Research Article

Performance of Unreinforced Hollow-Block Masonry Houses During 23 August 2017 Ranya Earthquake

Hawkar A. Haji [1,a], Najmadeen M. Saeed [1,2,b,*], Brwa H. Salihi [3,c], Araz A. Hamza [1,d]

[1] Department of Civil Engineering, University of Raparin, Ranya, Sulaymaniyah, Kurdistan Region, Iraq
[2] Department of Civil Engineering, Tishk International University, Erbil, Kurdistan Region, Iraq
[3] Department of Civil Engineering, Faculty of Engineering, Koya University, Koya, Erbil, Kurdistan Region, Iraq

[a] hawkar.ali@uor.edu.krd, [b] najmadeen_qasre@uor.edu.krd, [c] brwa.hasan@koyauniversity.com, [d] araz.hamza@uor.edu.krd

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Abstract

The earthquake in Ranya City took place at local time 16:42 (GMT+3) on August 23rd 2017, with a magnitude of 5.3 Richter scale in the Kurdistan Region of Iraq. The earthquake with an approximate duration of 5 seconds occurred near Lake Dokan with a depth of 10 km below the surface of the earth. It caused a lot of damages to the structures in the region. The most vulnerable buildings were unreinforced hollow-block masonry houses which are composed of hollow-concrete blocks. This paper discusses the performance of unreinforced masonry houses of Ranya City with illustrative photos taken during on-site investigation for a number of damaged houses subjected to seismic actions. The main structural deficiencies that caused the wall cracks were highlighted, such as; very low tensile and shear resistance of the walls, large openings and their positioning, weak mortar and binding between the masonry units, existing weak joints between the crossing walls.

Keywords: Unreinforced Masonry Houses, Earthquake Damages, Hollow-Concrete Block, Seismic Performance, Ranya Earthquake.

1. Introduction

Construction is an ancient human activity that began with the essential requirement of providing an appropriate environment for daily human life. During the primary era of civilization, mud blocks and stone were commonly used for building their habitats since these natural materials were attainable in their own living places (Avila et al., 2012). The earliest forms of the construction process were load-bearing walls. Masonry block or brick wall is still one of the most common building materials with mortar. Due to the masonry wall having low tensile strength, the newer and older forms of masonry structures are extremely susceptible to earthquakes (Khadka, 2013).

Generally, in today’s construction industry process in the region, the most common type of housing is unreinforced masonry building, which mostly uses hollow concrete block units. It consists of a wall footing, unreinforced hollow block walls, lintels and reinforced slabs. The main reasons that have encouraged citizens of this region to use hollow concrete blocks; are the availability of raw materials, the rivers providing necessary sand and gravel (Ibrahim et al., 2016), and their characteristics such as durability, fire resistance and low cost. The performance of this type of structure during earthquakes mainly relies on the basic materials, which are mortar and masonry units.

Doğangün et al. (2008) reported that even in countries where there is much concern about earthquakes, most of the research had been focused on studying complex structures such as high-rise buildings, while little attention has been given to masonry houses. Additionally, observed damages on masonry buildings were very few compared to investigations on reinforced concrete buildings.

It can be noted that from an earthquake point of view, unreinforced masonry buildings are the most dangerous types of construction. Ordinarily, the walls are load-bearing and the masonry units are put on top of each other and joined together with mortar. Then the roof is built on top of the walls and its weight is transferred to the foundation through the walls. During earthquakes, inertial forces in higher amounts apply to the house at every position on the building walls and the floors (Korkmaz et al., 2010). These forces are transferred through the elements of the house, i.e., roof, wall and foundation; it can be seen that the most susceptible element to damage is the walls. As a result, the walls tremble and tip over and different types of cracks appear on the walls. Bruneau (1994) and Magenes (2006) noted that the appropriate seismic behavior of masonry buildings relies on the shear resisting mechanisms and the adequate connection between intersecting walls and between walls and floors and ceilings. Its large mass and low tensile strength of the materials is the main and most influential factors for the brittle behavior of this type of constructive system. It can be observed that for such building construction types, a number of failure mechanisms and collapses have already been distinguished when exposed to seismic forces. It is supposed that with a proper design and construction based on gained experiences registered in previous earthquakes the construction system with masonry materials can be developed to satisfy both the safety and acceptable quality conditions for constructing residential buildings (Avila et al., 2012).

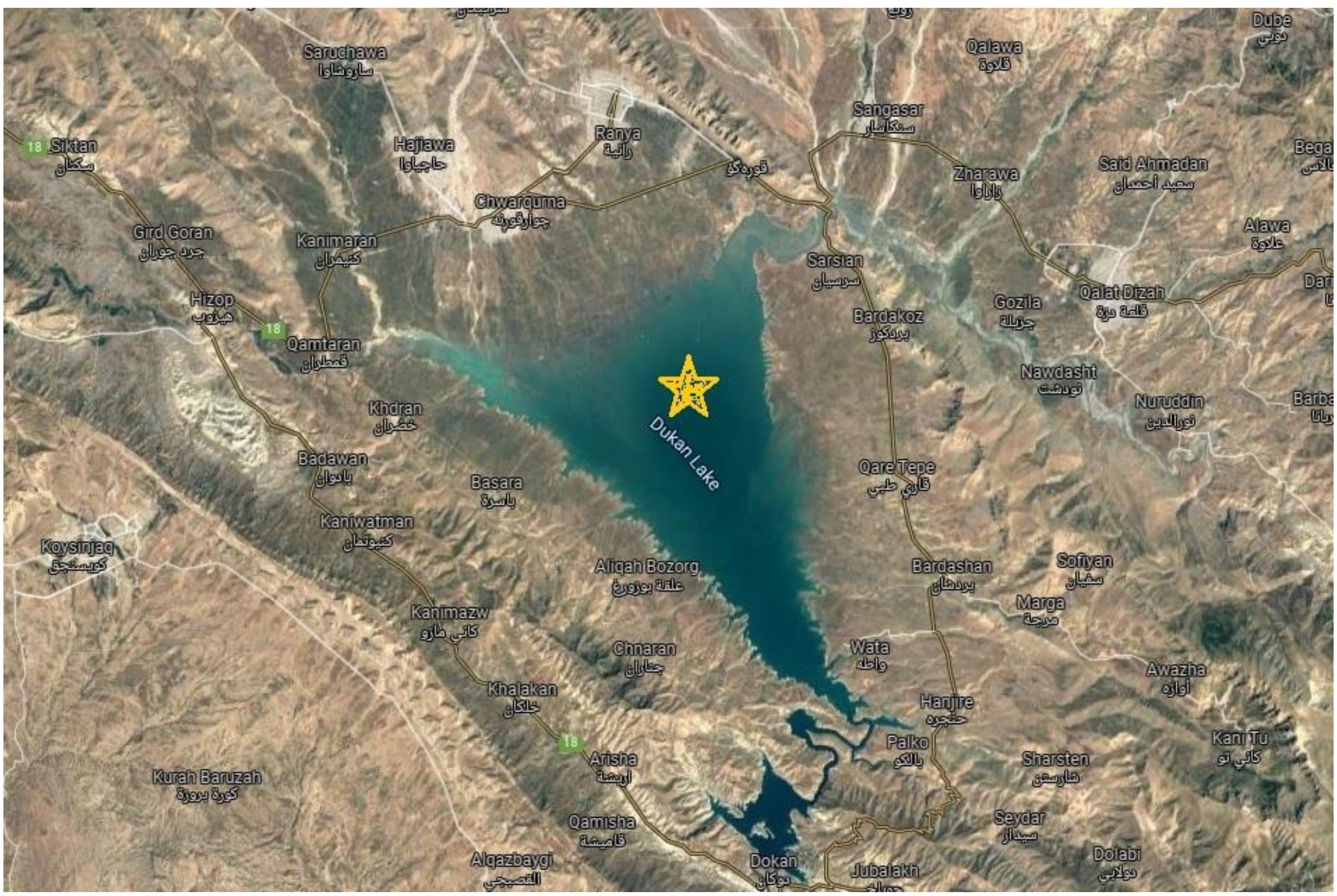

Figure 3. The Map Shows the Epicenter and The Dwellings at Risk for Damage (Earthquake-Report, 2018).

This paper investigates the behavior of unreinforced masonry buildings and their responses to the earthquake that occurred on 23rd August 2017 in Ranya with a magnitude of 5.3 at the epicenter. The earthquake hit the north of Iraq below or near Lake Dokan with a depth of 10 km and the shaking lasted around 5 seconds (see Figure 1) (Earthquake-Report, 2018).

2. The Characteristics of Unreinforced Masonry Houses

The main elements of the unreinforced masonry system used in the construction of residential houses are wall footing, unreinforced hollow block walls, lintels, and reinforced slabs with parapets (see Figure 2). In this section, these features will be described in detail.

2.1. Wall Footings

It is reinforced concrete footing along the whole bearing walls, one or two layers of steel bars with stirrups depending on the bearing capacity of the soil and the number of floors of the building. A typical dimension for the footing is about (50 cm – 80 cm) in width and (40 cm – 50 cm) in thickness. The majority of the houses in the study area have been constructed on strip footing without a proper foundation design process.

2.2. Load-Bearing Walls

The masonry unit that is used in this type of structure is a hollow concrete block. The raw materials and local factories for manufacturing this block type are available in the region. In the building market of the northern part of Iraq, different face sizes (Length, width, height) of blocks are produced. The old Iraqi-Standard-Specification (1987) sets detailed information concerning the dimension, category and physical requirements of the blocks. In general, Class A block is recommended to be used for load-bearing walls internally and externally. The maximum threshold of $\mp$ 3 mm is allowed in the face size variations in any dimension and the minimum compressive strength of 10 N/mm^2 as an average value for solid and hollow concrete blocks is a must-have physical requirement (Siram, 2012). However, (Rostam et al., 2016) in their major study identified several deficiencies in dimensions, density, mixtures, production methods and strength of the concrete blocks in the regional building market and these shortcomings do not meet the Iraqi-Standard-Specification (1987). Length of 400 mm, 200 mm width and 200 mm height is the most common size for normal load-bearing walls. The block size with a length of 300 mm, width of 300 mm and height of 200 mm is usually employed under the ground and above the wall footing until the height of the damp proofing course (DPC). This reduces the bearing stress from the walls to the wall footing. Another block size with a different dimension of (Length 400 mm, width 100 mm and height 200 mm) is used for parapets and partition walls; this is mainly utilized to decrease the dead load on the slab and provide more space in the house. A mortar mix of (1:3) cement-sand (C:S) ratio to bind building blocks with 15–20 mm thickness is usually used.

2.3. Lintels

For supporting the walls upon the door and window spaces, simply supported reinforced concrete beams are used with different heights (200, 300 or 400 mm) and the width depends on the wall width.

2.4. Roof

Reinforced concrete slabs with 150-200 mm thickness are generally utilized to cover the whole structure with no joints. The concrete used for slab units usually has a compressive strength of 21 to 25MPa.

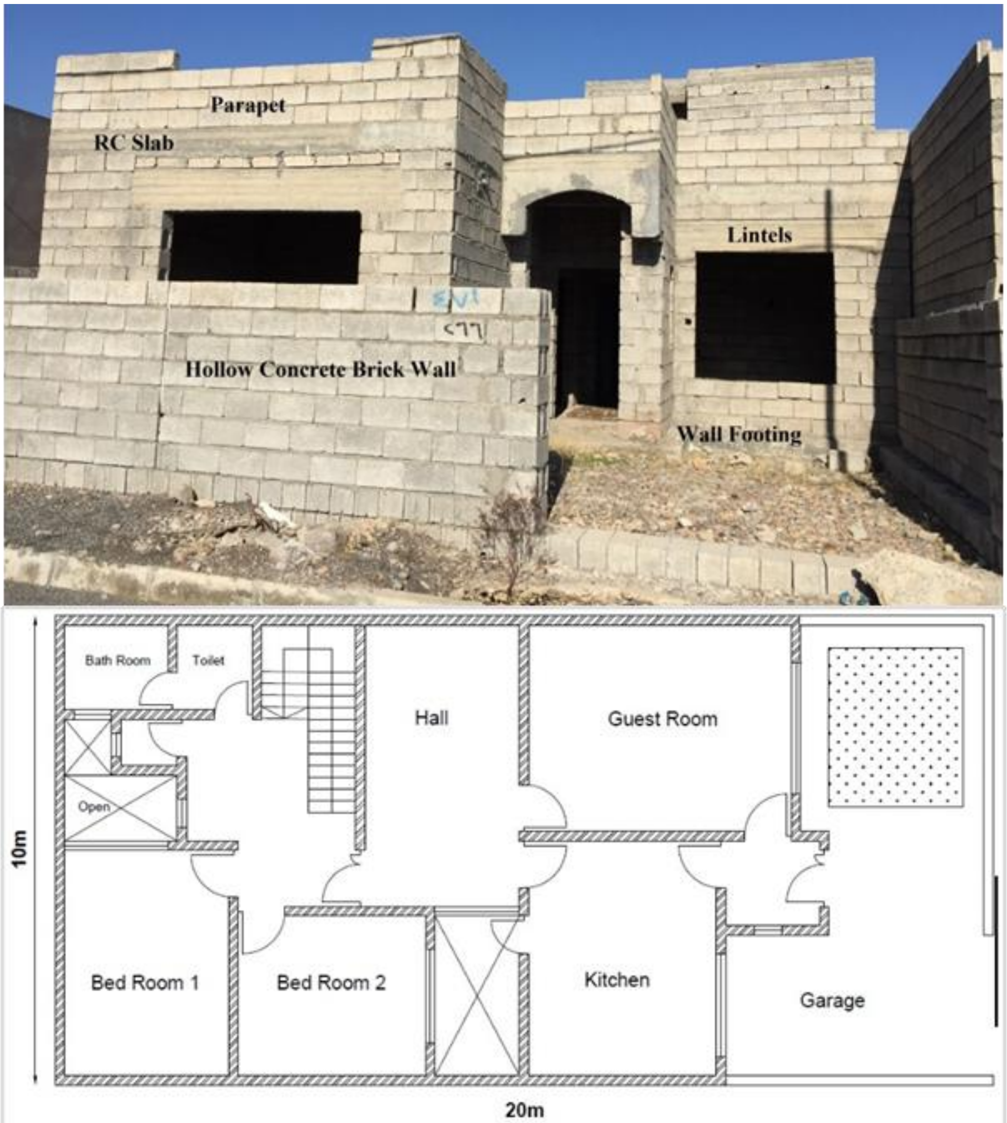

Figure 4. Typical Masonry House Components and Plan of a House.

3. Common Observed Cracks and Damages

As explained before, the earthquake with a magnitude of 5.3 is moderate and can induce different levels of damage to poorly constructed buildings. Unreinforced masonry houses were damaged and cracked the most compared to other steel and concrete frame structures. Therefore, this study performs an in-depth analysis of the collocated data regarding the damaged houses in the area hit by the earthquake. It discovers the most noticeable reasons behind the occurrence of the cracks and failures in the unreinforced masonry buildings. After a thorough investigation of the damaged houses, the following dominant cracks and damages have been detected due to the earthquake.

It should be made clear that different types of cracks and damage in the unreinforced masonry walls are mainly the product of generating extreme tensile and shear stresses in the load-bearing walls. During earthquakes, in-plane and out-of-plane failures are the two most likely modes to which unreinforced masonry walls are generally exposed. The former is represented by the diagonal tensile cracks and the latter is described mainly by cracks that occur along the joints of the masonry units (Saatcioglu et al., 2005).

From the observations in Figure 3, it is apparent that the diagonal tension forces primarily cause these types of cracks, as shown in Figure 4, a schematic diagram showing the mechanism of cracks at corners. These cracks pass through the mortar joints or diagonally through the masonry units. They mostly begin at the corners of the windows and doors.

During extensive ground motion, this type of failure considerably damages the building and in extreme cases, it causes a collapse in the building.

a. Cracking of spandrel wall between openings

b. Cracks at the corners of openings (door)

c. Diagonal stepped shear cracking

d. Cracks at the corners of openings (window)

e. Double diagonal shear cracks (x shape)

Figure 3. Most Common Cracks in Bearing Walls Due to Bending and Shear.

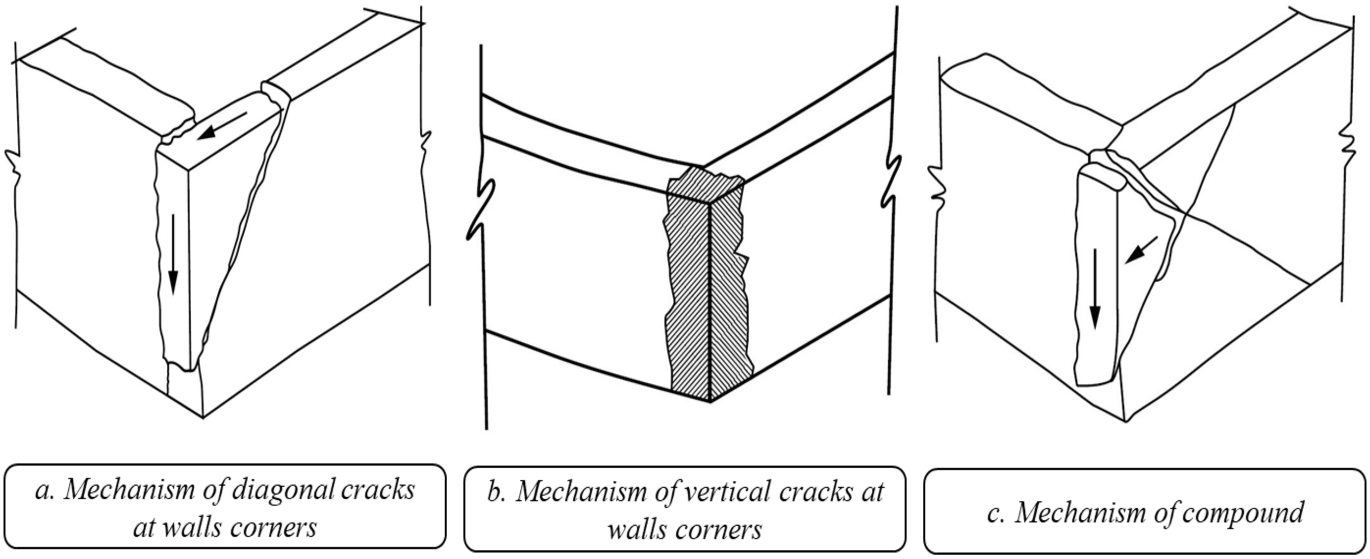

Figure 4. Mechanism of Cracks at Corners (Mardani et al., 2019).

In-plane damage and cracks are produced excessively due to the intense long ground motions. This is mainly dependent on the aspect ratio of the wall, which in turn generates excessive shear forces. If this ratio is moderate, tension cracks appear on the walls diagonally (Decanini et al., 2004). During the earthquake reversal of loading, the cracks become double diagonal shear cracks that have an X shape (see Figure 3e). A study investigating the seismic risk of unreinforced masonry buildings (Erbay, 2004) reported that the cracks become stair-stepped diagonal cracks and horizontal flexural cracks in the central part of the walls (see Figure 5). These damage patterns are typical to walls that run parallel with the direction of shaking. Due to their orientation, these walls provide the lateral load resistance of the building and undergo in-plane deformation and stresses.

Figure 5. Horizontal Shear Crack at the Base of The Wall.

Pindoria et al. (2001) revealed that unreinforced masonry walls with small and few windows and doors experience less deterioration during earthquakes. Moreover, the earthquake resistance of the walls increases where the openings are far away from the corners. On the other hand, shear failures may occur to the walls with several numbers of openings. This concludes that the resistance of an unreinforced masonry building is considerably reliant upon the position, number and extent of the openings (see Figure 6).

Figure 6. Cracks in Load-Bearing Masonry Walls With Many Openings.

It is clear that all directions of a building undergo the earthquake effects at the same time. The load-bearing walls orthogonal to the direction of motion are imposed to seismic inertia forces and the wall may fail in bending. As a result, vertical tension cracks initiate at the corners, ends and center of the walls. Simultaneously, the separation of intersecting walls at the corners becomes another mode of failure due to poor connection at the wall junctions. Figure 7 shows some of the damage and out-of-plane vertical cracks that occurred to the unreinforced masonry concrete hollow block walls.

Figure 7. Corner Failure of Hollow-Block Masonry Houses.

As described previously, a reinforced concrete slab directly rests on the walls without any type of connection between the walls and the slab. The top end of the walls is free to move under seismic loading. This, in turn, raises the possibility of occurring out-of-plane failure. It has been noticed that those houses having a bond beam that extends over the entire walls provide a diaphragm and they performed well with micro-cracks appeared on the surface of the walls.

The out-of-plane bending generated by the perpendicular inertial forces on the walls is the primary cause of higher tensile stresses at the corners and this induces vertical cracks.

The causes of the aforementioned damage and failures are mainly due to: (1) lack of vertical confining elements which absorb the seismic forces and increase the lateral resistance of the walls at the jambs of the openings, ends of load-bearing masonry walls, and interesting of walls; (2) the construction materials used in bed joints which are very weak in resisting tensional forces; (3) the quality of mortar which plays a pivotal role in binding the masonry units; (4) the position, size and number of openings in the walls; (5) lack of appropriate connections at the junctions of load-bearing walls; (6) the aspect ratio of the wall; (7) irregularities in the plan of the residential houses.

4. Conclusions

The 5.3 magnitude earthquake that stroked Ranya City on the 23rd of August 2017 damaged several unreinforced masonry structures. As mentioned earlier, the residential houses of this area were built by using hollow-block masonry units and mortar. The most failure mechanisms that occurred to the hollow-block masonry buildings were in-plane, out-of-plane and connection failures. Based on the damages observed and discussed, the following conclusions can be drawn:

The irregularity of the house plans and the unequal distribution of the walls in both directions made possible the out-of-plane failure and those walls underwent severe seismic forces and were damaged the most.

1) It was observed that the lateral resistance of the walls at the sides of openings, wall ends and crossing walls were insufficient. This caused the separation of the wall junctions and vertical cracks at corners at these locations.
2) It was noticed that the number, size and location of the openings in the houses had a significant impact on the performance of unreinforced hollow-block masonry houses during earthquakes. In most of the houses, openings substantially contributed to the level of damage. Most of the cracks occurred at the corners of the openings and the wall portion between the two openings.
3) The connection between the crossing walls was not appropriate and some load-bearing walls were separated with the application of seismic forces.
4) This study confirms previous findings of the performance of unreinforced masonry houses during earthquakes and contributes additional evidence that suggests the use of more proper techniques and methods to increase the lateral resistance of this type of structure.
5) Even though the earthquake was moderate, the damages and cracks were extensive. Therefore, it is recommended to increase the public awareness and workforces to construct according to standards and integrate earthquake-resistant techniques in unreinforced masonry houses.

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