The influence of brick masonry on the response of the b/a building in the phase of the seismic event

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Abstract

The study will consist of the seismic reaction of a six-story building with a reinforced concrete structure, including the impact of brick masonry in the seismic event phase. Partition walls are part of the building's structure used to create separate spaces within the building and to limit the building from the exterior and other objects. Despite their intended functions, partition walls can be involved in transmitting seismic forces due to their stiffness and strength. Since partition walls are rigid, they tend to capture more seismic forces and transmit them to frame-type structures. This can cause damage to the structure. For this reason, it is important to analyse the effects of partition walls on the building's structure, especially in the context of seismic activity. The structure with masonry will be calculated in engineering software, and conclusions will be drawn about the way of connecting the masonry to the frame.

Key words: *Seismic activity, partition walls, load-bearing structure, cracks*

Introduction

Reinforced concrete frame structures dominate modern construction in Albania and other nations. Such frameworks consist of reinforced concrete beams and columns, forming the load-bearing skeleton. Alongside, buildings include partition walls, slabs, and stairs. Firm connections between beams and columns are crucial.

Three main features characterise these structures:

- Wide columns to withstand bending and shear forces, especially on lower floors.
- Proper beam dimensions respecting the beam-column hierarchy.
- Secure bonds between columns and beams.

Partition walls, though non-structural, support from below and above. This study focuses on analysing partition and perimeter walls, often overlooked as non-essential. Recent Albanian earthquakes have revealed stability risks if these elements lack proper connections. During seismic events, poorly connected partition walls can lead to significant issues. To prevent potential severe consequences, understanding and strengthening these walls is crucial. Through calculations and ETABS18 software analysis, we aim to identify optimal methods to attach walls to frames, bolstering structures against seismic forces.

The Aim of Study

Throughout history, numerous masonry structures have been created, many of which remain in use today, including residential buildings, hospitals, schools, and more, some of which hold historical significance. During this time, earthquakes of varying strengths have highlighted their vulnerability.

This study aims to theoretically analyse partition and perimeter walls and their integration with load-bearing structures, with the goal of enhancing their resilience against seismic forces.

Study Objectives

- Analysing partition walls based on their constituent materials (mortar and bricks).
- Exploring the response of the examined partition walls to seismic tremors.
- Should walls be connected to the main frame? If so, what recommendations from Eurocodes and KTP-89 exist for implementing such connections?

Research Questions

- Given the extensive use of partition walls, what challenges are associated with them?
- Why do these walls demand special analysis in seismic regions? What insights did recent earthquakes in Albania provide about walls in general?
- How do partition walls' seismic performance and influence impact overall structural stability?

Literature Review

The seismic response of load-bearing structures, particularly those with reinforced concrete frames, has garnered significant attention in the realm of structural engineering due to its implications for safety and resilience during seismic events. This literature review aims to synthesise key insights from various authors and studies, shedding light on the influence of brick masonry on the seismic behaviour of such structures.

"Eurocode 8 provides comprehensive guidelines for seismic design and behaviour, enabling engineers to ensure structures are equipped to withstand seismic forces," elucidates Eurocode 8's principles (European Commission, 1998). Additionally, KTP-N.2-89's guidelines (*KTP-N.2-89, 1989)* furnish an essential framework for understanding seismic response mechanisms and the structural implications.

Frashëri's seminal work on "Seismicity" delves into the seismicity of the region, setting the stage for a deeper examination of how structures respond to seismic forces (Aliaj et.al, 2020). Meanwhile, Dolsek's study (Dolsek, 2008) undertakes a deterministic assessment of masonry infills' effect on the seismic response of reinforced concrete frames, indicating that "the presence of masonry infills can significantly alter a structure's dynamic behaviour."

Doudoumis' research introduces a novel approach by incorporating "infill finite elements" with unilateral contact friction and various material laws (Doudoumis, 2006). Dukuze (2000), Fardis (1966), and Merabi (1994) collectively contribute by conducting static and dynamic analyses, with Dukuze highlighting the role of "infilled elements in influencing overall structural stability."

Santhi's work (2005) focusing on the seismic response of soft-story infilled frames underscores the importance of accounting for the unique behaviour of these structures during seismic events. Hima's study (2016) and Krasniqi's insights

(2016) emphasize that "seismic vulnerability is closely tied to the presence and characteristics of masonry infills, urging designers to consider their impact."

Bachman (2000) underscores the significance of understanding structural responses, stating that "analysing seismic effects contributes to designing buildings capable of withstanding varying seismic intensities." Additionally, Seranaj's work (2016) underscores the importance of studying "reinforced concrete structures under different seismic conditions to derive comprehensive insights."

Case Study

The chosen subject of analysis is a typical residential building with 6 above-ground floors and 1 basement level. (The basement floor serves as utility space, while the other floors are for living, and the underground level is for parking.) It is located in Zone X, bordered by Object A to the North within 6 metres, Object B to the South, Object C to the East, and "Durres" road to the West.

The selected construction system is a hybrid system combining masonry infill and frame construction. In this scenario, the structure's resistance to lateral seismic forces is ensured through the combined contribution of masonry walls and frames.

This section will focus on the two main axes, Axis A and Axis F, where masonry infill has been incorporated. The study of the object comprises three computational models:

- Without masonry infill,
- With masonry infill,
- With masonry infill and cracks.

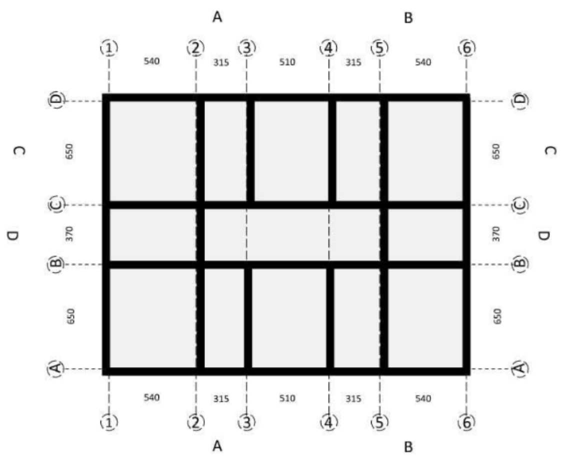

FIGURE 1 - Structure's plan

Computational Model

The structure has been modelled using the computer program CSI Etabs v.18. The frame portion is modelled using frame elements with concrete of class C 25/30. Columns of varying dimensions have been utilised, with their section decreasing as the height increases. This design choice is influenced by the decreasing weight carried by upper floors compared to lower ones. Four types of beams have been employed, two of which are tall beams (55 x 30; 60 x 30) placed along the perimeter, and the other two are short beams (30 x 55; 30 x 60) positioned within the building. Class B500 steel has been used for reinforcement.

For the structural elements' connection to the ground, "Frame" type elements are affixed with fixed base connections (the six degrees of freedom are restrained), while for walls, the connection to the base and column is considered a non-movable hinge. This is because the masonry rests on the foundation beams, and aside from contact, there is no reinforcement providing fixed base connection between these structural elements. The infill masonry is represented as a thin shell, with all brick parameters accounted for.

The selected brick type is perforated ceramic brick with dimensions of 250x140x120 mm. It should be emphasised that the brick parameters entered in the program represent average brick and mortar characteristics. This implies that an average parameter characterizing the masonry has been employed, rather than individual brick parameters.

Element	Foundation	Beam	Column	Wall
Concrete	C25/30	C25/30	C25/30	C25/30
Steel	B500	B500	B500	B500
Protective Layer				
Cmin	25mm	25mm	25mm	25mm
Cmin	25mm	25mm	25mm	25mm

TABLE 1 - Characteristics of the Building Construction.

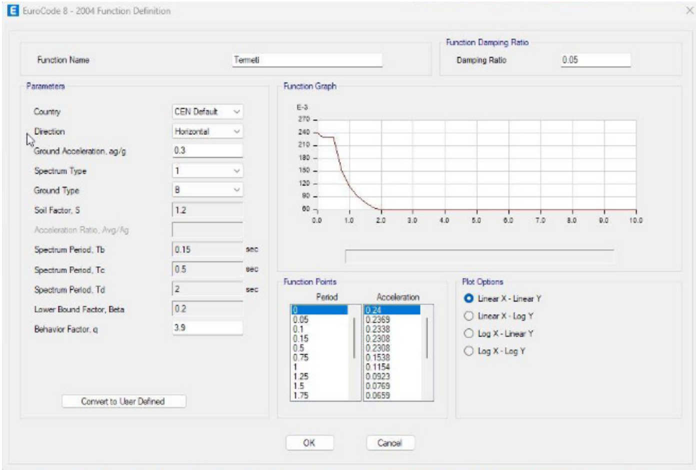

FIGURE 2 - Design spectrum.

	I rregullt në plan dhe në lartësi		I parregullt në plan		I parregullt në lartësi		I parregullt në plan dhe në lartësi	
SISTEMI STRUKTUROR	DCM	DCH	DCM	DCH	DCM	DCH	DCM	DCH
një-katësh (ramë ose ramë-ekuivalent)	3.30	4.95	3.15	4.73	2.64	3.96	2.52	3.78
rama shumëkatëshe, me një hapësirë	3.60	5.40	3.30	4.95	2.88	4.32	2.64	3.96
struktura ramash shumëkatëshe, me shumë hapësira ose duale ramë-ekuivalent	3.90	5.85	3.45	5.18	3.12	4.68	2.76	4.14
sisteme dual mur-ekuivalent, ose me mure të çiftuar	3.60	5.40	3.30	4.95	2.88	4.32	2.64	3.96
sisteme me mure me vetëm dy mure të palidhur për secilin drejtim horizontal	3.00	4.00	3.00	4.00	2.40	3.20	2.40	3.20
sisteme të tjera me mure të paçiftuar	3.00	4.40	3.00	4.20	2.40	3.52	2.40	3.36
sistem me fleksibilitet në përdredhje	-	-	2.00	3.00	1.60	2.40	1.60	2.40
sistem i tipit lavjerrës i përmbysur	1.50	2.00	1.50	2.00	1.20	1.60	1.20	1.60
shënim αo>2								

TABLE 2 - Behavior factor values for concrete structural systems

From the photos obtained from the program, we can discern that we are dealing with the same mixed structure of reinforced concrete frames (columns + beams) and shear walls. By introducing infill walls and creating cracks within them, we will observe how the key parameters of the structure will be altered.

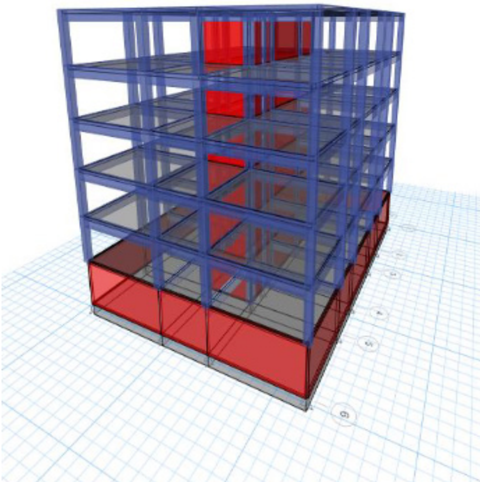

FIGURE 3 - Modeling of the structure without infill walls

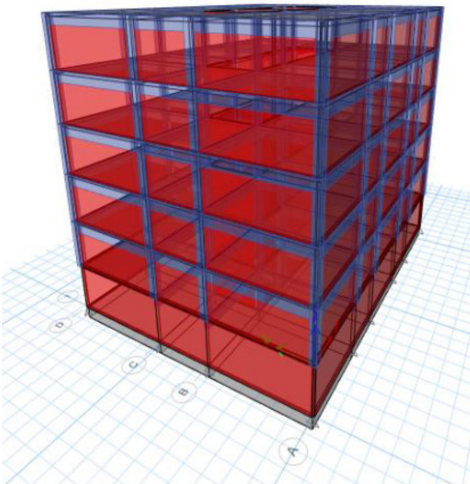

FIGURE 4 - Modeling of the structure with infill walls

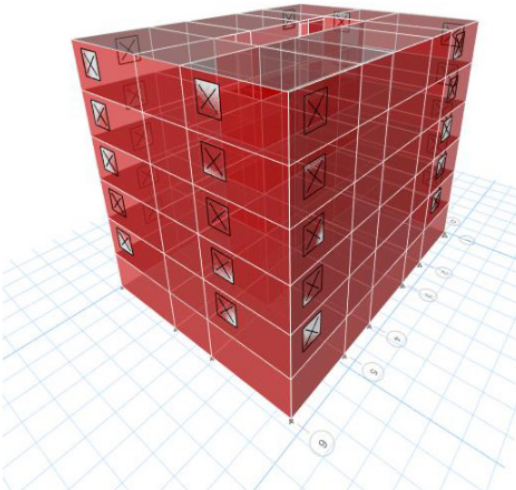

FIGURE 5 - Modeling of the structure with infill walls with cracks

In the program, we have considered the masonry material as "concrete," an isotropic material, and manually input the respective coefficients and modules of masonry. This considers that masonry consists of bricks and mortar, and for these inputs, an approximation of brick-and-mortar data has been utilised to derive a set of shared data points that approximate the behaviour of infill masonry.

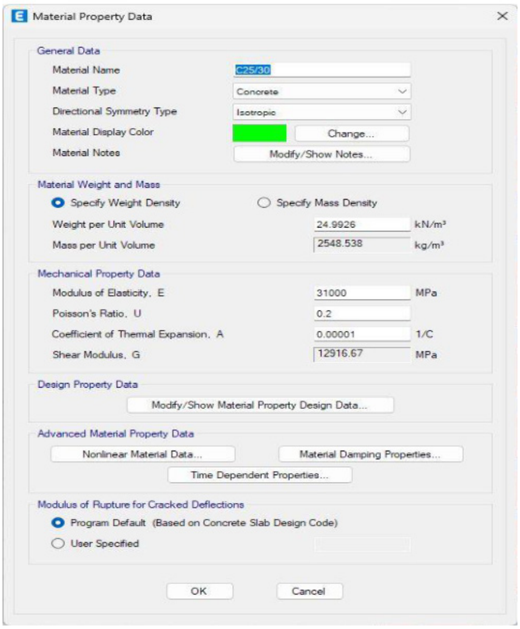

FIGURE 6 - The material on the program

Displacements of the Three Building Models

- Building without infill walls
- Building with infill walls
- Building with infill walls and cracks

TABLE: Story Response	Column1	Column2	Column3	Column4	Column5	Column6
Story	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
	mm	mm	mm	mm	mm	mm
Story6	1.574	18.534	0.888	14.64	0.942	15.073
Story5	1.292	15.378	0.681	12.46	0.758	12.786
Story4	0.935	11.699	0.507	9.687	0.576	9.913
Story3	0.576	7.823	0.325	6.624	0.373	6.756
Story2	0.261	4.009	0.159	3.479	0.193	3.54
Story1	0.193	0.954	0.181	0.892	0.183	0.898
Base	0	0	0	0	0	0
	Pa mure		Me mure		Me mure me carje	

TABLE 3 - Comparison of displacements

From the tabular values obtained by the program we notice that there is a difference between the three models. Which means that the addition of infill masonry affects the displacement of the floors.

Maximum Floor Drifts

- Building without infill walls
- Building with infill walls
- Building with infill walls and cracks.

TABLE: Story Response	Column1	Column2	Column3	Column4	Column5	Column6
Story	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
					mm	mm
Story6	0.00010065	0.0010535	7.1004E-05	0.00076466	0.94214437	15.0725188
Story5	0.00011891	0.00122674	6.0981E-05	0.00092572	0.75813647	12.7855829
Story4	0.00011969	0.00129275	6.3238E-05	0.00102222	0.57640453	9.91275469
Story3	0.00011708	0.00127141	6.9116E-05	0.00104858	0.3733093	6.75577818
Story2	0.00013594	0.00123914	9.5837E-05	0.00104465	0.19258449	3.54005078
Story1	6.4441E-05	0.00031792	6.0414E-05	0.00029744	0.18289681	0.89805947
Base	0	0	0	0	0	0
	Pa mure		Me mure		Me mure me carje	

TABLE 4 - Comparison of the Three Models for Floor Drifts

Shear Force at Each Floor

- Building without infill walls
- Building with infill walls
- Building with infill walls and cracks

TABLE: Story Response	Column1	Column2	Column3	Column4	Column5	Column6
Story	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
	kN	kN	kN	kN	kN	kN
Story6	0	-2886.418	0	-2967.4152	0	-2926.3516
	0	-2886.418	0	-2967.4152	0	-2926.3516
Story5	0	-5553.2926	0	-6047.6202	0	-5948.7298
	0	-5553.2926	0	-6047.6202	0	-5948.7298
Story4	0	-7686.7923	0	-8511.7841	0	-8366.6324
	0	-7686.7923	0	-8511.7841	0	-8366.6324
Story3	0	-9286.9171	0	-10359.907	0	-10180.059
	0	-9286.9171	0	-10359.907	0	-10180.059
Story2	0	-10353.667	0	-11591.989	0	-11389.011
	0	-10353.667	0	-11591.989	0	-11389.011
Story1	0	-10846.2451	0	-12159.12	0	-11951.76
	0	-10846.2451	0	-12159.12	0	-11951.76
Base	0	0	0	0	0	0
	0	0	0	0	0	0
	Pa mure		Me mure		Me mure me carje	

TABLE 5 - Comparison Among the Three Models for Shear Force

On the floors where we have added infill masonry, we have an increase in shear force, this is because the masonry as a structural unit and bars absorbs more shear force. Also, on the other hand, we see that with the opening of cracks in the masonry, this shear force decreases slightly, but still does not exceed the level of the building without infill walls.

Overturning Moment

- Building without infill walls
- Building with infill walls
- Building with infill walls and cracks

Story	X-Dir	Y-Dir	X-Dir	Y-Dir	X-Dir	Y-Dir
Column1	kN-m	kN-m2	kN-m3	kN-m4	kN-m5	kN-m6
Story6	0	0	0	0	0	0
Story5	8659.2539	0	8902.2455	0	8779.0547	0
Story4	25319.1317	0	27045.106	0	26625.2442	0
Story3	48379.5088	5.987E-07	52580.4584	0	51725.1416	0
Story2	76240.2602	0.00000083	83660.1798	0	82265.3198	0
Story1	107301.261	0.000001074	118436.147	0	116432.352	0
Base	139839.996	0.000001307	154913.507	0	152287.632	0
	Pa mure		Me mure		Me mure me carje	

TABLE 6 - Comparison Among the Three Cases for Overturning Moment

When we add the masonry, we have an increase in the value of this moment, and after making the cracks we see that it decreases a little, although it is still at higher values than in the building without infill walls.

Respective Periods of the Buildings

Case	Mode	Period sec
Modal	1	0.296
Modal	2	0.26
Modal	3	0.156
Modal	4	0.089
Modal	5	0.082
Modal	6	0.055
Modal	7	0.049
Modal	8	0.046
Modal	9	0.043
Modal	10	0.037
Modal	11	0.035
Modal	12	0.034

TABLE 7 - Building without infill walls

Case	Mode	Period sec
Modal	1	0.267
Modal	2	0.215
Modal	3	0.154
Modal	4	0.079
Modal	5	0.073
Modal	6	0.049
Modal	7	0.046
Modal	8	0.045
Modal	9	0.036
Modal	10	0.035
Modal	11	0.034
Modal	12	0.031

TABLE 8 - Building with infill walls.

Case	Mode	Period sec
Modal	1	0.27
Modal	2	0.218
Modal	3	0.154
Modal	4	0.079
Modal	5	0.074
Modal	6	0.049
Modal	7	0.046
Modal	8	0.045
Modal	9	0.036
Modal	10	0.035
Modal	11	0.034
Modal	12	0.032

TABLE 9 - Building with infill walls and cracks

From the tables in the program, we notice that with the addition of infill walls, there is a decrease in the oscillation periods. This happens because of the rigidity that is added to the structure of the building. Due to the increased rigidity, the change in the amount of movement of the structure during oscillations is reduced, bringing a decrease in the period of oscillations. With the addition of cracks in the walls, it is observed that the period increases slightly, but the difference is not very large.

Displacements at the Extreme Points of the Building

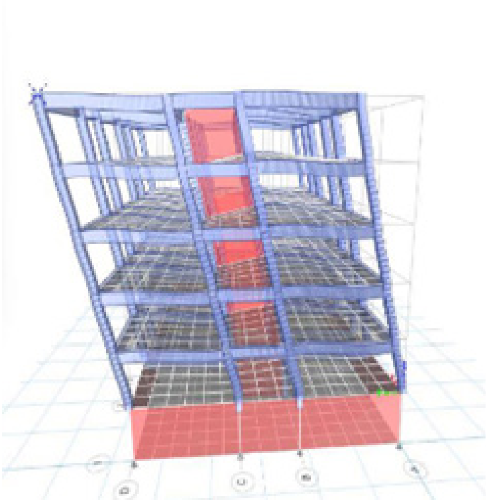

FIGURE. 7 - Building without infill walls

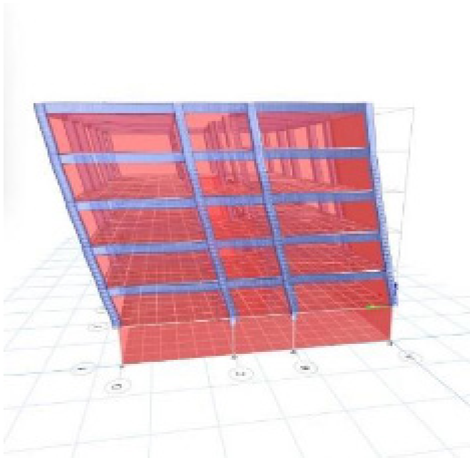

FIGURE. 8 - Building with infill walls

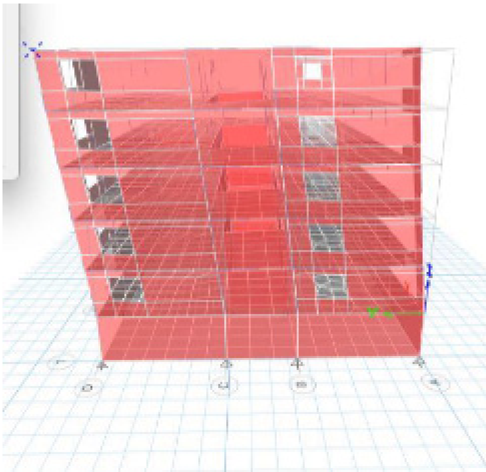

FIGURE. 9 - Building with infill walls and cracks

It is noticed that even in the displacements at the extreme points of the building, there is a small difference in the behaviour of the building with walls and without infill walls.

When walls are added, we have a decrease in displacement, and with the addition of cracks, we have a slight increase in displacement.

Discussions and Recommendations

Given that masonry is a vulnerable element, its behaviour needs to be carefully considered. Earthquakes pose the greatest threat to masonry and not just the masonry itself. Over the years, there have been numerous devastating earthquakes both in Albania and globally. Following the recent earthquakes in Albania, especially the one in November 2019, it was evident that a considerable number of buildings had issues arising from infill walls, which subsequently caused irreversible damage to the load-bearing structure in many cases.

There are several issues related to masonry that must be taken into consideration:

- Masonry cracking due to window or door openings
- Cracking of masonry near columns, leading to the short column effect
- Lack of infill walls in the lower floors, potentially causing soft-story effects, etc.
- It is advisable to consider infill walls for their significance and provide proper specifications and details for their placement and connection to the structure.

Conclusions

Several conclusions can be drawn from the case study and insights gathered from various researchers:

- The addition of infill walls increases the stiffness of the structure.
- Frame structures with infill walls on all floors can adequately withstand seismic forces due to the enhanced structural stiffness.
- Infill walls absorb more forces due to their stiffness and rigidity, subsequently transmitting them to the frame.
- If infill walls are considered in calculations, they should be well-connected to the frame to prevent stability loss.
- The absence of infill walls on the ground floor can lead to the "soft story" effect.
- Additionally, columns in the lower floors should be carefully considered as critical zones throughout the entire section due to the heightened vulnerability of the infill walls on the ground levels.

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