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Effect of brick masonry infill walls on seismic performance of reinforced concrete frame structures in Afghanistan

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Abstract

Reinforced Concrete (RC) frame structures are designed and constructed in the major parts of Afghanistan. Meanwhile, the brick masonry wall is one of the most common material that is used as internal and external walls inside the reinforced concrete frame for the building construction. The brick masonry infill wall is defined as a non-structural element for the common structural design software, where only weight is considered, not its strength or stiffness. The Hindu-Kush earthquake, October 2015 that happened in Afghanistan showed that, the buildings with brick masonry walls had less damage or small cracks on the walls. While the buildings without brick masonry walls (bare frames) had serious damage or shear failure on columns. Therefore, the current research aims to find out the effects of brick masonry walls to the seismic performance of RC frame structures by conducting earthquake response analyses of the frame models with and without brick masonry walls. The structural model is based on an actual school building (the 24-classroom school building project that has been designed as a special moment resisting frame with three-stories and constructed in Kabul, Afghanistan). Input earthquake ground motions are generated artificially based on the Afghanistan design spectrum and the phase spectrum of actual earthquake records, such as 1940 El Centro earthquake, 1995 Kobe earthquake and 2003 Bam-earthquake. The nonlinear frame analysis program, STERA 3D, developed by one of the authors is used for the analysis, where the backbone curve of the masonry element is defined including the deterioration of the bearing capacity after yielding. The performance of the frame model is examined to verify the effects of masonry elements from the natural period, the story drift and the damage of the frame and brick masonry walls.

Key words: Reinforced concrete buildings, brick masonry wall, earthquake response analysis

1 Introduction

Earthquake seriously threats human live and physical infrastructure continuously in Afghanistan. The country is in Alpine-Himalayan belt formed as the result of collision among the Indian, Eurasian, and Arabian tectonic plates [1]. The study conducted by Zakaria Shinzai (2020) [2] reveals that there are 22 active faults expanded in Afghanistan. Among these faults, the Chaman Fault which is extended about 650 km inside Afghanistan and crossing the Kabul region is moving northward 3cm each year [3], which has the potential to generate destructive ground motions every decade. Namely, the 1975 Earthquake (M6.8), the 1990 Earthquake (M6.2), the 1998 Nahrin earthquake that killed 7000 people and the latest one is the Hindu-Kush earthquake, October 2015 (M7.5) [4] that killed more than 300 people. The causality due to earthquake excitation is mainly caused by the damage and the collapse of brick masonry buildings, but the brick masonry wall (BMW) usage is increasing in rural and urban areas since 2001. It is because, the brick masonry production is simple, low cost, and product is durable. Now a days, with rapid increase of commercial and residential buildings, engineers employ the reinforced concrete frames together with the brick masonry wall to satisfy the market demands. Naqi and Saito (2017) evaluated the building performance of RC low-rise buildings with infill reinforced masonry and proposed a damage index to screen the vulnerable buildings [7]. Nasiry and Kang (2017) conducted a primary research about people awareness of natural disasters such as earthquake and ways how to stay safe during an earthquake to mitigate the earthquake disaster and enhance the public awareness [8]. After the Hindu-Kush earthquake, October 2015, the Structural Design Department (SDD) of the Ministry of Urban Development and Land (MUDL) of Afghanistan evaluated the damaged buildings in Kabul city. Based on the evaluation, the buildings with brick masonry walls had less damage or small cracks on the walls. While the buildings without brick masonry walls (bare frames) had serious damage or shear failure on columns. In the structural design process, such brick masonry walls are considered as “non-structural” members and the structure is assumed to carry the loads only by the frame elements. However, it is apparent that brick masonry walls also resist loads and impede deformations compatible with infilled frame action. Although few researchers have discussed about the contribution of brick masonry wall in the building. Therefore, the current research study is objected to evaluate the seismic performance of RC frame buildings with brick masonry walls and the contribution of brick masonry walls is further discussed for a prototype school building. The building is a 24-classroom school building which is a typical educational building constructed in several provinces of Afghanistan. The school building is designed as a special moment resisting frame with three-stories and all interior and exterior walls are solid brick masonry. The nonlinear frame analysis program, STERA 3D [9], developed by one of the authors is used for the earthquake response analysis.

2 Targeted building

A 24-classroom school building is selected from the Ministry of Urban Development and Land (MUDL) database as a target building to be evaluated. The building is a typical school building constructed almost in the entire Afghanistan during the past decade. It is assumed that the target building is located in the Kabul city with the soil type-D. As shown in Fig. 1, the building has a plan with a dimension of 41.7 m × 16.25 m consisting of nine and three spans in longitudinal and transvers direction, respectively. The building is a three-story RC frame, where each story is 3.3-meter height and the thickness of the RC floor-slab at each story is 15 cm. The detail of load-bearing elements (RC beams and columns) is summarized in Table 1 and Table 2. As for the floor weight in the seismic analysis, a total of 11 kN/m^2 dead load are combined with live load of 2.4 kN/m^2 which correspond to the recommend live load of school buildings. The compressive strength of concrete material is 28 MPa, where the tensile strength of flexural and shear reinforcing bars is 420 MPa.

According to the architectural drawings, the interior and exterior walls are brick masonry walls which are constructed as a solid wall or wall with opening of different sizes. The brick masonry wall has a typical thickness of 35 cm which are constructed from unreinforced solid brick of regular size (22x11x7 cm). The current research adopts the brick with 9 MPa compressive strength. Although, in the common practice, the brick masonry walls are considered as non-structural and non-bearing load members, but the current research uses the numerical model incorporating the brick masonry wall following the architecture configurations.

Table 1. Columns dimensions and reinforcement details

No	Columns	Story Level	Depth [cm]	Width [cm]	Main Rein. Bars	Shear Rein. Bars
1	C1	First, Second and third Floor	50	45	12 Ø D-20	Ø 10 @ 10cm
2	C2	First, Second and third Floor	50	45	14 Ø D-20	Ø 10 @ 10cm

Table 2. Beams dimensions and reinforcement details

No	Beams	Story Level	Depth [cm]	Width [cm]	Reinforcement details (Rebars)
1	B1	First and Second Floor	50	35	5 Ø-18 on Top and 4 Ø-18 on Bot.
2	B2	First and Second Floor	55	35	5 Ø-20 on Top and 5 Ø-18 on Bot.
3	B3	Third Floor	50	35	5 Ø-16 on Top and 4 Ø-16 on Bot.
4	B4	Third Floor	55	35	5 Ø-18 on Top and 5 Ø-16 on Bot.

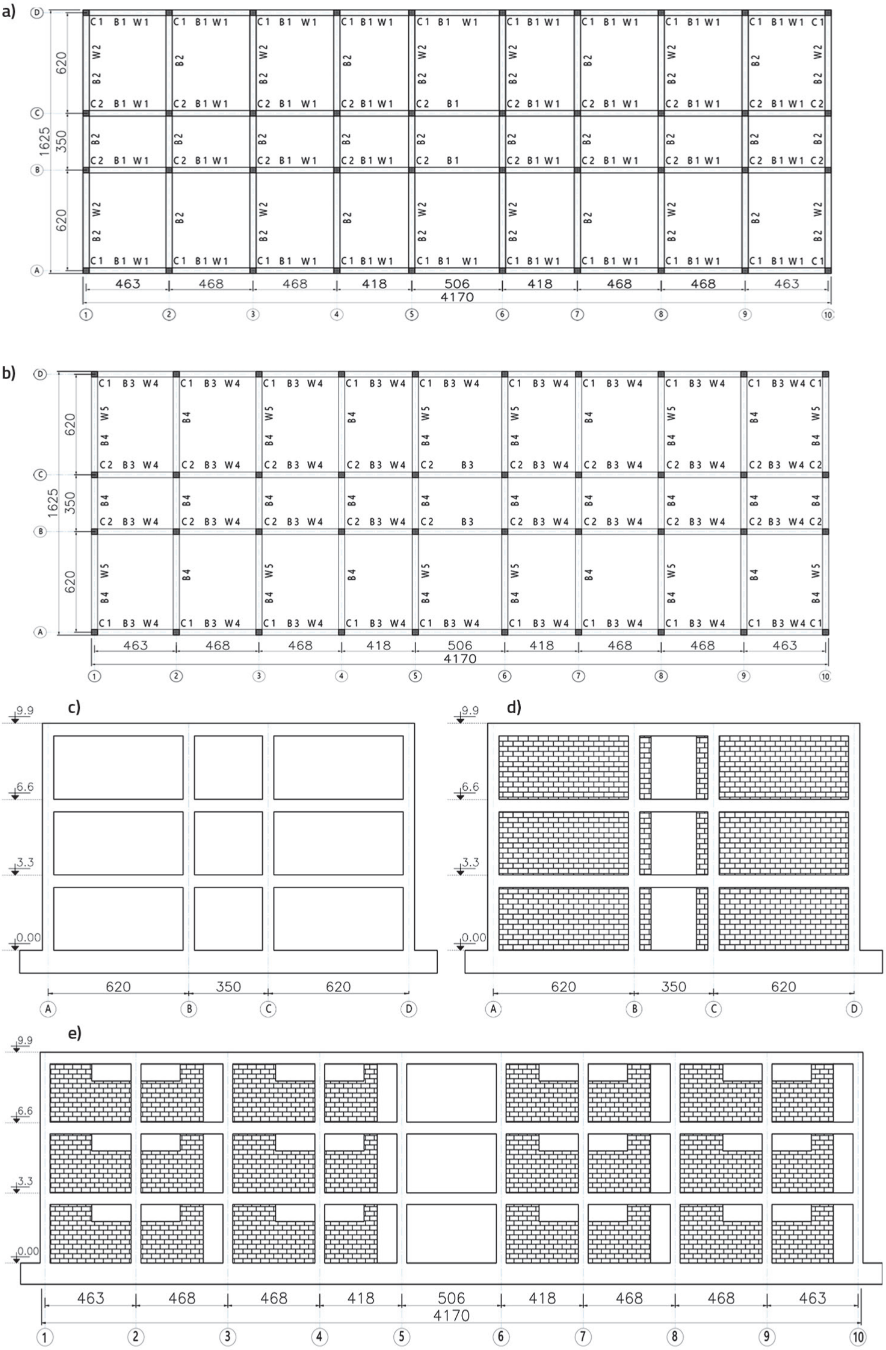

Figure1: a) First and second floors plan, b) Third floor plan; c) bare frame; d) Frame with brick masonry wall (longitudinal direction); e) Frame with brick masonry wall (transvers direction)

Table 3. Brick Masonry Wall (BMW) dimensions and details

No	Walls	Story Level	Beams	Wall. L [mm]	Wall. H [mm]	Wall. T [mm]	Comp. Brick [N/mm^2]
1	W 1	First and Second Floor	B 1	4225	2800	350	9
2	W 2	First and Second Floor	B 2	5700	2800	350	9
3	W 3	First and Second Floor	B 2	4600	2800	350	9
4	W 4	Third Floor	B 3	4225	2800	350	9
5	W 5	Third Floor	B 4	5700	2800	350	9

3 Numerical model of target building

The targeted RC building is modelled by STERA_3D (STructural Earthquake Response Analysis 3D), a finite element-based software, developed by one of the authors [13], considering the nonlinear behaviour of material and cross-sections geometry. In the model, the RC beam elements are presented by two nonlinear flexural springs at both ends and one shear spring at the middle. The column elements have nonlinear axial springs distributed in the sections of both ends and two nonlinear shear springs in the middle to represent the directional properties of the element. For both beam and column, the steel strength is modified 1.1 times than the nominal strength and the ratio of post-yield stiffness is $\gamma = K_0/K_y = 0.001$. Figs. 2 represent the hysteresis model of the nonlinear bending spring. The beam-column connection is assumed rigid.

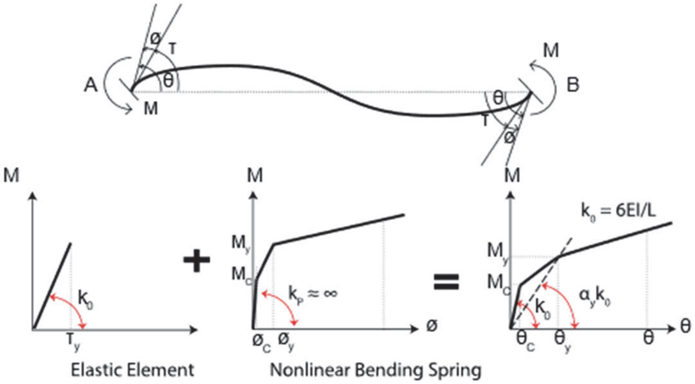

Figure 2. Hysteresis model of nonlinear bending spring of beam and column

The brick masonry wall is defined as a line element with a nonlinear shear spring in the middle and two axial spring in the edges as shown in Fig. 3a. The hysteresis model of non-linear spring is defined as the poly-linear slip model as illustrated in Fig. 3b. In the figure, the Q_u, Q_c and Q_y denotes the ultimate, crack and yield strength of brick masonry wall which are obtained based on the procedure recommended by Paulay and Priestley

[10]. Where the shear strength of brick masonry wall is estimated as the smaller value between the compression strength of diagonal strut presented in Fig. 3c and the sliding shear strength in Fig. 3d.

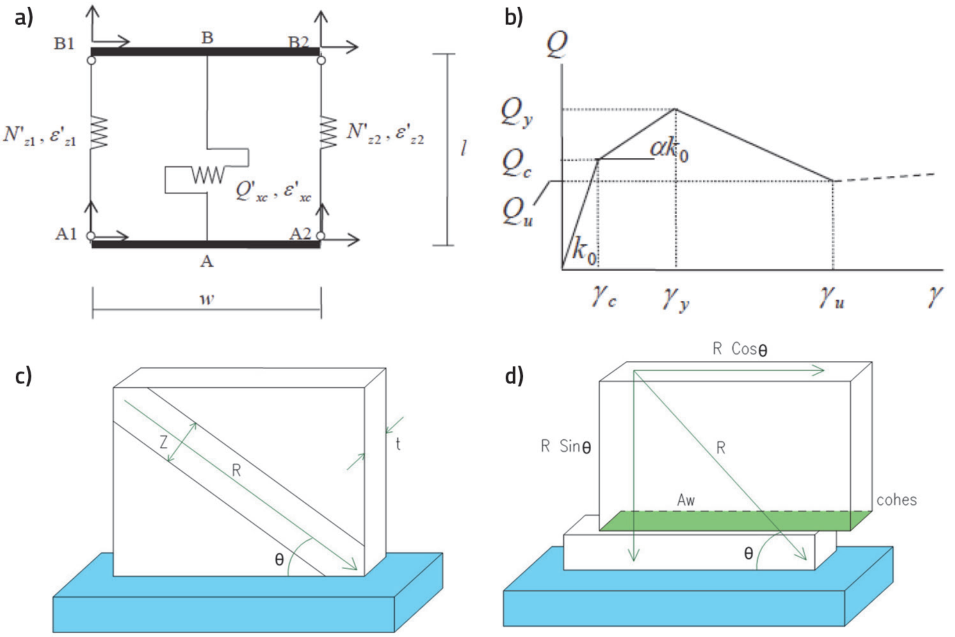

Figure 3. a) Element model for brick masonry wall; b) Force-deformation relationship of shear spring for brick masonry wall; c) Compressive strength of diagonal strut; d) Sliding shear strength

4 Demand spectrum of the earthquake ground motions

According to the Afghan Structural Code (ASC) [11], school buildings shall be designed to satisfy the earthquake ground motions of 2 % probability of exceedance in 50-years. Thus, in the ASC, the horizontal spectral response acceleration maps are introduced to obtain the maximum considered earthquake for designated locations. Since the prototype building, which is constructed in Kabul, the S_S = 1.28g (spectral response acceleration at 0.2 sec period) and S_1 = 0.51g (spectral response acceleration at 1-second period), under 5 % damping ratio, are determined. According to the procedure recommend in the ASC, the Design Response Spectra (DRS) is generated as indicated by blue-thick-line in Fig. 4.
For the time history analysis (THA) of the prototype building, three historical earthquake ground motions are selected for the phase spectrum: namely, the El Centro 1940 earthquake, Kobe JMA 1995 earthquake and the Bam-earthquake 2003. Then, the artificial ground motions are generated to be compatible with the DRS. For this purpose, the STERA_WAVE 1.0 [12] algorithm developed by one of the authors is practiced. The response spectra of artificial ground motions are also presented in Fig. 4.

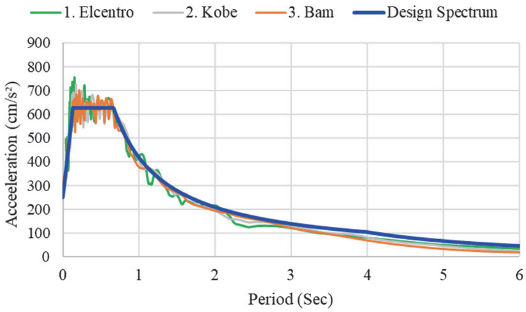

Figure 4. Response spectra of artificial ground motions with 5 % damping

5 Comparison of bare frame (BF) with brick masonry wall (BMW)

5.1 Natural periods of the building

Table 4 compares the pre-event natural periods of the prototype building with and without considering the contribution of brick masonry walls. As it is expected the building natural periods are significantly shorten when the brick masonry wall is included. This reductions for 1st to 3rd mode of vibration are about 34 %, 30 % and 24 % in transvers-direction, and about 45 %, 40 % and 31 % in longitudinal direction, respectively. Similarly, the post-event natural periods after time history analyses are presented in Table 4, which indicate the elongation of natural periods due to the degradation behaviour of load-resisting elements. For the 1st mode of vibration, the post-event natural period elongation is about 2.23~1.99 times of pre-event in case of prototype building without brick masonry wall, where this value is about 1.54~1.47 times in case brick masonry wall is considered.

Table 4. Pre-event natural periods (*sec*) of prototype building with and without brick masonry wall

No	Systems	Directions	1st mode	2nd mode	3rd Mode
1	RC frame without Infill Masonry wall	Trans. D.	0.4197	0.1338	0.0773
2		Long. D.	0.4172	0.1321	0.0744
3	RC frame with Infill masonry wall	Trans. D.	0.2760	0.0938	0.0585
4		Long. D.	0.2278	0.0789	0.0513

Table 5. Post-event natural periods (*sec*) of prototype building with and without brick masonry wall

No	Systems	Directions	1st mode	2nd mode	3rd Mode
1	RC frame without Infill Masonry wall	Trans. D.	0.9365	0.2505	0.2091
2		Long. D.	0.8329	0.2245	0.1465
3	RC frame with Infill masonry wall	Trans. D.	0.4270	0.2633	0.0927
4		Long. D.	0.3358	0.1342	0.0873

5.2 Inter-story drift ratio

To examine the contribution of brick masonry wall to the overall performance of target school building, the inter-story drift ratio is calculated from the time history analysis of three artificial earthquakes. The result for the building with and without brick masonry walls are compared in the Figs. 5a and 5b in longitudinal- and transvers-directions. It is depicted, in case of RC frame without brick masonry walls, the prototype building reaches 1 % and 1.5 % (transvers and longitudinal directions) story drift ratio which goes beyond the safety criteria given by Afghan Structural Code (ASC). On the other hand, when the prototype is modelled with brick masonry wall, the inter-story drift ratio is less than serviceability limit (0.5 %) for both directions, which indicates the contribution of brick masonry wall is about 50 %.

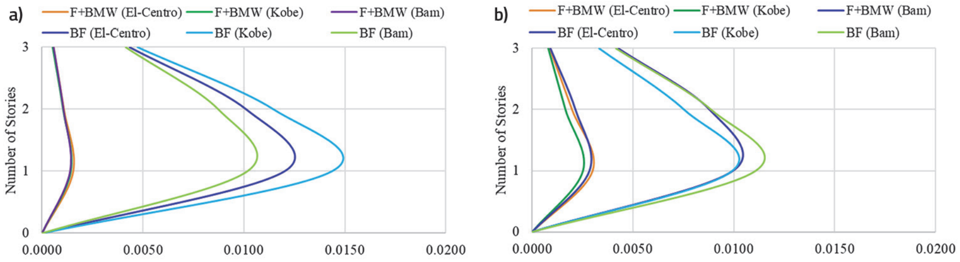

Figure 5. Inter-story drift ratio of prototype building with and without the contribution of brick masonry walls; a) Longitudinal direction; b) Transvers direction

5.3 Story shear force demand

The story shear forces for the three selected earthquakes are compared for the prototype building with and without the contribution of brick masonry wall in Fig. 6. It is observed, in contrast to inter-story drift ratio, the story shear force is increasing for the building with brick masonry wall. It is because of the additional stiffness provided by the brick masonry wall shorten the natural period of the building, and as can be seen in the response spectrum, it increases acceleration response. This amplification is about 50~60 % for longitudinal and transvers directions.

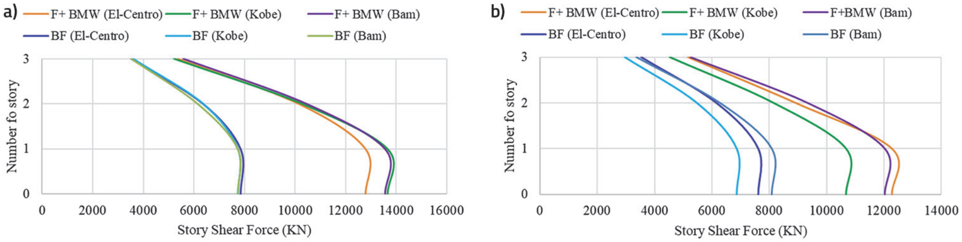

Figure 6. Story Shear force, a) Longitudinal direction; b) Transvers direction

5.4 Capacity curve

The story shear force and story drift relationship of the building is obtained from the non-linear static pushover analysis to further investigate the brick masonry wall contribution in seismic performance. The prototype building is pushed until the drift ratio at the equivalent hight of building reaches 2 % recommend in ASC. Then, the relation of seismic shear coefficient and story drift at each story level is obtained as shown in Fig. 7, for both cases in longitudinal and transvers directions. As depicted from the figure, the shear strength of the frame with brick masonry wall is about 3 times of the frame without brick masonry wall when the story drift ratio is in the range of 0~0.5 %. It notably observed, as the story drift ratio increases and reaches the 0.5 %~2.0 % range, the shear strength of target building declined gradually. This indicates, although, the brick masonry walls significantly increase the strength capacity of the buildings, but the brick masonry wall could easily lose its strength under higher level of drift ratio.

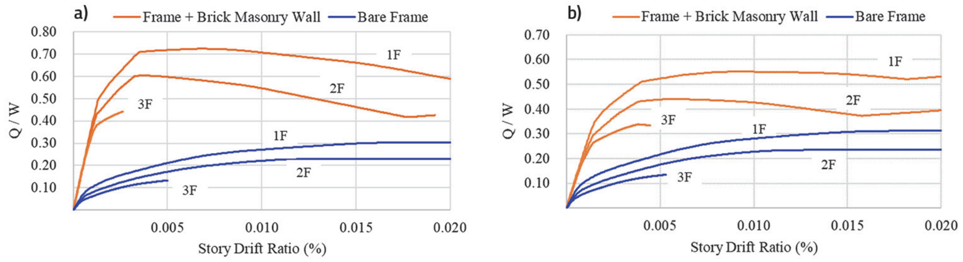

Figure 7. Capacity Curve of Prototype building with and without brick masonry wall; a) Longitudinal dir.; b) Transvers dir

6 Conclusions

The contribution of brick masonry wall to the overall performance of RC frame structure is investigated in this research paper. For this purpose, a 3-story RC frame school building which is typically constructed in Afghanistan is examined. Three historical earthquake ground motions are selected for the phase spectrum and the artificial ground motions are generated to be compatible of the design response spectra recommended in ASC. And the seismic performance of the building and the contribution of brick masonry walls are examined in terms of natural periods, inter-story drift ratio, and story shear force. It is observed that, the brick masonry wall is capable to significantly reduce the building damage and improve the seismic performance of the RC frames. Although, the Afghan Structural Code did not provide specific provision to ponder the contribution of brick masonry walls, it is recommended that the additional strength and stiffness inserted by brick masonry wall should be incorporated in design phase.

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