in the "bare" frame model for the X direction was 9320 kN at a limit displacement of 19.2 cm. The traditionally infilled frame model (model 2) activates base shear almost 60 % more than model 1. However, this base shear was achieved much earlier (at 11.9 cm) than the model with decoupled system. It is important to notice that in the case of decoupled frame model there is no significant change in the base shear force level. The horizontal limit force is 9410 kN at a limit displacement of 15.1 cm.



a)



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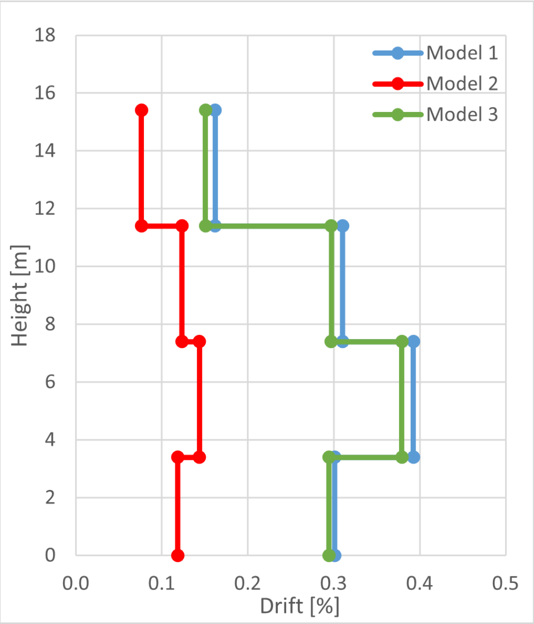

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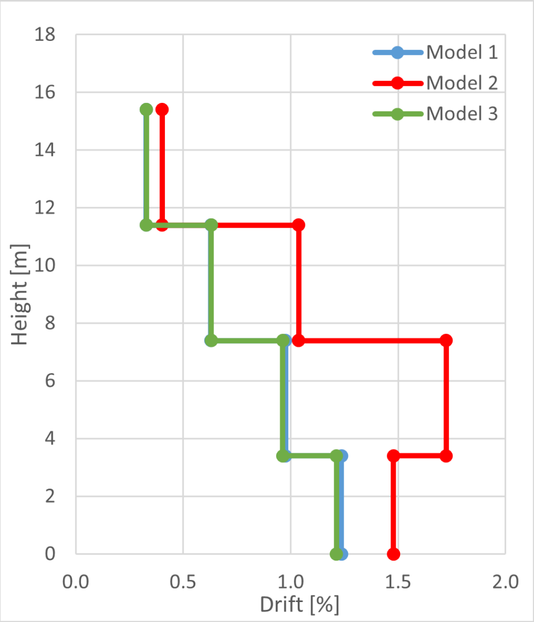


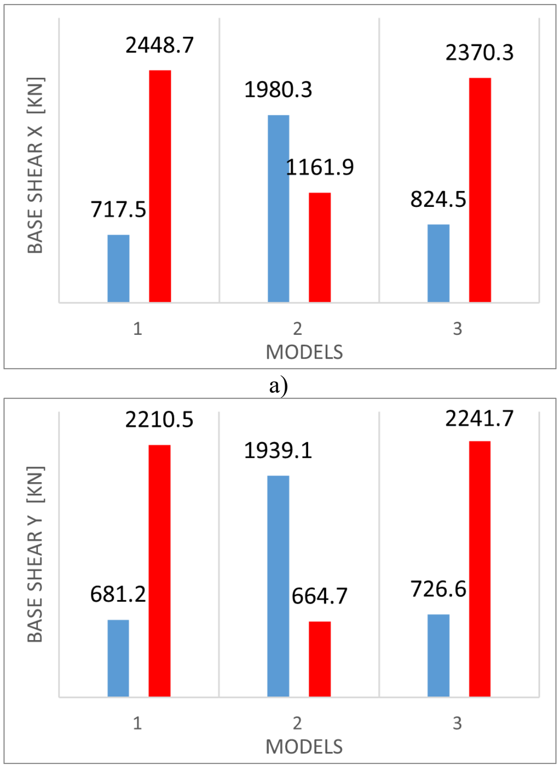
d)

Figure 8: Nonlinear "Pushover" analysis results: inter-storey drift for the moment before plasticisation of a structure: a) frame in axis 10 and c) frame in axis O; inter-storey drift for the moment of limit displacement of a structure: b) frame in axis 10 and d) frame in axis O.

Diagrams of the inter-story drifts by the height for "Pushover" analysis in X and Y direction for relevant frames in axes 10 and O are given for the moment before the plasticisation of a structure (Figures 8a and 8c), as well as for the moment of limit displacement (Figures 8b and 8d), respectively.

7.4 Nonlinear Dynamic ("Time History") Analysis

"Time history" analysis is a non-linear dynamic analysis where the time-dependent response of a structure can be obtained by direct numerical integration of its differential equations of motion, using the accelerograms defined in Eurocode 8 [12], representing ground motion. In particular, this complex non-linear analysis is rarely used to design multi-story residential buildings. Accelerogram used in time history analysis is generated artificially based on a Eurocode 8 [12] elastic response spectrum Type 1 and soil condition C. Since the acceleration values are given in m/s^2, it was necessary to determine the maximum acceleration value and divide all values by that value. In this way, the accelerogram is normalized in the software so that its maximum value is 0.1g (approximately 1 m/s^2).



a)

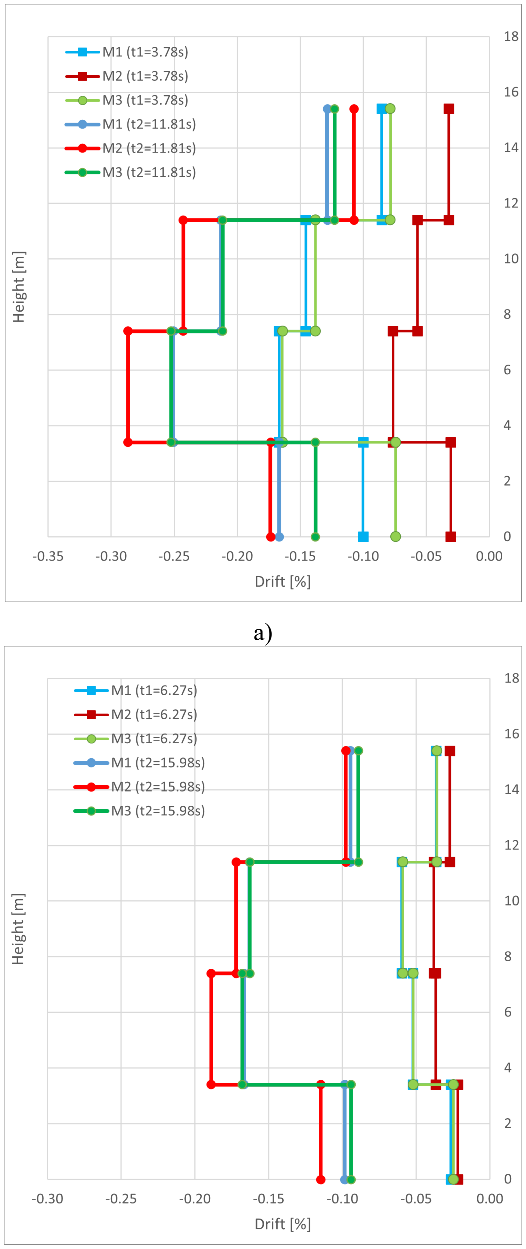
b)

Figure 9: "Time history" analysis results: a) Base shear X for t_1=3.78s and t_2=11.81s; b) Base shear Y for t_1=6.27s and t_2=15.98s (time period t_1 - blue, time period t_2 – red).

The change in the base shear forces in the best way presents the influence of traditional infill on a global behaviour of an RC structure under earthquake excitations. Figure 9 shows the change in the maximum value of the base shear forces at the moments before and after infill walls damage. The time moments for the “Time history” in the X direction were 3.78 s and 11.81 s, while in the Y direction were 6.27 s and 15.98 s.

In the first moments of the earthquake event, before the infill walls damage occurred, model 2 reached almost three times higher base shear forces than models 1 and 3, for both the X and Y directions, as you can see from Figure 9a) and b). Also, from Figure 9, it was observed that after the infill walls came into contact with the surrounding RC frame, in model 2 there was a drop in base shear forces by 2-3 times compared to the base shear force in models 1 and 3, both in X and Y direction.

Diagrams of the inter-story drifts by the height for "Time history" analysis for relevant frames in axes 10 and O are given for the same time moments as previously shown diagrams of base shear forces, i.e. in the X direction in Figure 10a) and the Y direction in Figure 10b).



a)

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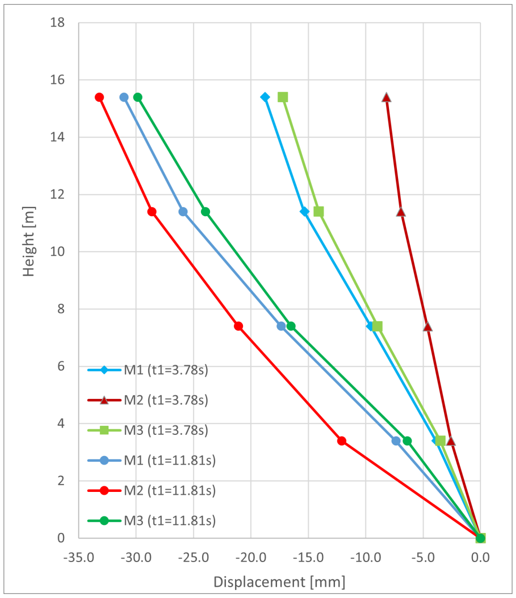
Figure 10: Nonlinear “Time history” results: a) Inter-storey drift for t_1=3.78s and t_2=11.81s in X direction; b) Inter-storey drift for t_1=6.27s and t_2=15.98s in Y direction.

The model's behaviour was also studied by analysing the maximum absolute displacements by the height of the school building. The diagram shows the absolute displacements during the earthquake at precisely selected moments t_1 and t_2, i.e. before and after damage of infill walls. "Time history" analysis results in the X direction for frame in axis 10 and the Y direction for frame in axis O are shown in Figures 11a) and 11b), respectively.



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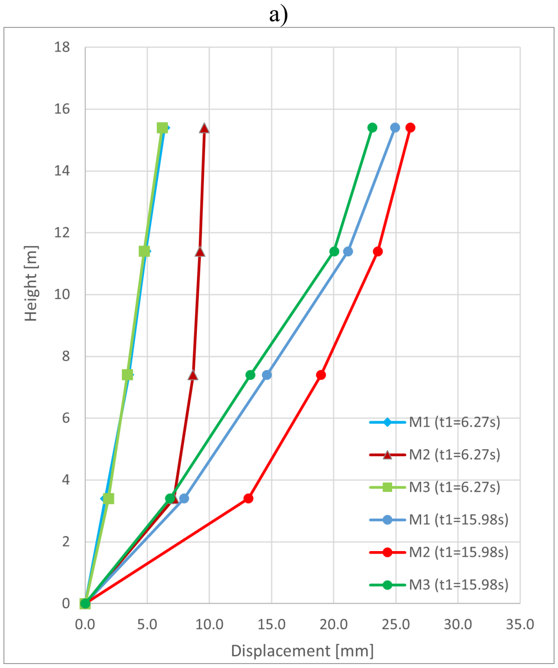

b)

Figure 11: Nonlinear "Time history" results: a) absolute displacements for t_1=3.78s and t_2=11.81s in X direction; b) absolute displacements for t_1=6.27s and t_2=15.98s in Y direction.

8. CONCLUSION

Field observations after major earthquakes in our immediate surroundings have shown that the territory of Serbia is close to an area of high seismic hazard. There are numerous educational facilities in areas with a high seismic hazard on the territory of Serbia, and special attention should be paid to this fact. Because RC structures with masonry infill comprise a significant portion of the building stock in the Republic of Serbia and throughout the world, it was decided to conduct numerical analyses of the school building of this popular structural system.

The paper presents the comparative results of numerical analyses of a representative school building on three numerical models, including bare frame model (model 1) and two upgraded models with traditional and decoupled masonry infill (models 2 and 3, respectively). Special attention was placed on comparing the behaviour of models with traditional and decoupled masonry infill.

The results clearly show huge difference in natural period between "bare" frame model and model with traditional infill walls. This is not the case with a model with decoupled infills, where natural periods differ from the "bare" frame one by about 5 %.

Results of nonlinear "Pushover" analysis (Figures 8a and 8c) show that model with traditional infills have in overall a much smaller inter-storey drift than the other two models (model 1 and 3) for the moment before the plasticisation of a structure. On the other hand, at the moment of limit displacement, a huge difference in the inter-storey drift between the ground floor and first floor can be seen in model 2 (Figures 8b and 8d). Looking at the results of the nonlinear "Pushover" analysis in the X and Y direction, the maximum inter-storey drift at the ground floor level is 2.01 % and 1.72 %, respectively. It can be observed, there was a significant reduction in the drift, i.e. 0.98 % and 1.04 %. It should be noted that model 2, before the plasticisation of a building, represents a significantly stiffer structure than the others. In contrast, after plasticisation and damage of the infills, the model continues further and has larger inter-storey drifts.

For the model with decoupled infill walls, the inter-storey drifts are in the range of the values of the "bare" frame model. The effects of the appearance of a "soft-storey" mechanism, as well as the effects of torsion cannot be observed in this model. This is a significant improvement coming from the system for decoupling that diminishes the increase of stiffness coming from the infill walls, and thus there are no jumps in stiffness between the floors. This is also confirmed with diagrams of shear forces in model 3, as seen in Figure 7b.

Results of nonlinear “Time history” analyses (Figures 10 and 11) show that model with traditional infill has lower absolute displacements and a much smaller inter-storey drift both for time moment before and after the infill walls damage occurred. As was expected due to the increase in stiffness caused by the infill walls, the top floor displacements of the relevant frames with traditional infills in model 2 are significantly lower than for the same frame in the models 1 and 3. For the traditionally infilled model in the X direction, the absolute displacements were 0.82 cm and 0.61 cm, respectively for time moments t1 and t2. At the same time moments, with the decoupling system, they were 1.88 cm and 3.1 cm. It can be concluded that for the traditional infilled system, the absolute displacements are several times smaller than the “bare” frame model and the model with decoupled system.

Negative effects such as “soft-storey” mechanism and torsional effects are removed with the application of decoupled system resulting in smooth change of absolute displacements drifts. Both absolute displacements and inter-storey drifts of the model with decoupled infills are in the range of the “bare” frame model. This shows the potential of use of a "bare" frame model in the design of RC frame buildings with decoupled infills. The INODIS system allows us to reach large values of inter-storey drift without the appearance of damage in the infills.

This paper presents the positive effect of applying decoupled masonry infill in the example of an existing school building. For the reasons above and the significant advantages of using this system to the modelling of traditional infills, it is necessary to carefully consider whether, in the reconstruction of old buildings, but also the design of new buildings, masonry infill should be taken into account in the way it was done in the INODIS system. Finally, the nonlinear dynamic analysis, which is undoubtedly the most detailed analysis, clearly demonstrated the disadvantages of traditional infills and the advantages of decoupled infills.

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