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On the Numerical Modeling of Confined Masonry Structures for In-plane Earthquake Loads

The seismic design of confined masonry structures involves the use of numerical models. As there are many parameters that influence the structural behavior, these models can be very complex and unsuitable for the current design purposes of practicing engineers. Simplified models could lead to reasonably accurate results, but caution should be given to the simplification assumptions. An analysis of various parameters considered in the numerical modeling of confined masonry structural walls is made. Conclusions regarding the influence of simplified procedures on the results are drawn.

Keywords: *confined masonry, numerical modeling, push over analysis*

1. Introduction

Confined masonry is one of the most used structural systems for low and mid rise buildings in Romania. The seismic design of this type of structures is done in accordance with the in-force national and European regulations [1], [2] and generally requires the use of numerical models.

As the structural behavior of masonry structures submitted to earthquake loads is influenced by many parameters [3], a very accurate numerical modeling involves complicated tools [4] that are generally hard to implement by practicing engineers for current structural design.

For this reason, recent research [5] was done in order to identify the major factors affecting the behavior of the confined walls and to suggest simplified models. Commercially available structural design software can lead to accurate modeling while being simple enough to be used by professional engineers [6].

The above mentioned works focus mainly on the influence of the mechanical properties of the materials and of the type of elements that are implemented in the numerical model. But post elastic deformations of concrete or masonry structures submitted to earthquake loads depend on a much wider range of factors, including vertical load pattern, reinforcement ratios, and structural geometry [7].

The present work investigates the influence of various parameters on the structural behavior of confined masonry structures. Using the ETABS software, a numerical simulation on several plane models of a structural shear wall is carried out. The parameters considered involve the way of defining the loads, the wall and coupling beams dimensions, the reinforcement of beams and columns and the coupling beam type. Conclusions are drawn on the behavior of the structure as well as on the influence of simplified procedures on the numerical modeling results.

2. Model description

A 5 storey building with 3 m floor height was considered. The analysis of an outer wall with 4 spans (figure 1) was carried out. A 500 cm spacing between the walls axes was chosen. The wall was modeled as a grid of linear elements (posts and beams). The geometry of the linear elements was defined using the section designer feature of the software.

The chosen materials in the model were solid brick masonry f_k=6 N/mm^2, C20/25 concrete and PC52 (f_{yd} = 300N/mm^2) reinforcement.

Nonlinear hinges were assigned to the columns and beams ends. For the intersections, perfectly rigid zones were specified based on element geometry.

For the in-plane seismic action, push-over analyses were carried out.

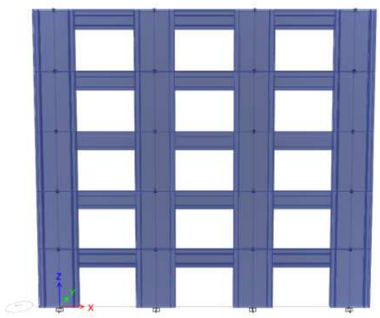


Figure 1. Geometry of the analyzed structural wall

3. Analyzed parameters

Several parameters were considered: the way of defining the loads, the wall and coupling beams dimensions, the reinforcement of beams and columns and the coupling beam type.

The way of defining the loads: two cases were considered for applying the gravitational loads on the structure. The first case involved loading both the walls and the beams (60 kN point load at nodes and 30 kN/m on beams). The second case involved applying the entire load directly on the columns (150 kN on the central nodes and 105 kN on the side nodes).

The length of walls and coupling beams: for the masonry walls, three lengths were considered - 2 m, 3m and 4 m. A value of 25 cm was chosen for the width of the walls. At both ends of the walls 25 x 25 cm concrete columns were defined, reinforced with 4 longitudinal bars (figure 2).

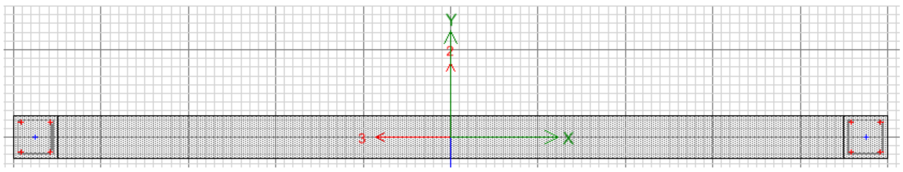


Figure 2. Geometry of the confined masonry elements

Coupling beams: as shown in figure 3, six types of coupling beams geometry were considered.

Columns and beams reinforcement: the 25x25 cm columns were analyzed for 3 cases of reinforcement - 4Φ14, 4Φ16 and 4Φ20 bars. The beam elements were analyzed for 3 cases of reinforcement - 4Φ12, 4Φ14 and 4Φ16 bars.

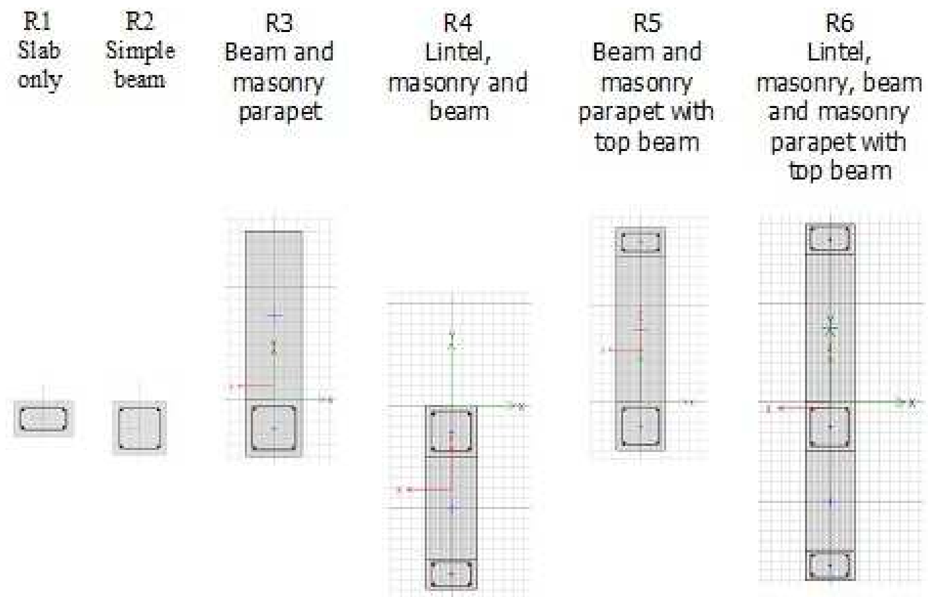


Figure 3. Types of coupling beams considered

4. Influence of the load definition pattern

The load definition pattern has an influence only on the 2 m wall 3 m coupling beam model. For this scenario a difference in behavior appears between the loaded and unloaded beams models for the R2 type beams. For the loaded beams, the maximum displacement at the top of the building under seismic loads is 359 mm, while for the unloaded beams the displacement is 427 mm (that is a 19% difference). In contrast, when the maximum base shear is compared, the difference between the loaded and unloaded beams model is much lower (961 kN vs. 909 kN, that is a 6 % difference).

This can be explained by the fact that in the loaded model, the 3 m long R2 beams reach their bending capacity from gravitational loads, while the seismic load leads to collapse faster than for the unloaded beams models. For the other types of beams (3m long) there is no significant difference in behavior between the loaded and unloaded beam models. When considering the short span beams (2 m and 1 m), no significant difference was observed between the loaded and unloaded beam models for any type of beam.

5. Influence of the coupling beam geometry

The diagrams for the 2 m long walls (with 4 Φ14 reinforcement bars in the columns) and for the 3 m long beams (with 4Φ12 reinforcement bars) are shown in figure 4. A lower stiffness for the R1 and R2 models can be observed.

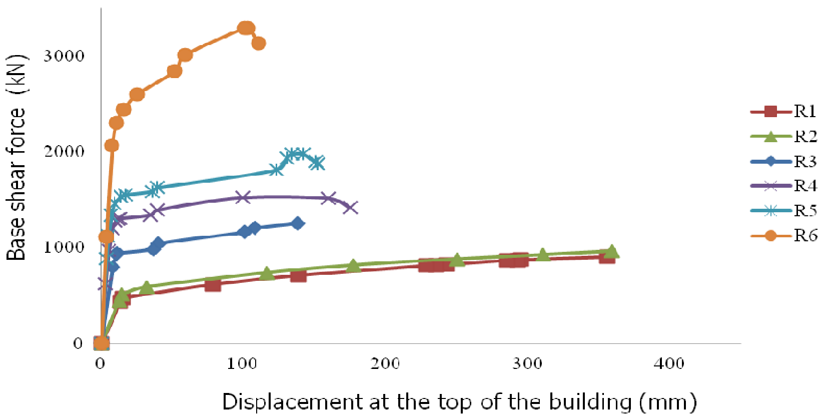


Figure 4. Force - displacement curve for different coupling beam types (3m charged beams 4 Φ12 rebars, 2m columns 4 Φ14 rebars)

In the case of the 2 m long beams, a very interesting behavior is observed. The R1 and R2 models which show not only high displacement capacity, but also high values for maximum base shear (figure 5). A similar behavior is observed for the 1m long beams.

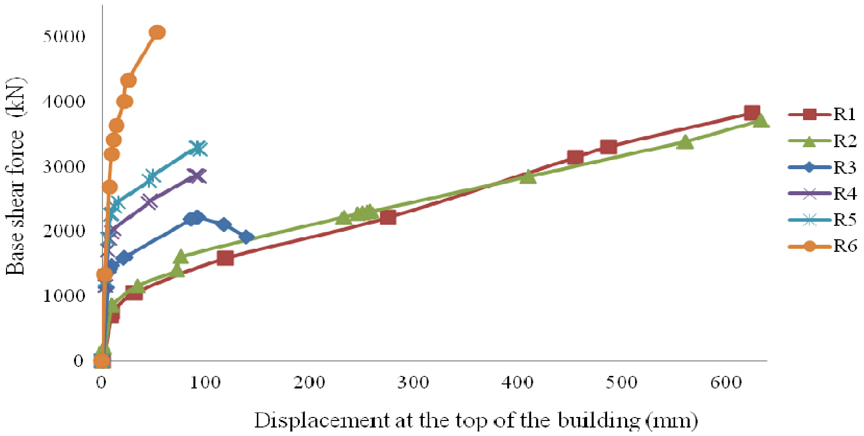
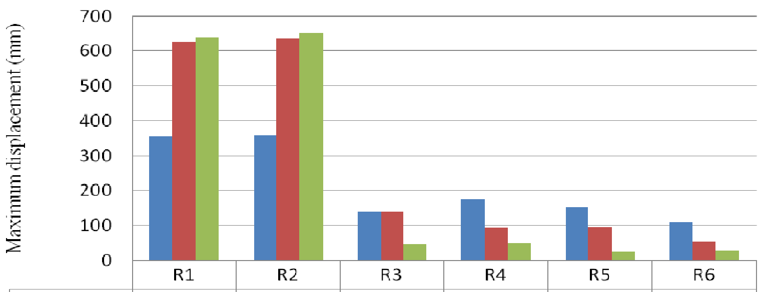


Figure 5. Force - displacement curve for different coupling beam types (3m charged beams 4 Φ12 rebars, 2m columns 4 Φ14 rebars)

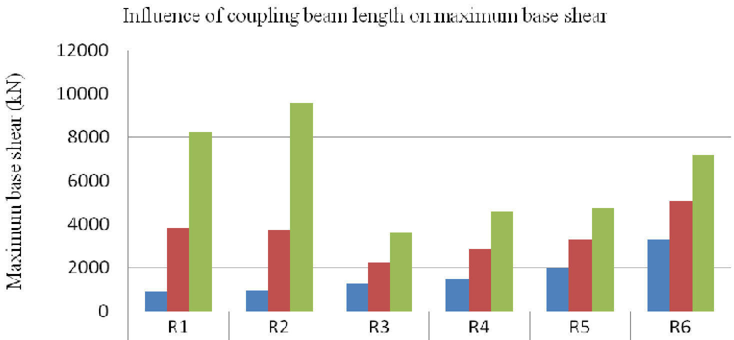
6. Influence of the length of walls and coupling beams

The influence of the walls and the coupling beam length on the maximum displacement and the maximum base shear is analyzed for the 4Φ14 walls 4Φ12 beams.



	R1	R2	R3	R4	R5	R6
3 m beams	356	359	138	175	153	111
2 m beams	625	634	139	93	94	53
1m beams	639	653	47	49	25	26

Figure 6. Influence of the coupling beam length on the maximum displacement



	R1	R2	R3	R4	R5	R6
3 m beams	903	961	1255	1525	1979	3297
2 m beams	3826	3719	2222	2866	3295	5082
1m beams	8227	9554	3619	4605	4725	7170

Figure 7. Influence of the coupling beam length on the maximum base shear

The R1 and R2 beams models show a very different behavior from the R3-R6 models with regard to the maximum displacement (figure 6) and the maximum base shear (figure 7). When the R3 to R6 beams are analysed, a linear increase in the maximum base shear with a linear decrease of the maximum displacement appears (except for R3 where similar displacements are observed for 3 and 2 m long beams). In the case of the R1 and R2 beams, there is a very high increase in the maximum base shear as well as in the displacement.

The difference can be explained by the high rotation capacity of the R1 and R2 beams when compared to the rigid beams R3 to R6. This leads to higher deformation capacity.

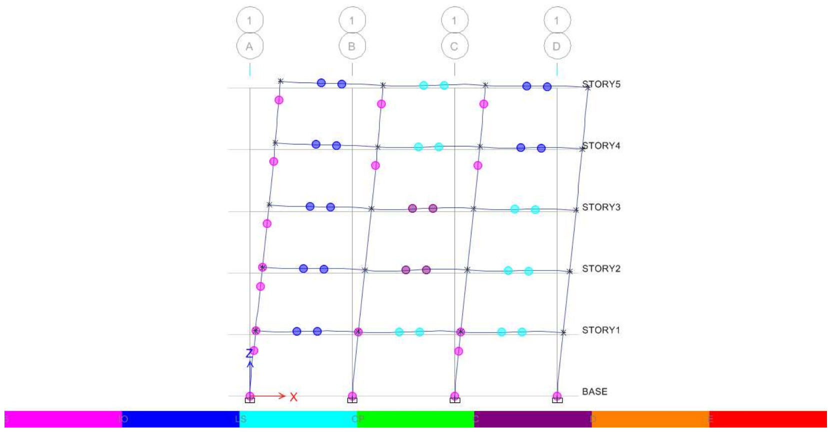


Figure 8. Status of the nonlinear hinges for the 4 m long walls coupled with 1 m long R4 type beams at the last step of the push-over loading case

When comparing the deformed geometry of the structure for the maximum displacement, a much favorable structural behavior is observed for the R1 beams (figure 9) when compared to the R4 beams (figure 8). This is because more plastic hinges are developed, with a higher structural post-elastic displacement capacity.

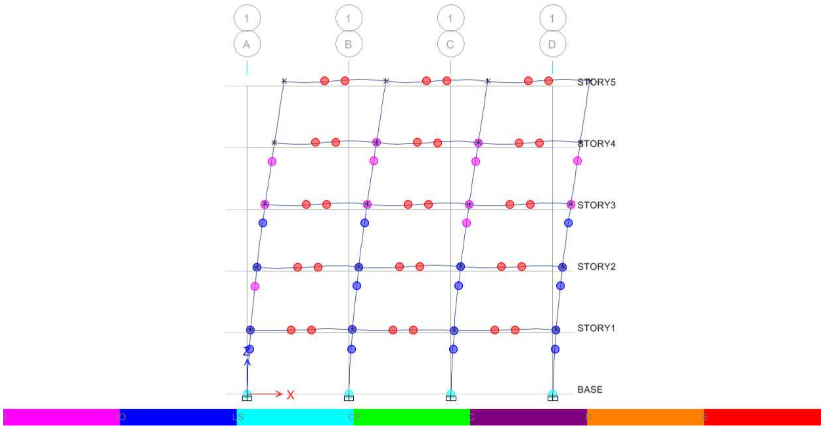
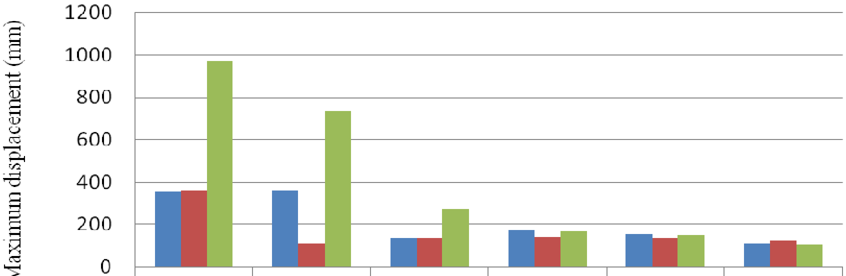


Figure 9. Status of the nonlinear hinges for the 4 m long walls coupled with 1 m long R1 type beams at the last step of the push-over loading case

7. Influence of the wall reinforcement

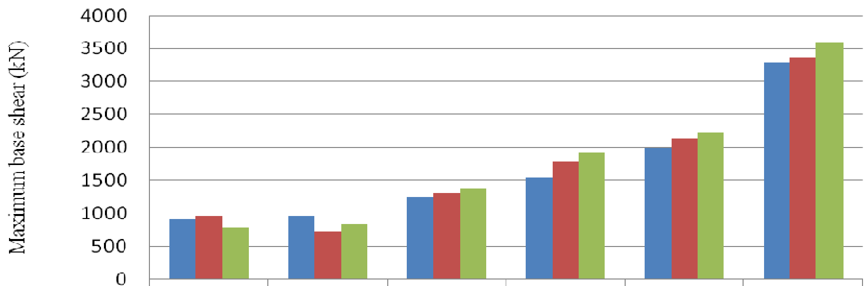
The influence of the rebar diameter used for the walls on the maximum top displacement and base shear is analyzed. No clear influence of the reinforcement on the maximum displacement can be established (figure 10).



	R1	R2	R3	R4	R5	R6
D14 rebar	356	359	138	175	153	111
D16 rebar	360	109	139	141	139	120
D20 rebar	973	736	272	166	152	107

Figure 10. Influence of the wall reinforcement on the maximum displacement for 3 m beams and 2 m walls models

As the reinforcement ratios are higher, an increase in the maximum base shear is observed (figure 11).

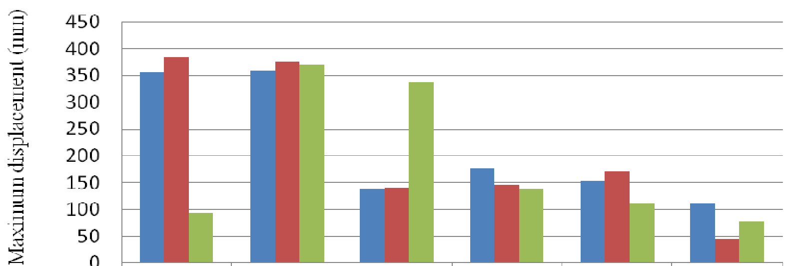


	R1	R2	R3	R4	R5	R6
D14 rebar	903	961	1255	1525	1979	3297
D16 rebar	954	719	1307	1785	2125	3362
D20 rebar	786	829	1366	1908	2217	3597

Figure 11. Influence of the wall reinforcement on the maximum base shear for 3 m beams and 2 m walls models

8. Influence of the coupling beams reinforcement

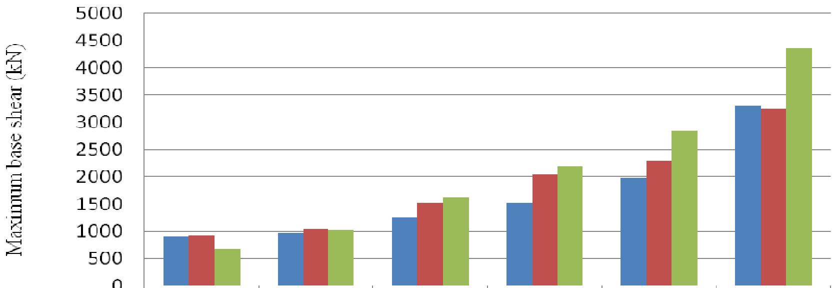
The influence of the rebar diameter on the maximum top displacement and the base shear is analyzed. For the 3 m beams, no clear influence can be established regarding maximum displacement (figures 12, 13). For R1 and R2 beams, the reinforcement has little to no influence on the maximum base shear (figure 13).



	R1	R2	R3	R4	R5	R6
D12 rebar	356	359	138	175	153	111
D14 rebar	385	375	141	146	171	46
D16 rebar	93	370	337	137	113	78

Figure 12. Influence of the coupling beam reinforcement on the maximum displacement for 3 m beams 2 m walls models

When considering the R3 to R6 beams, higher reinforcement leads to higher base shear (up to 44% base shear increase for R5 between D16 and D12 rebar). A similar behavior is observed for the 1 m beam 4 m walls models.



	R1	R2	R3	R4	R5	R6
D12 rebar	903	961	1255	1525	1979	3297
D14 rebar	922	1029	1519	2052	2281	3248
D16 rebar	663	1019	1627	2179	2846	4368

Figure 13. Influence of the coupling beam reinforcement on the maximum base shear for 3 m beams 2 m walls models

9. Conclusions

A numerical simulation on plane models of a confined masonry wall was carried out. Several parameters were considered: the way of defining loads, the wall and coupling beams dimensions, the coupling beam types, the reinforcement of beams and columns.

Similar results were obtained on the models with loads only applied at nodes and on models with loads applied both on beams and at nodes.

Low height coupling beams (R1 and R2) showed a very high post elastic rotation capacity, which leads to a relatively high displacement capacity of the building.

When the behavior of the high coupling beams was analyzed, a lower displacement capacity of the building was observed when the beam length was lower. Still, a linear increase of the maximum base shear was observed for 3 m, 2 m and 1 m long beams.

The beam reinforcement had no clear influence on the maximum displacement of the building. For low height beams, the reinforcement had little influence on the maximum base shear. In the case of high coupling beams, higher reinforcement ratios led to higher base shear.

Higher ratio of the reinforcement in walls led to an increase in maximum base shear. The increase can be as large as 20% when D20, rather than D12, bars are used.

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