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Research Article

Seismic performance of masonry buildings in Iraq

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Abstract

Masonry buildings in seismic active regions experienced severe damages and collapses during earthquakes. Many researches were published concerning the seismic assessment of masonry buildings. Almost, all previous studies focused on historical buildings located in different regions in the world. This paper evaluates the seismic performance of ordinary residential masonry buildings located in three different regions in Iraq with various seismic intensities. Masonry buildings included houses, public and commercial buildings are common construction practice in Iraq. A three dimensional finite element modeling was adopted for the investigations in which nonlinear static pushover analyses were conducted to derive capacity curves of the building models. The finite element model was verified against experimental results presented in the literature. Capacity curves were compared with seismic capacity demands derived for each building model in both perpendicular principle axes. Two house building models with semi-regular and irregular plan layouts were considered in the investigations. The influence of the strength of the local clay bricks and the quality of the mortar on the seismic performance of the buildings was considered. Investigations have demonstrated that the plan layout and the strength of bricks and mortar are significantly influencing the seismic performance of the considered masonry buildings. For the considered models, the base shear capacity of the semi-regular house and that for the irregular house model have increased up to 233 % and 100 %, respectively by increasing strength of clay bricks from 9 MPa to 18 MPa. Using cement sand mortar with a compressive strength of 15.2 MPa rather than lime mortar that have compressive strength equal to 3.1 MPa contributes in increasing building shear capacity up to 20 %. Seismic vulnerability of masonry buildings in the considered cities with low to medium seismic intensities could be averted by using relatively high strength mortar and brick as well as adopting regular plans.

1. Introduction

Past earthquakes that occurred in many parts in the world cause severe damages and collapses to masonry buildings. In the last few decades, many researches have been conducted to investigate the efficient measures to mitigate the risk of earthquakes on buildings. Regarding to masonry buildings, the attention was relatively low with prime focus on historical buildings [1–8]. Investigations showed that the building is susceptible to heavy damages and collapse when subjected to the specified moderate to high seismic intensities. The past investigations have revealed the noncompliance of the built masonry buildings with requirements of design codes and standards especially for the moderate to strong earthquakes. Most of the previous studies were focused on old and heritage buildings with thick walls and four to five floors and located in moderate to high intensity earthquake regions. A great attention on seismic behavior of heritage and historical is

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clear in recent studies. Among of these resent studies; Michele Betti et al. [9] used nonlinear static pushover analysis for the seismic assessment of basilica-type masonry church considering the Italian seismic guidelines. Also, Gianni Bartoli et al. [10] studied the seismic performance of historic masonry towers considering the Italian seismic guidelines. The Italian seismic guidelines specified three levels for seismic assessments. Gianni Bartoli et al. [10] reported and compared results of first and third specified levels of assessments and draw the conclusions based on the third level that involves nonlinear static pushover analysis. Francisco Brandão et al. [11] investigated the seismic resistance of the historical Nossa Senhora das Dores Church in Brazil using three dimensional finite element modeling. Linear time-history analyses were conducted considering two actual earthquake records. The results showed large displacements and high stresses in many parts of the church in which the potential damages were identified. These investigations provide the indications for the demanded retrofitting measures. Giulio Castori et al. [12] investigated the seismic vulnerabilities and defects of a multistory medieval building, located in Perugia, Italy. The investigations included simulating the building using three dimensional finite elements and the analysis were conducted by adopting nonlinear static pushover analysis. The analysis results showed poor seismic resistance compared to the demanded resistance. Motsa et al. [13] proposed a numerical investigation procedure for the seismic assessment of ancient monuments made of megalithic stones considering middle temple of the Mnajdra Megalithic structure. Demirlioglu et al. [14] studied the seismic behaviour of a historic brick masonry building using both linear and nonlinear pushover analyses considering equivalent frame method and finite element modeling. Bilgin and Ramadani [15] evaluated the structural behavior of historical Bajrakli Mosque located in western of Kosovo using static and dynamic analyses and considering both gravity and lateral seismic loads. Tomic´ et al. [16] suggested parametric investigations to assess the seismic behavior of historical masonry buildings that mainly affected by the uncertainty in material properties, construction details and modeling parameters. Usta [17] used three dimensional finite element modeling and fragility analysis to study the seismic performance of historical minarets in Antalya, Turkey. Hökelekli [18] conducted linear and nonlinear time history dynamic analysis considering actual earthquake records in Turkey to investigate the seismic performance of historical minaret in Turkey. Maras et al. [19] assessed the performance of historical Sütlü minaret mosque in Turkey using three dimensional finite element modeling and dynamic analysis. Six earthquake excitation records were applied to the model in which the performance was investigated. Further studies focused on public masonry buildings. among these studies; Estêvão and Tomás [20] studied the seismic performance of masonry school buildings in the region of Algarve (Portugal) according to provisions of Eurocode 8 (EC8) and based on nonlinear pushover analysis.

It is obvious that almost all the previous studies deal with seismic assessment of historical and heritage buildings in different regions in the world. In contrast; very little attention on investigating ordinary commercial or residential masonry buildings. In this paper, a focus is made on the seismic performance of ordinary masonry residential buildings in three different regions in Iraq. In Iraq, houses and some public and commercial buildings are limited to two stories and constructed using structural bearing wall systems. Bearing walls used for buildings in Iraq usually constructed using different types of clay brick units and concrete block units. Usually, the brick wall buildings in Iraq are constructed with slender walls of thickness equal to 0.25 m, height equal to 3 m and length up to 8 m and constructed without any consideration to the lateral loads. Iraq is located within a region of low to moderate seismic action [21]. During the last two decades, several low intensity earthquakes occurred in Iraq. Fortunately, the recorded intensity of the earthquakes was low and resulted in minor damages to some buildings [22]. Resent seismic events as well as the new design requirements for buildings in Iraq demands the seismic evaluation of masonry buildings in Iraq. This paper presents a study on the seismic performance of ordinary masonry residential buildings (brick bearing wall type) considering the specified intensities of earthquakes in three different regions in Iraq. The investigations are focused on two storey residential houses constructed using clay brick units that represent the majority of masonry buildings in Iraq. The influence of different types of local clay bricks (Type A, Type B and Type C) and mortar strength on the seismic performance of the building models are also considered in this study. Nonlinear static pushover analysis method recommended by FEMA 356 [23] guidelines is adopted for the investigations. Macro model of the masonry walls is developed and adopted in this study by utilizing multi-purpose commercial finite element software ANSYS 11.0 [24]. Initially, the developed finite element model has been verified against experimental and numerical results published in the literature. Capacity curves that represent the varying drift at the top of the building with base shear are derived by conducting pushover analyses considering two principal directions. The pushover analysis approach was widely adopted in the previous studies [8,12,25–27]. Also, Capacity demands of the building model in different regions in Iraq are derived based on seismic intensity of each region, soil properties and the building model characteristics. Then the building models are assessed by comparing results of the capacity curves with the capacity demand of those considered building models. In the following sections, a model for masonry representation and verification of the developed model are presented. Also, analysis procedure, details of the considered models as well as the investigation results are presented and discussed. Finally, study considerations are highlighted and main conclusions points are drawn.

2. Masonry Representation

Masonry walls are modeled using equivalent homogeneous isotropic macro model that has properties accounting for the interaction effect of both bricks and mortar. The modeling is conducted by using the multi-purpose finite element software ANSYS 11.0 [24] in which the masonry walls are modeled using three dimensional solid elements (SOILD 65). The three dimensional brick (SOLID 65) elements with rectangular parallelepiped or cube shapes that have eight nodes at the corners is considered in this study. Each node has three translational degrees of freedom with capability of accounting cracking in tension and crushing in compression. In this study, the walls are discretized using the solid elements (SOLID 65) in which both linear elastic and nonlinear properties as well as failure criteria are defined for the elements. Elastic properties and nonlinear parameters for the solid elements represent the properties of masonry prism that accounting for the combined effect of brick units and mortar. Also, nonlinear stress strain curve is defined to model the nonlinear response of masonry walls that simulates the combined effect of bricks and mortar. This model was previously presented by Betti and Vignoli [2] and Betti and Galano [3] and Avossa and Malangone [28] to simulate masonry walls in which equivalent Drucker-Prager elastic perfectly plastic model along with William and Warnke [29] failure criteria were considered. In this study, macro model of masonry walls is developed considering stress-strain relation along with William and Warnke [29] failure criteria. The masonry walls are defined by the average stress strain relations of the constitutive materials involving bricks and mortar. The elastic modulus of masonry prism (E_m) and the compressive strength of a masonry prism (f'_m) in MPa are defined by the following relations [30]:

$$E_m = 550\, f'_m \tag{1}$$

$$f'_m = 0.63. f_b^{\ 0.49}. f_j^{\ 0.32} \tag{2}$$

where f_b = compressive strength of bricks in (MPa) and f_j = compressive strength of mortar in (Mpa).

A stress-strain curve of masonry prism is modeled using multi-linear relation for compression as depicted in Figure 1. The ascending part (first part) of the curve is defined by [30]:

$$f_m = f''_m \left(2\left(\frac{\varepsilon_m}{\varepsilon'_m}\right) - \left(\frac{\varepsilon_m}{\varepsilon'_m}\right)^2\right) \qquad \text{for} \qquad \varepsilon_m \le \varepsilon'_m \tag{3}$$

where: $f''_m = 0.75\, f'_m$, ε'_m= strain at the ultimate stress f''_m, ε_m= strain corresponding to stresses f_m below ultimate value.

In this study, a constant strength of masonry prism equal to f''_m is assumed after the ultimate strength (f''_m) for the second part of the stress-strain curve in which (see Figure 1):

$$f_m = f''_m \qquad\qquad \varepsilon'_m < \varepsilon_m \le \varepsilon_{mu} \tag{4}$$

The tension part is modeled using linear brittle stress strain relation up to ultimate tension strength that equal to 0.1 f''_m. The Poisson' s ratio for masonry is set equal to (0.18) [28].

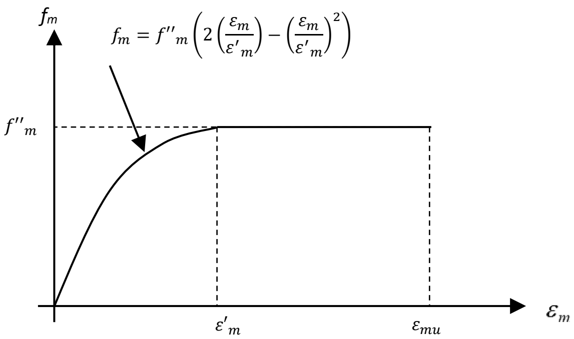


Fig. 1 Idealized stress-strain relationship of masonry prism

3. Verification of The Developed FEM Model of Wall Panels

The developed model is verified via experimental results of masonry wall specimen presented in Avossa and Malangone [28]. The studied model consisted of plane wall with two vertical flanges at the two ends of the wall. The dimensions of the wall model were 3.6 m length, 2.0 m height and 0.15 m thickness. The dimensions of the two flanges were 0.6 m width and 0.15 m thickness. In addition; two concrete slabs were placed at the top and beneath the wall specimen. The dimensions of the top slab were 0.16 m x 1.4 m x 4.0 m;

while that of the bottom slab were 0.18 m x 0.9 m x 4.0 m. Material properties include modulus of elasticity of the masonry wall E_m= 2460 MPa, compressive strength f'_m = 5.576 MPa, Poisson's ratio $v = 0.18$, density of the masonry wall $= 1.8 \times 10^{-5}\ N/mm^3$ and tensile strength of the masonry wall (f_t) =0.194 MPa. The finite element of the considered masonry wall is shown in Figure 2. In this study a cube brick element is adopted with dimensions equal to 150 x 150 x 150 mm^3. This model has been verified against experimental and numerical analysis and provide very good agreement. Several preliminary trials with other models were considered with different smaller size elements equal to 50 x 50 x 50 mm^3 and 75 x 75 x 75 mm^3 in which took much longer time with slightly different results that make the analysis very tedious. The lateral load was applied at the top slab in the direction parallel to the plane of the wall. The experimental and numerical results of the lateral load versus lateral displacement that presented by Avossa and Malangone [28] are illustrated in Figure 3. Also, the numerical results obtained by using the developed FEM model in this study are illustrated in Figure 3. It is obvious from Figure 3, that the predicted results of the load displacement curve have a good agreement with the previous experimental and numerical results.

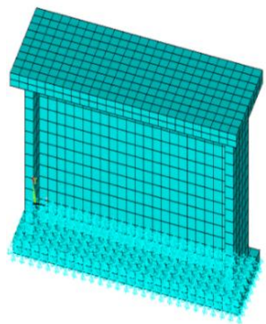


Fig. 2 Finite element modeling model of in-plane loaded masonry wall with end flanges

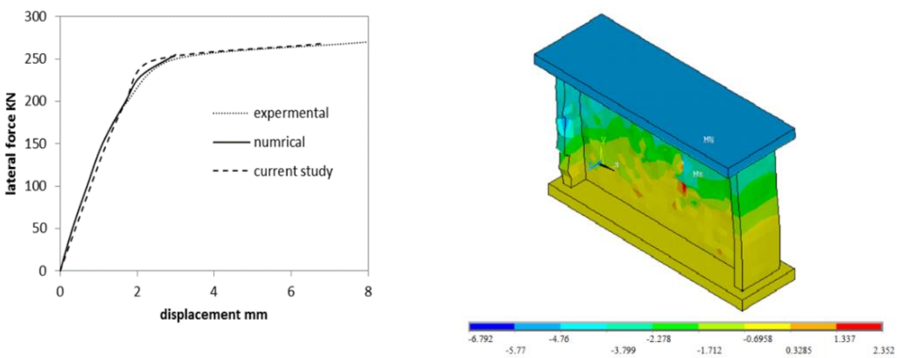
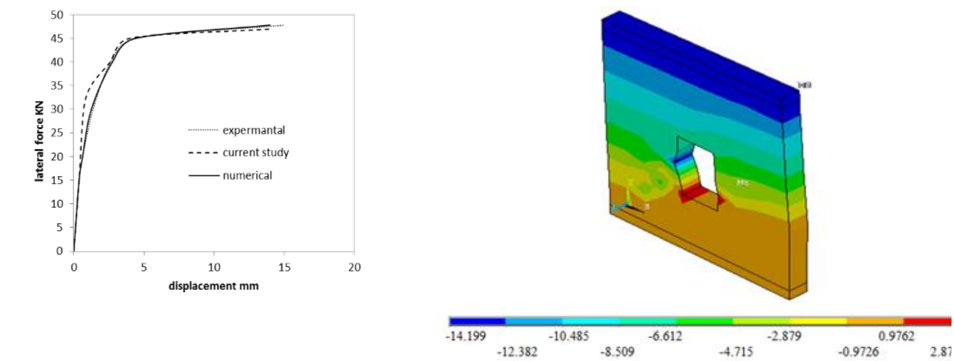


Fig. 3: a) Load- displacement curve; b) deformation shape of the wall model

In addition, experimental test of a simple model of in- plane loaded masonry wall panel with central opening that presented by Akhaveissy [31] is considered for the verification of the developed model. The wall was made from clay brick units had dimensions equal to

210 mm x 52 mm x 100 mm. The mortar thickness was 10 mm. The height/width ratio of wall was equal to about one in which the height and the width of the wall were equal to 1000 mm and 990 mm, respectively. Two relatively stiff steel beam sections were installed for clamping the top and bottom boundaries of the wall for the laboratory test. The masonry have modulus of elasticity E_m= 7635 MPa, compressive strength of masonry prism f'_m=10.5 MPa, Poisson's ratio $v = 0.15$ and tensile strength f_t=1.05 MPa. The finite element idealization and boundary conditions are shown in Figure 4. A vertical pressure of 0.3 MPa was applied at the top of the wall before applying the horizontal load. Pushover horizontal load was applied gradually (considering 10 kN each load step) at the top steel beam section in which the drift was recorded versus the load. Analysis results including deformed shape as well as the load – displacement curve are presented in Figure 5. Also, comparison with previous experimental and numerical results are given in Figure 5. An excellent agreement between the results obtained from the developed model with previous experimental and numerical model has demonstrated as shown in Figure 5.



(a) (b)

Fig. 4 Finite element modeling of in-plane loaded masonry wall with central opening

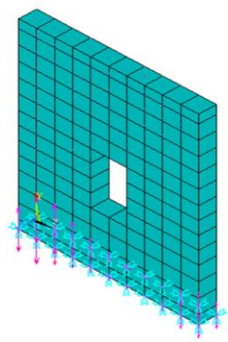


Fig. 5 a) Load- displacement curve; b) deformation shape of the wall model

4. Non-Linear Pushover Analysis

This study is limited to nonlinear static push over approach for evaluating seismic performance of masonry buildings. The nonlinear static pushover approach was used to investigate the ultimate base shear. Then determined base shear was compared with demanded base shear to evaluate the seismic performance of the considered model. A non-linear static pushover analysis is conducted to derive lateral load displacement capacity curves of building models. The pushover capacity curves refer to the relation between base shear and horizontal displacement at the top of the building (the control point at the roof). The seismic performance of the building is evaluated by comparing the base shear capacity with the seismic base shear demand corresponding to the brittle behavior. However, the ultimate displacement is compared with displacement demand for the ductile behavior. The safe performance of the building is achieved by satisfying either the base shear demand for brittle response or the displacement demand for ductile response [32]. The seismic base shear demand is determined using the procedure specified in FEMA 356 [23]. This study focuses only on base shear demands in which masonry buildings exhibit brittle behavior that demonstrated by very small ultimate lateral displacements. In the non-linear static analysis, initially the gravity loads are placed and kept constant for a specific period of time, subsequently the lateral forces that represent seismic action are applied gradually considering load time steps. In this study, each load step equal to 0.1 of demanded base shear is considered in this study. The analysis is conducted by applying the lateral forces in two perpendicular directions, not acting simultaneously. Pushover analysis is conducted twice on each house buildings along two orthogonal directions. At the beginning, the pushover analysis is performed by applying lateral loads along transverse direction. Then the pushover analysis is performed by applying lateral loads along longitudinal direction. The lateral loads are distributed along the building height and applied at the floors level by adopting the lateral load distribution formula specified by FEMA 356 [23]. The seismic base shear demand is obtained using the following equation [33]:

$$V = C_s \ W \tag{8}$$

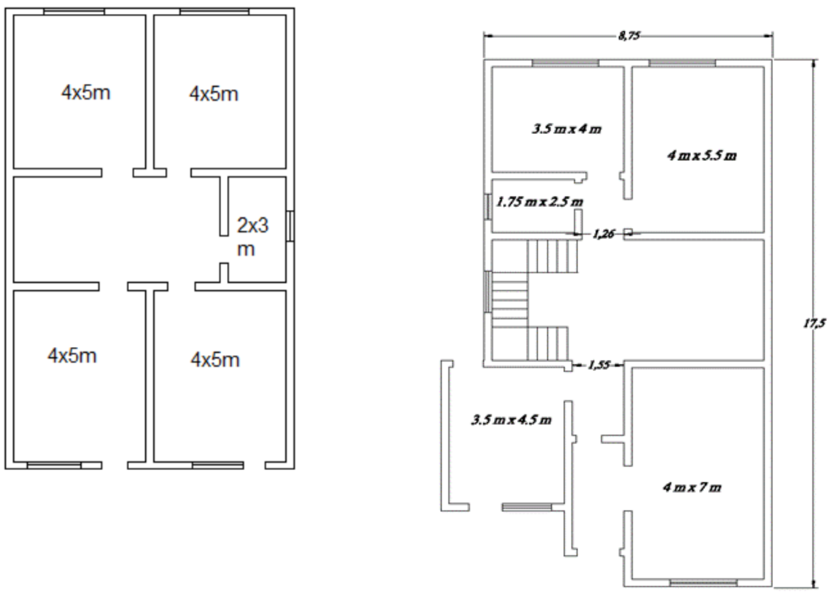
where; C_s = seismic response coefficient and W = effective seismic weight. Both seismic response coefficient and the effective seismic weight are computed using the procedure specified in ASCE 7-17 [33] based on the soil properties of the region and the earthquake spectral acceleration at the considered region.

5. Building Models

In this study, two house models each with two storeys are considered. Figure 6 illustrates two typical plans of considered house models including dimensions, locations of doors and windows. The first house represents simple typical semi regular house model, while the second house represents typical irregular house.

The height of storey is 3 m, the dimensions of all the doors are 1 m width and 2.1 m height and the dimensions of the windows are 2 m width and 1.5 m height. In Iraq, it is common of practice casting continuous reinforced concrete lintel beam along the walls at the level above the openings (doors and windows). The lintel dimensions are 0.24 m width and 0.3 m depth. The walls are constructed using clay brick units in either lime mortar or cement sand mortar. In this study, the influence of the strength of brick units and mortar on the seismic performance of masonry buildings in Iraq is considered. In Iraq, clay bricks are classified into three types according to the strength that include type A, type B and type C that have compressive strength of 18 MPa, 13 MPa and 9 MPa, respectively. Two types of mortars are considered including lime mortar has strength equal to 3.1 MPa denoted by mortar 1 and cement sand mortar with a compressive strength equal to 15.2 MPa and denoted by mortar 2.

Table 1 illustrates the properties of the materials corresponding to the considered models. The houses are subjected to both live loads (2 kN/m^2) and dead loads (7.6 kN/m^2 and 4.8 kN/m^2 for roof and floor; respectively, including self-weight). The houses are studied for seismic demand of three regions including Baghdad city, Kirkuk city and north of Amara city. Spectral response acceleration at short period (Ss) are 0.3, 0.6 and 1.0 for Baghdad city, Kirkuk city and north of Amara city, respectively [34]. Site class D for soil properties is adopted in this study as recommended by ASCE 7-17 [33] when the details of soil properties are unknown. The finite element models of the considered houses are shown in Figure 7. Masonry walls are modeled using the developed model in previous section. Slabs and the continuous lintel are modeled using linear elastic material considering properties of concrete. house.

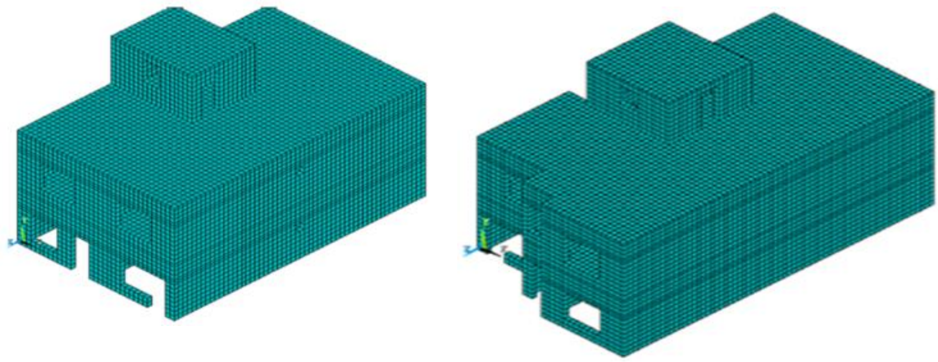


(a) House 1 (b) House 2

Fig. 6 The details and dimensions of the typical house models

Table 1. Strength of mortar, brick and masonry prism

Brick Type	Mortar	Compressive strength (MPa)		
		Mortar fj	brick fb	Wall f''_m
A	1	3.1	18	2.79
B	1	3.1	13	2.38
C	1	3.1	9	1.99
A	2	15.2	18	4.65
B	2	15.2	13	3.96
C	2	15.2	9	3.31

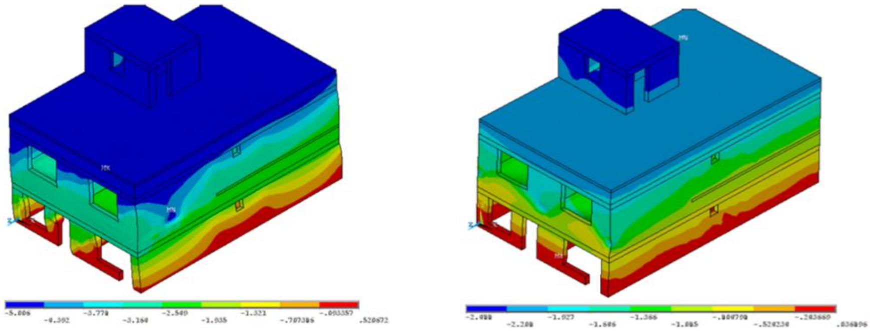


(a) House 1 (b) House 2

Fig. 7 Finite element modeling of the houses

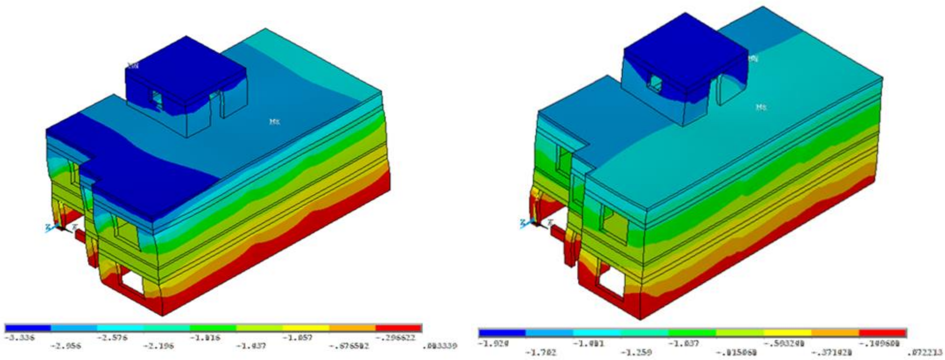
6. Analysis Results

Pushover analysis is conducted twice on each house buildings along two orthogonal directions. At the beginning, lateral loads were applied along transverse direction in which the analysis was conducted and the results were predicted. Another analysis was conducted separately by applying the lateral loads along the longitudinal direction. The load is applied gradually considering load time steps. In this study, each load step equal to 0.1 of demanded base shear is considered in this study. Results of pushover analysis in terms of final deformations pattern are illustrated in Figures 8 and 9 for both house models. The capacity curves that represent base shear versus lateral displacement of the house models are illustrated in Figures 10 and 11. Tables 2 to 5 illustrate the comparison results of the ultimate base shear determined from pushover analysis with the seismic base shear demand. The seismic demand in Tables 2 to 5 are obtained based on the spectrum accelerations recommended by Iraqi seismic code. The capacity curves illustrated in Figures 10 and 11 show that both house models exhibit better seismic performance in longitudinal direction (z- direction) than in the transverse direction (x-direction). Also, it is obvious from Figures 10 and 11 and Tables 2-5 that the performance of the house models has significantly improved by using brick type A instead of using brick type B and brick type C due to the increase in compressive strength of the brick type A over those of brick types B and C. Also, Tables 2-5 show a significant increase in base shear capacity of the house models by using mortar 2 rather than mortar 1 due to increase in compressive strength. For instance, Table 2 shows that base shear capacity of the house 1 with mortar 1 have increased up to 233.3 % and 225 % in the longitudinal and transversal directions, respectively by using brick type A over that of using brick type C. On the other hand, Table 3 shows that base shear capacity of the house 1 with mortar 2 has increased up to 71.4 % and 50 % in the longitudinal and transversal directions, respectively by using brick type A over that of using brick type C. Also, Tables 2 and 3 show that using stronger cement sand mortar rather than the weak lime mortar results in increase in base shear capacity of the house 1 with brick type A by about 20 % and 15.4 % in the longitudinal and transversal directions, respectively. Furthermore, Tables 2-5 illustrate the seismic performance of the adopted house models in terms of potential collapse.



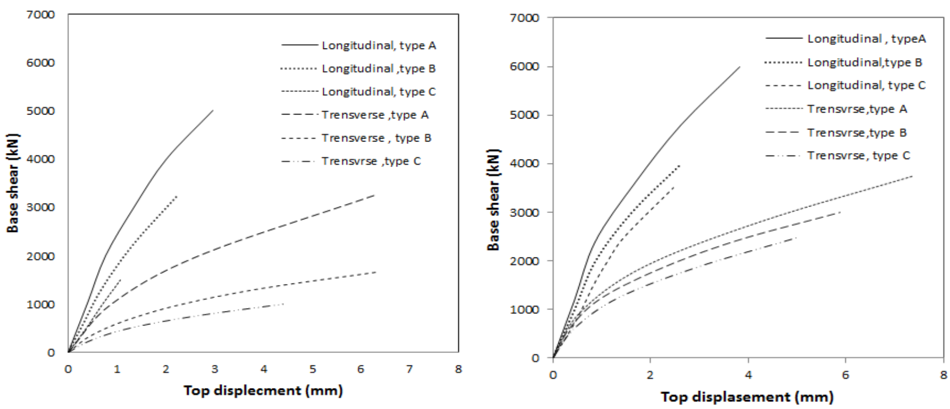
(a) Transverse action, brick Type C (b)Longitudinal action, brick Type C

Fig. 8 Deformation shapes of the house 1



(a) Transverse action, brick Type C (b)Longitudinal action, brick Type C

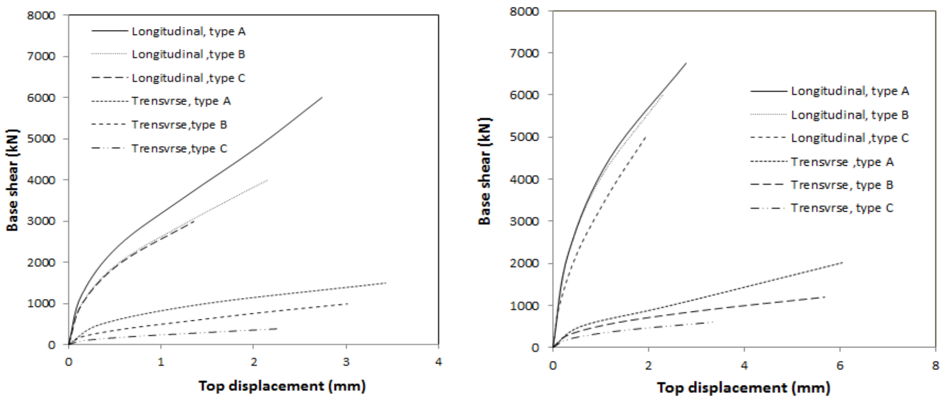
Fig. 9 Deformation shapes of the house 2



(b) Transverse action, brick Type C (b)Longitudinal action, brick Type C

Fig. 10 Capacity curves corresponding to house 1

Regarding the seismic performance of the house 1, Table 2 shows that the house 1 with brick type A has survived the collapse in which the base shear capacity is larger than the demanded base shear. However, the collapse of the house 1 with brick type C and lime mortar 1 in north of Amara city has demonstrated due to the higher demand base shear compared with the house base shear capacity. In contrast, Tables 4 and 5 show that the house 2 performs well along the longitudinal direction while the collapse has demonstrated in the perpendicular direction except for case with brick type A and cement sand mortar in Baghdad city in which has the lowest shear demand. The poor performance along the transversal direction compared to the longitudinal direction of the house 2 stems from its irregular plan that causing additional torsional stresses.



(a)Transverse action, brick Type C (b)Longitudinal action, brick Type C

Fig. 11 Capacity curves corresponding to house 2

Table 2. Ultimate capacity of the house1versus seismic demands considering mortar 1

Brick Type	City	Demand Base shear (kN)	Base shear capacity (kN)		Result
			Short direction	Long direction	
A	Baghdad	732	3250	5000	Survived from collapse
	Kirkuk	1267	3250	5000	Survived from collapse
	North of Amara	1785	3250	5000	Survived from collapse
B	Baghdad	732	1667	3250	Survived from collapse
	Kirkuk	1267	1667	3250	Survived from collapse
	North of Amara	1785	1667	3250	Collapse along short
C	Baghdad	732	1000	1500	Survived from collapse
	Kirkuk	1267	1000	1500	Collapse along short
	North of Amara	1785	1000	1500	collapse

Table 3. Ultimate capacity of the house1versus seismic demands considering mortar 2

Brick Type	City	Demand Base shear (kN)	Base shear capacity (kN)		Result
			Short direction	Long direction	
A	Baghdad	732	3750	6000	Survived from collapse
	Kirkuk	1267	3750	6000	Survived from collapse
	North of Amara	1785	3750	6000	Survived from collapse
B	Baghdad	732	3000	4000	Survived from collapse
	Kirkuk	1267	3000	4000	Survived from collapse
	North of Amara	1785	3000	4000	Survived from collapse
C	Baghdad	732	2500	3500	Survived from collapse
	Kirkuk	1267	2500	3500	Survived from collapse
	North of Amara	1785	2500	3500	Survived from collapse

Table 4. Ultimate capacity of the house 2 versus seismic demands considering mortar 1

Brick Type	City	Demand Base shear (kN)	Base shear capacity (kN)		Result
			Short direction	Long direction	
A	Baghdad	1021	1500	6000	Survived from collapse
	Kirkuk	1768	1500	6000	Collapse along short direction
	North of Amara	2490	1500	6000	Collapse along short direction
B	Baghdad	1021	1000	4000	Collapse along short direction
	Kirkuk	1768	1000	4000	Collapse along short direction
	North of Amara	2490	1000	4000	Collapse along short direction
C	Baghdad	1021	460	3000	Collapse along short direction
	Kirkuk	1768	460	3000	Collapse along short direction
	North of Amara	2490	460	3000	Collapse along short direction

The presented investigation results in Tables 2-5 represent the global performance of masonry buildings considering nonlinear static analysis. Considering the global seismic performance of the buildings in this study is in line with several previous published studies [10,16,20]. In contrast, investigations presented in Francisco Brandão et al. [11], Hökelekli [18] and Maras et al. [19] considered local damages in buildings using stress analysis by adopting linear or/and nonlinear time history analyses. On the other hand, several previous investigations considered both local and global performance of buildings [9,17]. Investigation results have demonstrated various performance of masonry buildings due to various earthquake intensities as well as various building plans and structural characteristics of the buildings that stem from using various construction methods and materials. This study focused on modern ordinary masonry buildings located in three cities in Iraq while almost all previous studies had focused on old and historical masonry buildings [9-20] located in different regions in the world.

Table 5. Ultimate capacity of the house 2 versus seismic demands considering mortar 2

Brick Type	City	Demand Base shear (kN)	Base shear capacity (kN)		Result
			Short direction	Long direction	
A	Baghdad	1021	2003	6750	Survived from collapse
	Kirkuk	1768	2003	6750	Survived from collapse
	North of Amara	2490	2003	6750	Collapse along short direction
B	Baghdad	1021	1200	6000	Survived from collapse
	Kirkuk	1768	1200	6000	Collapse along short direction
	North of Amara	2490	1200	6000	Collapse along short direction
C	Baghdad	1021	600	5000	Collapse along short direction
	Kirkuk	1768	600	5000	Collapse along short direction
	North of Amara	2490	600	5000	Collapse along short direction

7. Conclusions

Almost, the majority of building construction in Iraq were designed and constructed without adopting any seismic provisions especially residential masonry buildings. During the last two decades, several earthquakes occurred in Iraq. Fortunately, the recorded intensity of the earthquakes was low and resulted in minor damages to some buildings. However, Iraq is located within low to moderate seismic action region. Therefore, the seismic design and assessment of buildings is demanded according to the new design requirements for buildings in Iraq. In this study, the seismic performance of unreinforced masonry building models in Iraq is investigated considering three regions with different seismic levels. In Iraq, houses and some public and commercial buildings are limited to two stories and constructed using structural bearing wall systems. Bearing walls used for buildings in Iraq usually constructed using different types of clay brick units and concrete block units. A three dimensional finite element simulation is adopted for the investigations using multi-purpose finite element software ANSYS. The finite element model is verified against experimental results of masonry wall models available in the literature. Two typical house models constructed using local clay brick unites represent an important percentage of masonry building stock in Iraq are considered in this study. Three types of local clay brick units including type A, type B and type C that classified in Iraqi Standards according to their strength are considered in the parametric investigations. Also, two typical mortar types including lime mortar and cement sand mortar with different compressive strengths are considered in the parametric investigations. The two house models involve two storey houses, one with semi regular plan and the other with irregular plan. Capacity curves representing base shear versus lateral displacement at the top of the building models are derived using pushover analysis conducted in two principal directions and compared with the seismic demands in different regions in Iraq.

Based on the numerical analysis results, the following conclusions can be drawn:

1. The verification analysis results show that homogenized three-dimensional model that developed in this study have been successfully predict the nonlinear behavior of the masonry walls under lateral loads.
2. The base shear capacity of the brick wall buildings is very sensitive to the building layout as well as material properties and site location.
3. For the considered models, the base shear capacity along the longitudinal direction of the semi-regular house 1 model have been increased up to 233 % by increasing strength of clay bricks from 9 MPa to 18 MPa that representing strength of clay brick types C and A, respectively. In contrast, the base shear capacity of the irregular house 2 model has shown an increase of up to 100 % by increasing strength of clay bricks from 9 MPa to 18 MPa that representing strength of clay brick types C and A, respectively.
4. Using cement sand mortar with a compressive strength of 15.2 MPa rather than lime mortar that have compressive strength equal to 3.1 MPa contributes in increasing building shear capacity up to 20 %.
5. The seismic vulnerability has demonstrated along the short length of the building more than along the long direction regardless the total length of the walls along any direction.
6. House model with semi regular plan perform better than that with irregular plan due to producing torsional response that increases the stresses especially along the short direction.
7. Seismic vulnerability of masonry buildings in the considered cities with low to medium seismic intensities could be averted by using relatively high strength mortar and Type A brick as well as adopting regular plans.

The above conclusions were drawn based on nonlinear static pushover analysis and limited to only two storey houses with typical plans. Further investigations are recommended for future study considering public buildings such as one and two storey masonry schools, health centers and two storey office buildings that are common practice masonry buildings in Iraq. Also, further investigations are required by adopting nonlinear time history analyses considering actual recorded earthquake excitations.

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References

[1] Lopes M. Evaluation of the seismic performance of an old masonry building. 11th World Conf. Earthq. Eng., 1996, p. 1484.
[2] Betti M, Vignoli A. Numerical assessment of the static and seismic behaviour of the basilica of Santa Maria all'Impruneta (Italy). Constr Build Mater 2011;25:4308-24. https://doi.org/10.1016/j.conbuildmat.2010.12.028
[3] Betti M, Galano L. Seismic analysis of historic masonry buildings: The Vicarious

Palace in Pescia (Italy). Buildings 2012;2:63-82. https://doi.org/10.3390/buildings2020063
[4] Khadka SS. Seismic Performance of Tradational Unreinforced Masonry Building in Nepal. Kathmandu Univ J Sci Eng Technol 2013;9:15-28.
[5] Clementi F, Gazzani V, Poiani M, Lenci S. Assessment of seismic behaviour of heritage masonry buildings using numerical modelling. J Build Eng 2016;8:29-47. https://doi.org/10.1016/j.jobe.2016.09.005
[6] Kocaman I, Kazaz I, Kazaz E. Seismic load capacity of historical masonry mosques by rigid body kinetics. Int J Archit Herit 2019. https://doi.org/10.1080/15583058.2019.1570389
[7] Bilgin H, Korini O. Seismic capacity evaluation of unreinforced masonry residential buildings in Albania. Nat Hazards Earth Syst Sci 2012;12:3753-64. https://doi.org/10.5194/nhess-12-3753-2012
[8] Bartoli G, Betti M, Monchetti S. Comparative seismic assessment of masonry towers through nonlinear analysis: The RiSEM experience. Brick Block Mason. Proc. 16th Int. Brick Block Mason. Conf. Padova, Italy, 26-30 June 2016, CRC Press; 2016, p. 87-94. https://doi.org/10.1201/b21889-9
[9] Betti M, Borghini A, Boschi S, Ciavattone A, Vignoli A. Comparative seismic risk assessment of basilica-type churches. J Earthq Eng 2018;22:62-95. https://doi.org/10.1080/13632469.2017.1309602
[10] Bartoli G, Betti M, Monchetti S. Seismic Risk Assessment of Historic Masonry Towers: Comparison of Four Case Studies. J Perform Constr Facil 2017;31:4017039. https://doi.org/10.1061/(ASCE)CF.1943-5509.0001039
[11] Brandão F, Diógenes A, Fernandes J, Mesquita E, Betti M. Seismic behavior assessment of a brazilian heritage construction. Frat Ed Integrita Strutt 2018;12:14-32. https://doi.org/10.3221/IGF-ESIS.45.02
[12] Castori G, Corradi M, Borri A, Sisti R, De Maria A. Macro element and dynamic seismic analysis of the medieval government building of Perugia, Italy. Int J Mason Res Innov 2019;4:297-311. https://doi.org/10.1504/IJMRI.2019.102529
[13] Motsa SM, Drosopoulos GA, Stavroulaki ME, Maravelakis E, Borg RP, Galea P, et al. Structural investigation of Mnajdra megalithic monument in Malta. J Cult Herit 2020;41:96-105. https://doi.org/10.1016/j.culher.2019.07.004
[14] Demirlioglu K, Gonen S, Soyoz S, Limongelli MP. In-Plane Seismic Response Analyses of a Historical Brick Masonry Building Using Equivalent Frame and 3D FEM Modeling Approaches. Int J Archit Herit 2020;14:238-56. https://doi.org/10.1080/15583058.2018.1529208
[15] Bilgin H, Ramadani F. Numerical Study to Assess the Structural Behavior of the Bajrakli Mosque (Western Kosovo). Adv Civ Eng 2021;4620916. https://doi.org/10.1155/2021/4620916
[16] Tomić I, Vanin F, Beyer K. Uncertainties in the seismic assessment of historical masonry buildings. Appl Sci 2021;11:1-36. https://doi.org/10.3390/app11052280
[17] Usta P, Bozdağ Ö, Işil Çarhoğlu A. Appraisal of structural behavior of afyon sandıklı ulu mosque. El-Cezeri J Sci Eng 2020;7:871-81.
[18] Hökelekli E, Demir A, Ercan E, Nohutçu H, Karabulut A. Seismic assessment in a historical masonry minaret by linear and non-linear seismic analyses. Period Polytech Civ Eng 2020;64:438-48. https://doi.org/10.3311/PPci.15126
[19] Maras MM, Özmen A, Sayın E, Ayaz Y. Seismic Assessment of the Historical Sütlü

Minaret Mosque. Period Polytech Civ Eng 2022;66:445-59. https://doi.org/10.3311/PPci.19400
[20] Estêvão JMC, Tomás B. Ranking the Seismic Vulnerability of Masonry School Buildings according to the EC8-3 by Using Performance Curves. Int J Archit Herit 2021:1-16. https://doi.org/10.1080/15583058.2021.1904458
[21] Sissakian VK, Abdul Ahad AD, Hamid AT. Geological Hazards In Iraq. Classification And Geographical Distribution. 2011.
[22] Jasim NA. Seismicity Evaluation of Central and. Iraqi J Sci 2010;54:911-8.
[23] FEMA. Prestandard and Commentary for the Seismic Rehabilitation of Buildings. Rehabil Requir 2000:1-518.
[24] ANSYS 11.0 Inc., "ANSYS user's manual", Version 11.0, U.S.A.
[25] D'Ayala D. Assessing the seismic vulnerability of masonry buildings. Handb. Seism. risk Anal. Manag. Civ. Infrastruct. Syst., Elsevier; 2013; 334-65. https://doi.org/10.1533/9780857098986.3.334
[26] Castori G, Borri A, De Maria A, Corradi M, Sisti R. Seismic vulnerability assessment of a monumental masonry building. Eng Struct 2017;136:454-65. https://doi.org/10.1016/j.engstruct.2017.01.035
[27] Aşıkoğlu A, Vasconcelos G, Lourenço PB, Pantò B. Pushover analysis of unreinforced irregular masonry buildings: Lessons from different modeling approaches. Eng Struct 2020;218:110830. https://doi.org/10.1016/j.engstruct.2020.110830
[28] Avossa AM, Malangone P, Civile I, Ingegneria F, Università S, Ce A. a New Model for the Seismic Performance Assessment of Masonry Structures. IX Int Forum Le Vie Dei Merc SAVE Heriatage, Aversa, Capri 2002;1:1-10.
[29] Chen WF, Saleeb AF, Dvorak GJ. Constitutive Equations for Engineering Materials, Volume I: Elasticity and Modeling. J Appl Mech 1983;50:703-703. https://doi.org/10.1115/1.3167127
[30] Kaushik HB, Rai DC, Jain SK. Uniaxial compressive stress-strain model for clay brick masonry. Curr Sci 2007;92:497-501.
[31] H. Akhaveissy A. The DSC Model for the Nonlinear Analysis of In-plane Loaded Masonry Structures. Open Civ Eng J 2012;6:200-14. https://doi.org/10.2174/1874149501206010200
[32] Engineering AS of C. Seismic rehabilitation of existing buildings, American Society of civil engineers; 2007.
[33] Engineers AS of C. Minimum design loads and associated criteria for buildings and other structures. American Society of Civil Engineers; 2017.
[34] Jasim ML, Yassin LA, Resheq AS. Seismic Maps in the Iraqi Seismic Codes and their Impact on Buildings. Cent ASIAN J Theor Appl Sci 2022;3:137-46.