Performance of Masonry Buildings in November 12, 2017, Sarpol-e Zahab - Ezgeleh Earthquake (M_W 7.3)

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ABSTRACT

Sarpol-e Zahab - Ezgeleh earthquake (M_W 7.3) occurred in Kermanshah province of Iran near the Iraq - Iran border on November 12, 2017 at 18:18 UTC (21:48 local time). The epicenter was located about 5 km from Ezgeleh town. Sarpol-e Zahab - Ezgeleh earthquake is the most destructive seismic event in Iran in recent decade in terms of financial and human losses. Based on field observations, carried out by the authors between November 25 and 30, 2017, extensive non-structural and structural damages were inflicted to all types of masonry buildings. Post-earthquake observations showed that the use of URM buildings in the area with high relative hazard of seismicity lead to significant damages. Moreover, defects in design and construction of buildings, which was the result of the lack of enough supervision by responsible organizations, can be considered as other causes of damages. In this paper, observed damages in masonry buildings are presented and investigated in detail.

Keywords:
Sarpol-e Zahab - Ezgeleh Earthquake; Masonry structures; Failure types; Seismic code

1. Introduction

Iran is frequently exposed to destructive earthquakes with the return period of about 10 years. The last event was the earthquake of M_W 7.3 occurred at 21:48 local time on November 12, 2017 in Kermanshah province and adjacent areas, which is located in west of Iran, quite close to the Iraq and Iran border. During this destructive earthquake, not only non-engineered rural structures, but also engineered structures faced severe damages that caused many casualties and economic losses. Earthquake records and response spectra corresponding to the main shock event, recorded in Sarpol-e Zahab city are presented in Figure (1). As is shown in Figure (1a), the maximum PGA in the case of N-S component was 0.68 g. In Figure (1a), earthquake response spectra are compared with design spectra for various soil conditions as are mentioned in Iranian seismic code [1]. The displacement map for the earthquake, provided by United Nations Institute for Training and Research (UNITAR) is shown in Figure (2).

A reconnaissance team of engineers from the International Institute of Earthquake Engineering and Seismology (IIEES) visited the affected region shortly after the Sarpol-e Zahab - Ezgeleh earthquake to record the damage patterns in the buildings. According to the observations, engineered masonry buildings with one or two stories, have shown

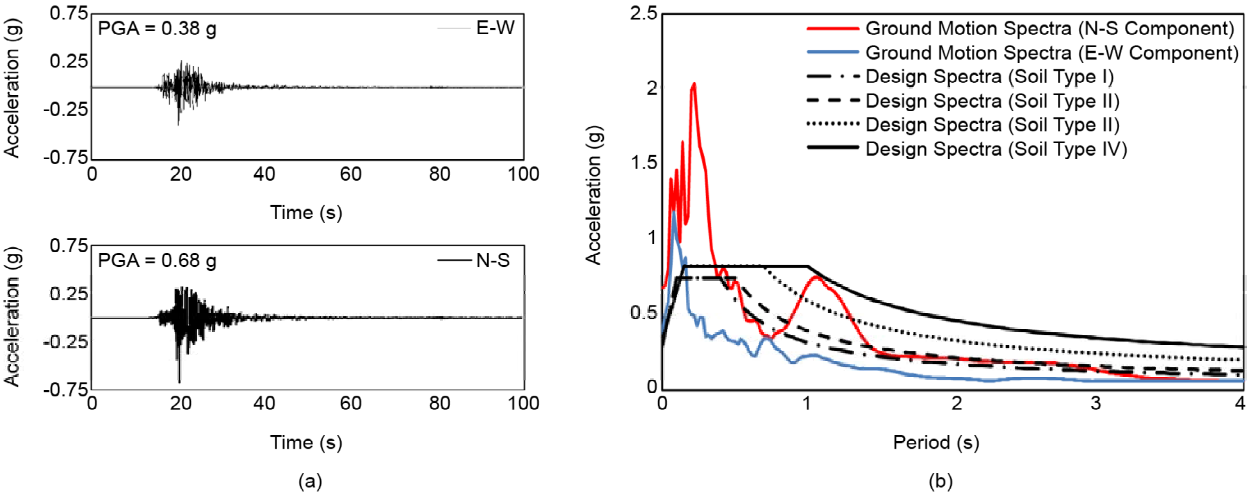

Figure 1. (a): Acceleration time histories recorded for the main shock event recorded in Sarpol-e Zahab station (b): Elastic response spectra for the main shock and design spectra for various types of soils according to Iranian code of practice for seismic resistant design of buildings.

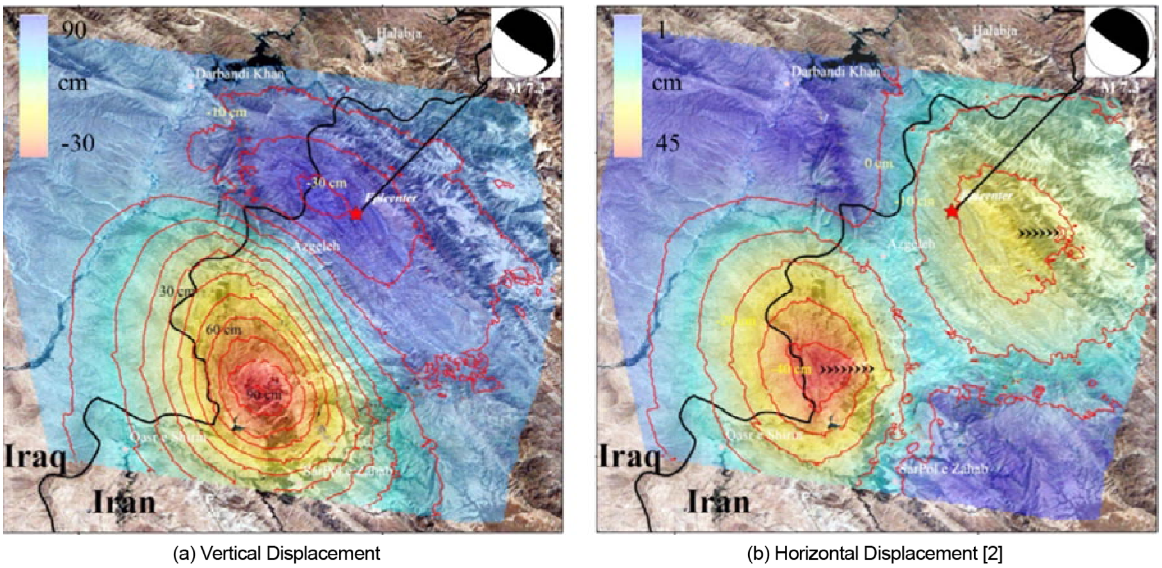

Figure 2. Displacement map of M_W 7.3, Sarpol-e Zahab - Ezgeleh earthquake.

acceptable performance in the earthquake while non-engineered masonry buildings experienced extensive damages or collapse during the earthquakes especially in rural areas.

Most of the buildings in the rural areas of earthquake affected regions, were unreinforced masonry buildings. A large number of the unreinforced masonry buildings entirely collapsed, or were extensively damaged, near the epicenter of the main shock of M_W 7.3. The structural damage density map for the north of Sarpol-e Zahab County, where most of the buildings were unreinforced masonry structures provided by UNITAR is shown in Figure (3). The structural damage density presented in Figure (3) is consistent with observed damage patterns by the authors in shown area.

The performance of masonry buildings during the November 21, 2017, Sarpol-e Zahab - Ezgeleh earthquake, is examined herein. Evidences of significant damages and several structural deficiencies were observed on masonry structures after the event.

2. Materials Used in Masonry Buildings

Masonry buildings are the most prevalent type of buildings in earthquake affected areas especially in rural regions where almost all of residential buildings, schools and healthcare centers are classified as masonry structures. Local and typical materials were used to build masonry structures. The most common masonry units were rigid and hollow clay bricks, hollow cement tiles and building stone.

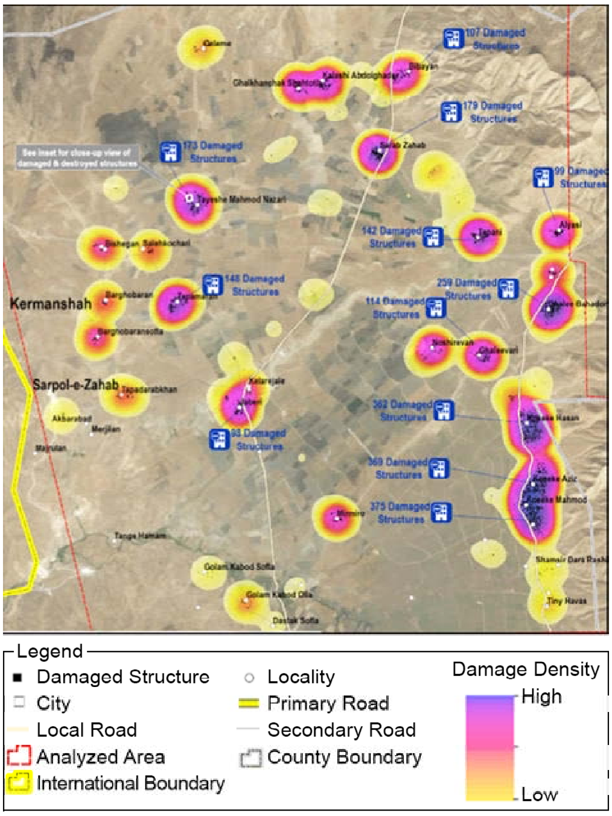

Figure 3. The structural damage density map for masonry buildings in the north of Sarpol-e Zahab County, provided by UNITAR [2].

Cement mortar is the most common binding material in masonry buildings. Moreover lime mortar and cob are rarely used in some masonry buildings. Tie elements are generally made out of concrete and steel elements like structural steel profiles are rarely used. In a general view, rigid and hollow clay bricks with or without concrete confinement elements are the most common materials used in masonry walls. The roof systems are typically in the form of brick arch spanning between steel I-beams (Jack-arch or "Taqzarbi" in Farsi) and one-way hollow concert slab between concrete joists. Jack-arch roofs generally are made out of rigid clay bricks and gypsum mortar as binding material forming a shallow arcade between two joists at a distance of 0.5 to 0.8 meter.

3. Type of Masonry Buildings Used in Earthquake Affected Area

Generally, masonry buildings can be classified with respect to structural type of masonry walls. As a common method, masonry walls are classified in three major structural groups: Confined Masonry (CM), Reinforced Masonry (RM) and Unreinforced Masonry (URM) walls. A masonry wall is called to be confined when vertical bounding elements (tie-columns) confine the wall at all corners [3]. Bonding beams generally are used to provide a consistent anchorage for floor or roof structure. Confining is more effective in improving the ductility and solidarity of the wall rather than the strength. The unconfined masonry walls can be grouped as Reinforced or Unreinforced masonry walls as are described in FEMA 306 [4].

According to observations rising from site visits, reinforcing the masonry walls is not a common practice in constructing the masonry buildings in earthquake affected areas and almost all the unconfined masonry walls can be classified as unreinforced masonry. Both CM and URM buildings experienced significant damages or completely collapsed within the earthquake affected area and the performance of each type of buildings during the Sarpol-e Zahab - Ezgeleh earthquake are investigated in the following sections.

4. Deficiencies in Design and Construction of Masonry Buildings

Most prevalent defects in design and construction of masonry buildings are presented and investigated in this section. Iranian seismic code (St. 2800) [1] and part 8 of Iranian National Building Code (NBRI-8) [5] are the main regulations of design and construction of masonry buildings in Iran. In this section, the assessment will be based on the regulations of these documents.

4.1. Inadequate Amount of Bearing Walls

According to the Iranian seismic code and NBRI-8, the amount of bearing walls in each direction of principal axes of building should not be less than a minimum limit mentioned in these codes. These limits depend on parameters like type of masonry building (confined or unreinforced masonry), building material used in the walls, relative hazard of seismicity and finally, the number of stories. Based on these limitations, the wall sections that contain openings, should not be taken into account. In many cases, failure to provide the proper amount of bearing walls and lack of attention to the presence of openings in the walls, caused the lateral resistance capacity of the building to be less than the lateral seismic demand. This issues are known as a source of damages in the masonry buildings. Figure (4) shows a two-story, damaged residential building. As is shown, load bearing walls are provided only in the border of building. Considering second story of building and existing of the openings in surrounding walls, the amount of existing and effective bearing walls was less than the amount of seismic demand on these walls and caused large drifts in first story. It should be noted that poor quality of mortar, inappropriate use of confining elements and vertical extension of building can also be mentioned as other factors of damages in this case.

4.2. Inappropriate Use of Openings

Openings are considered as a main source of weaknesses in masonry walls, decreasing the resistance of the walls against earthquake excitations. In masonry buildings in which the walls act as lateral load resisting system, wall openings should be regular and minimized to improve lateral stiffness and resistance of buildings. Iranian seismic code and NBRI-8 provide regulations about openings to restrict density, dimension and location of openings in masonry wall. As specified in Iranian seismic code, openings shall be located in central part of the wall and the total area of the openings should be less than one third of the area of the wall. Maximum dimension of the openings is limited to 2.5 m, except if proper confining elements (tie-columns and beams) are located around the openings. Moreover, the total length of the openings should be less than half of the length of the wall [1].

Figure (5) shows damages caused by inappropriate use of openings in masonry walls. Oversized and disproportionate openings, reduced the walls lateral strength and caused extensive damages in surrounding walls. In addition, existing of the opening reduced the lateral stiffness of the building that caused damages in other elements of masonry building like support elements especially in the first story.

Figure 4. Instance of residential masonry building damaged due to the inadequate amount of bearing walls.

4.3. Deficiencies in Roofs

As mentioned in section 2, jack-arch and one-way slab combined with joists are two common roof systems in masonry buildings in Iran. Integrity of roofs and connection between roof and supporting walls are two issues that are highlighted by the official codes. Due to the intrinsic structure and common construction method, one-way slabs are known as integrated roof system, which has adequate in-plane stiffness. However, traditional methods of construction make the jack-arch roofs vulnerable under seismic load. Figure (6) shows some of

(a) (b) (c) (d)

Figure 5. Instance of damages due to the inappropriate use of openings.

(a) (b)

Figure 6. Low integrity of jack-arch roofs.

damages caused by weakness of this type of roofs.

Connection between roof and supporting walls are another issue that takes a key role in performance of masonry buildings. As declared in Iranian seismic code and NBRI-8, it is necessary to set a concrete or steel tie-beam as interface elements between roof and supporting walls in order to establish a reliable path for inertia forces of roof to be transferred to supporting walls. The joists of roof should be restrained by connecting to the tie-beam in an appropriate manner. According to the observations, in many cases, regulations of Iranian seismic code and NBRI-8 about the connection of roof and supporting walls were ignored and caused damages to masonry buildings. A masonry building consists of jack-arch roof, placed on masonry walls is shown in Figure (7a). The absence of interface tie-beam caused sliding of roof on supporting walls. Another instance of weak connection between roof and its supports is shown in Figure (7b).

It should be noted that in some cases, the roof detachment from supporting walls saved the masonry building from further damages. Figure (8) shows a case of masonry building in which roof-wall detachment in early excitations led to a reduction in the seismic forces acting on the masonry walls and prevent more damages in building.

4.4. Defects in Confining Elements

Defects in confining elements in CM buildings were another source of damages. The main defects in concrete confining elements are as follows:

- Poor quality of the concrete used in tie-beams and tie-columns: According to observations, segregation and honeycombing in RC confining elements were observed as the result of poor mixing of concrete, poor aggregation, insufficient cement and high water/cement ratio of concrete (Figures 9a and 9b).
- Failure to comply with the regulations about the standard hook of reinforcement bars: Code regulations about standard hooks in official codes consist of radius and angle of bent of bar and length of bar that continues after the bent. These regulations are prescribed in order to transfer the stress between concrete and reinforcement bars. Ignoring proper anchorage of the tie elements reinforcement causes early collapse of masonry buildings as shown in Figure (9c).
- Failure to comply with the regulations about the connection of confining elements: connections between tie-beams and tie-columns takes a key role in integrity of CM walls. Iranian seismic code introduces regulations about the connections of confining system. Damages caused by ignoring these regulations are shown in Figure (9d).
- Excessive spacing of transverse reinforcements: As mentioned in Iranian seismic code, maximum spacing of stirrups should be less than the depth of concrete element and 25 cm. This limitation is decreased to 15 centimeters in critical length near the connections. As can be seen in Figures (9c)

(a) (b)

Figure 7. Disconnection between roof and supporting wall.

Figure 8. A case of detachment between roof and supporting wall led to a reduction in the seismic forces acting on the masonry walls.

Figure 9. Instances of defects in confining elements and resulting damages.

and (9e), excessive spacing of transverse reinforcement throughout the tie elements was responsible of some damages and failures in masonry buildings.

- Insufficient integration between wall and confining elements: in confined masonry buildings, integration between wall and confining columns are provided by toothing the interface between wall and column or by using the dowel bars crossed within the column to the wall. Lack of attention to these instructions had negative effect on confining behavior and caused damages (Figure 9f).

4.5. Inappropriate Extension of Existing Buildings

In some cases, the existing buildings are extending by adding new stories (vertical extension) or increasing the occupied area (horizontal extension) by the owners. According to Iranian seismic code, the horizontal extension should not violate the regulations about symmetry, length to width ratio and projections or setbacks of plan. In many horizontally extended buildings in earthquake affected area, implementation of separation joints caused the above-mentioned regulations to be satisfied. However, vertical extension caused damages in some cases. Adding new stories to an existing building increases the mass of structure and the inertia force that developed during the earthquake. Ignoring the code-based regulation for building extension, causes the existing walls not to be able to withstand the developed forces. Figure (10a) shows a masonry building that is extended vertically by adding a new story on the old existing part. Damages in the old part of building can be seen in Figure (10b). This building is tagged as highly damaged by the IIEES earthquake damages assessment team. Another instance of masonry building that is damaged due to aforementioned reason is presented in Figure (11a). Another


(a) Exterior View of the Building


(b) Interior View of the Building

Figure 10. An instance of vertical extension of existing masonry building.


(a)


(b)

Figure 11. Other instances of vertical extension of existing masonry building.

defect in vertically extended buildings is the use of material or structural system that is different from old section's one. This issue cause in irregularity in height of the building and is the responsible of some damages (Figures 10a and 11b).

4.6. The Use of Unreinforced and Unconfined Masonry Buildings

According to NBRI-8, construction of unreinforced and unconfined masonry buildings is allowed only in the zone with low level of relative hazard of seismicity [5]. Although Sarpol-e Zahab and Ezgeleh are located in a zone with high level of relative seismic hazard [1], the majority of masonry buildings, even the new ones were unconfined and unreinforced, which caused many human and financial losses.

4.7. The Use of Poor Quality of Materials

Masonry walls are made of two main parts: mortar and masonry units. In the case of confined masonry walls, concrete confining elements are another elements that play an important role in structural behavior. Poor quality of materials of mentioned components was the main cause of damages in many cases. Generally, the strength of masonry units are greater than the strength of mortar and limited weakness in masonry units does not have much impact on structural behavior of masonry buildings. By contrast, weakness of mortar reduces the integrity between mortar and masonry units and causes damages in masonry walls. Figure (12) presents cases of damages due to the weakness in used mortar. Poor quality of concrete of confining elements was another factor of damages in confined masonry buildings, which was investigated in pervious sections.

5. Performance of Unreinforced Masonry Buildings

As mentioned earlier, URM walls have poor performance under seismic loads and consequently are banned to be used in the zones with high and very high relative hazard of seismicity. Although the area affected by the Sarpol-e Zahab - Ezgeleh earthquake is located in the zone with high relative hazard of seismicity [1], URM walls are widely used and suffered significant damages. The out-of-plane and in-plane response of URM walls are investigated in this chapter.

5.1. Out-of-Plane Performance of URM Walls

Masonry walls that are subjected to the normal seismic actions are faced to out-of-plane (OP) modes of failure. Various types of cracks and collapses can be occurred during the OP performance of URM walls, depending on several parameters such as dimension of the wall (absolute and relative values of length, height and thickness of the wall), material property, existing and location of openings, boundary conditions and in-plane stiffness of overhead diaphragm [6]. Some instances of OP failure of URM walls are presented and investigated in this section.

Weak corner bond is one of the main causes of OP damages in URM walls. As can be seen in

(a)

(b)

Figure 12. Instances of the use of poor quality mortar and resulted damages in masonry walls.

Figures (13a) to (13c), lack of proper interlock between masonry wall and returned wall caused OP collapse. Figure (13d) shows a masonry wall with proper corner bond. However, high mass of the wall resulted high amount of OP inertia force and caused OP collapse of the wall. In the case of Figure (13c), long unsupported length of the wall is another reason of OP collapse. The issue of the walls with long unsupported length caused damages in many cases of the surrounding walls especially of schools' yard. Instances of the walls that collapsed due to the long unsupported length is presented in Figures (13e) to (13g).

The staircase walls in roof or roof access enclosure (which is called "Kharposhte" in Farsi), is one of the most vulnerable part of buildings in term of the OP failure. These staircase walls are intrinsically located at top level of the building and

(a) (b) (c) (d) (e) (f) (g)

Figure 13. Instances of OP failure of URM walls.

consequently are affected by larger amount of inertia forces than the lower stories. This cause more OP damages in roof staircase level. Some instances of damages in these walls are presented in Figure (14). In many cases, the damages caused debris to fall into the stair case and blocked the way out of the inhabitants (Figures 14b and 14d).

5.2. In-Plane Performance of URM Walls

Various parameters such as wall aspect ratio, vertical axial compressive force acting on the wall, absolute and relative strength of materials of mortar and masonry blocks and boundary conditions are effective on the seismic performance of the URM wall and may result various in-plane failure modes under extreme seismic loads [4, 7]. There are various classifications of in-plane failure mode of URM in recent researches [1-2], but in a general view, in-plane failure modes of URM walls can be categorized as Diagonal Shear (DS), Sliding Shear (SS) and Flexure (F).

5.2.1. Diagonal Shear Failure

Diagonal Shear (DS) failure appears as diagonal cracks which may be developed either through masonry blocks (which is known as diagonal tension failure) or through bed and head joint (which is known as stair step crack). The case of diagonal tension cracking has rarely happened in Sarpol-e Zahab - Ezgeleh earthquake. This was due to the fact that the strength of masonry blocks (brick, clay or cement tile or stone) is normally greater than the strength of mortar. By contrast, the stair step cracking is the most common failure mode of URM walls. Figure (15a) shows an instance of DS failure mode appeared as stair step cracking. Figure (15b) shows a wall that half of its height is covered by overlay of ceramic tiles and cement grout. Presence of this layer of overlay forced the X pattern of cracking to be developed on the top part of the wall. DS failure mode in the piers near the openings is shown in Figures (15c) and (15d).

Figure 14. Instances of failures in roof access enclosures.

5.2.2. Sliding Shear Failure

Sliding Shear (SS) is known as a ductile mode of failure in masonry walls [4]. Poor quality of mortar and low vertical load acting on the wall are main reasons of occurrence of SS failure mode. Figure (16a) shows an instance of SS failure mode developed in horizontal plane form. In many cases, horizontal plane of SS were formed on the top level of the wall. It is necessary to note that the presence of overlays that increase the lateral stiffness of the wall can change the pattern of SS failure. As shown in Figure (16b), the use of overlay of stone

(a) (b) (c) (d)

Figure 15. Instances of diagonal shear failure mode of URM walls.

(a) (b)

Figure 16. Instances of sliding shear failure mode of URM walls.

and cement grout in bottom half of the wall, forced the horizontal plane of crack to be developed in the margin of the overlaid part.

5.2.3. Flexural Failure

In the case of slender walls or walls with high shear resistance, flexural failure mode would be likely to be occurred. Various events like cracking in the heel, overall rocking of wall and compression cracking in the toe may be occurred in this mode of failure. It should be noted that, typically, flexure failure comes with other failure modes. Due to the material and geometric properties of walls, flexural failure mode rarely observed due to this earthquake. One case of this mode of failure is shown in Figure (17).

6. Performance of Confined Masonry Buildings

Typically, confined masonry (CM) buildings consist of masonry walls surrounded by vertical and horizontal reinforced concrete (RC) elements, which are known as tie-columns and tie-beams. The key feature for appropriate performance of CM walls is the integrity of the masonry part and RC elements. As mentioned before, generally, CM buildings which observed the regulations of the seismic design codes (Iranian seismic code and NBRI-8) had acceptable seismic behavior. Figures (18a) and (18b) presents the cases of single and multi-story CM buildings showing proper performance during the earthquake. Two cases of CM buildings and adjacent damaged RC moment resisting frames (MRF) are shown in Figures (18c) and (18d). In the case of Figure (18c), RC MRF was entirely collapsed due to the soft-story in contrast to the masonry building. Presented instances show that well-designed and executed CM buildings are able to ensure acceptable performance during the earthquake.

Figure 17. Instance of flexure failure mode of URM wall.

Although CM building generally had proper performance during the earthquake, some of well-designed CM buildings are damaged due to the severity of the occurred earthquake. Depending on direction of external forces, two types of failure modes of CM walls may be occurred: out-of-plane (OP) and in-plane (IP) failure modes. Instance of each of these sub-divisions is presented and investigated in following sections.

6.1. Out-of-Plane Performance of CM Walls

One type of OP damage of CM walls is related to the inertia forces developed in the wall due to the mass of the wall and OP seismic induced acceleration [7]. Typical crack pattern of this type of OP damages is presented in Figure (19a). Instance of this type of damage is shown in Figures (19b) and (19c). This type of OP failure mode, mostly observed in upper stories of CM buildings which induced acceleration are greater than lower stories. Another type of OP failure mode of CM walls may be observed in the CM masonry buildings with rigid diaphragm and large drifts in stories. Due to the integrity between the masonry wall and the confining elements in CM buildings, the drift of the story can be transferred to the walls and cause OP failure of masonry walls in the case of large drifts orthogonal to the plane of the wall.

6.2. In-Plane Performance of CM Walls

6.2.1. Shear Failure

Shear failure of CM walls, generally emerges in the form of diagonal cracks that may either be path from masonry units or mortar bonds. Mechanical

Figure 18. Instance of confined masonry buildings with good performance.

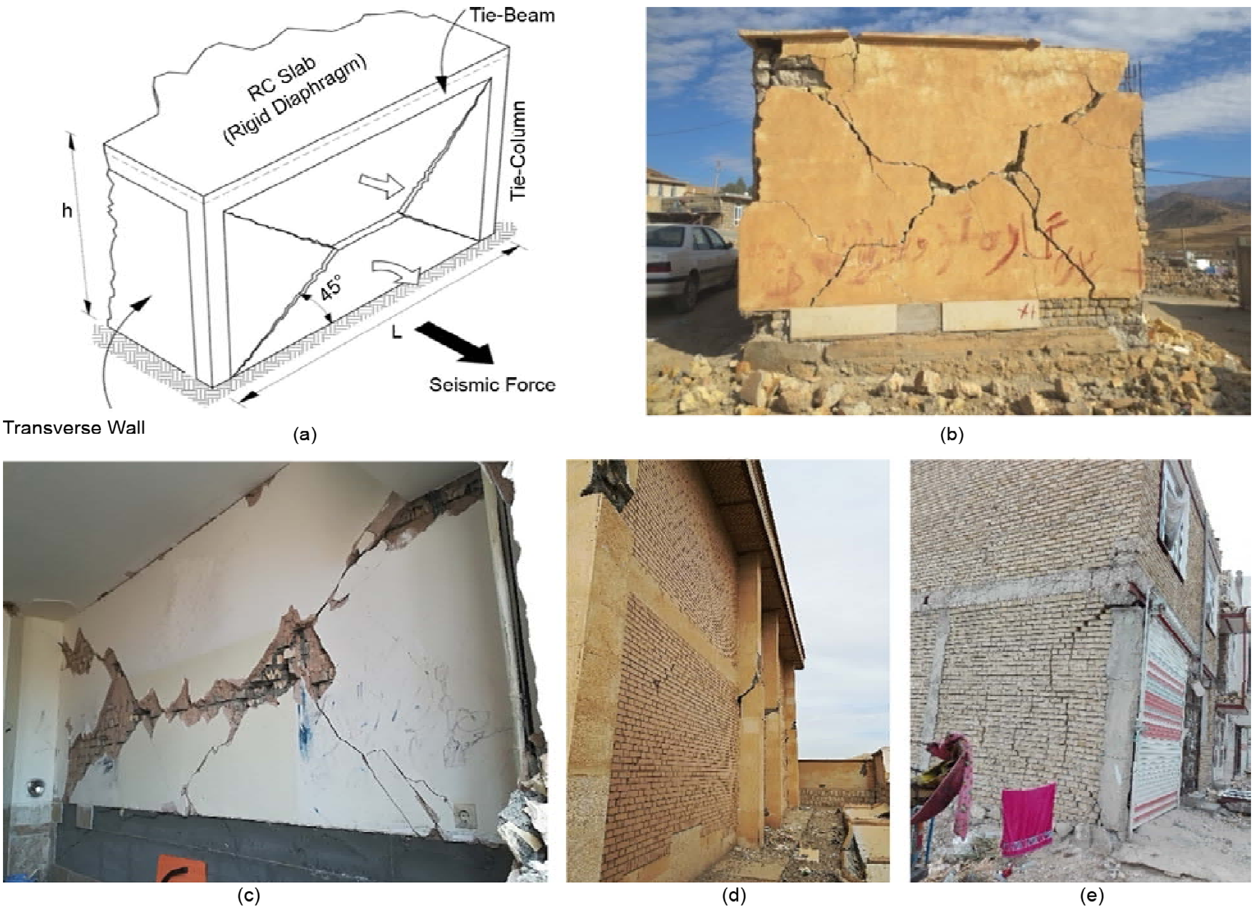

Figure 19. (a) Typical crack pattern of OP failure of CM walls due to the inertia force [8], (b, c) Instances of OP damage of CM walls due to the inertia force, (d, e) Instances of OP damage of CM walls due to the large inter-story drifts.

(a) (b)

Figure 20. Instances of shear failure of confined masonry walls.

properties of tie-columns and the amount of integrity between tie-columns and masonry walls play the key role in seismic behavior of CM walls [8]. Generally, the shear failure of CM walls are initiated by forming diagonal cracks in masonry part of the wall and ends with propagating the cracks to RC confining elements. This type of failure is the most common failure mode of CM walls in Sarpol-e Zahab - Ezgeleh earthquake. Instances of this failure mode are presented in Figure (20).

6.2.2. Flexural Failure

Another failure mode of CM walls is known as flexural failure mode and associated damages are mostly due to the tension and compression stresses resulting from the combination of axial force and bending moment acting on the wall. Because of the mechanical properties of masonry materials and geometric properties of masonry walls that are commonly used in earthquake affected area, flexure failure mode of CM walls is rarely occurred. An instance of this type of failure is presented in Figure (21). As can be seen, compression stresses caused toe crushing in the both of brick and RC parts of CM wall.

7. Analytical Investigation of a Real Case

In this section, a case study of damaged pier is investigated based on the regulations of FEMA 356 [9] and Iranian Code-360 [10] in term of strength in order to find out the correspondence between these regulations and what happened in reality. Based on FEMA 356 [9], expected lateral strength of an unreinforced masonry pier is the lesser of strengths based on expected bed-joint sliding shear strength or expected rocking strength and the lower bound strength of masonry pier is the lesser of the strength values based on diagonal tension stress or toe compressive stress. If the expected lateral strength of the masonry pier is less than the lower bound lateral strength, the component is known as displacement control and in the opposite case, the component is known as force control. In another view, the lesser of four aforementioned strength value declares the failure mode of the masonry pier. The strength value corresponding with this failure modes can be calculated as:

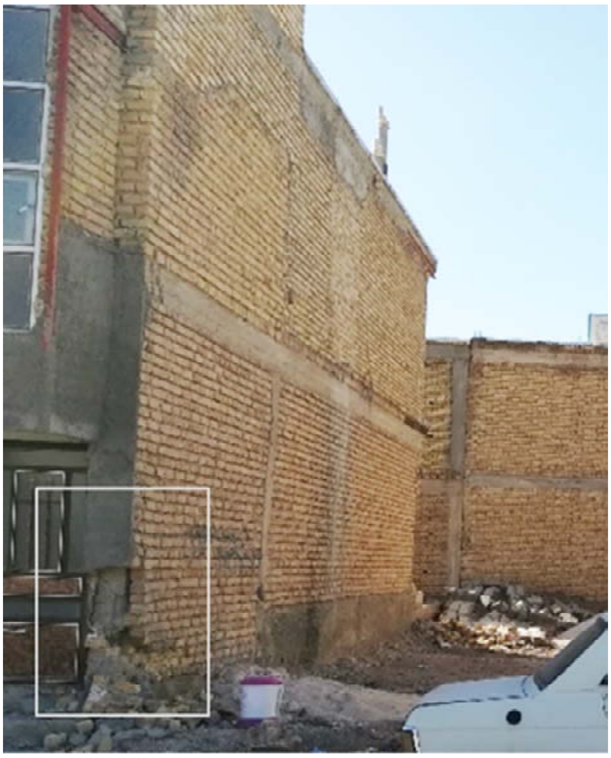

Figure 21. Instance of flexure failure mode in CM wall.

$$V_{bjs} = v_{me} A_n \tag{1}$$

$$V_r = 0.9\,\alpha\, P_E \left(\frac{L}{h_{eff}}\right) \tag{2}$$

$$V_{dt} = f'_{dt} A_n \left(\frac{L}{h_{eff}}\right) \sqrt{1+\frac{f_a}{f'_{dt}}} \tag{3}$$

$$V_{tc} = \alpha\, P_E \left(\frac{L}{h_{eff}}\right)\left(1-\frac{f_a}{0.7 f'_m}\right) \tag{4}$$

where V_{bjs}, V_r, V_{dt}, V_{tc} are the lateral strength of masonry pier corresponding to bed-joint sliding shear, rocking, diagonal tension and toe crushing failure modes respectively, A_n is the area of net mortared/grouted section, h_{eff} is the effective height to resultant of lateral force, L is the length of the pier, PE is the expected axial compressive force due to the gravity loads, vme is expected bed-joint sliding shear strength based, α is factor equal to 0.5 for fixed-free cantilever wall, or equal to 1.0 for fixed-fixed pier, f_a is axial compressive stress due to the gravity loads, f'_{dt} is lower bound masonry diagonal tension strength, f'_m is lower bound masonry compressive strength, *PL* is lower bound axial compressive force due to the gravity loads.

A case of masonry pier that is damaged in the diagonal manner is presented in Figure (22). In site survey is not conducted on this case; however, the values of f'_{dt}, f'_m can be obtained based on the default values presented in Iranian Code-360 for masonry walls for different conditions of materials used in masonry wall (poor, mediocre and good condition). Based on the observation of exposed condition, the materials of pier are in poor condition and the values of 0.03 and 2.6 MPa can be used for f'_{dt}, f'_m respectively. The value of v_{me} is not available and consequently the value of V_{bjs} cannot be calculated. The pier has dimensions of 3600-2200-200 mm as length, height and thickness, respectively. The gravity load of the roof that induced to the pier is about 45 kN, and the pier has the weight of about 37.5 kN. Consequently, P_E and f_a equal 82.5 kN and 0.108 MPa respectively. In addition, the pier has the fixed-fixed condition and α equals 1.

Considering above-mentioned values for variables used in Equations (1) to (4), the value of V_r, V_{dt}, V_{tc} are obtained as 121.5, 75.6, 127.8 kN, respectively.

Figure 22. The case study of masonry pier.

Based on these values, one can predict the occurrence of diagonal tension failure in this pier. As can be seen in Figure (22), the dominated failure mode is diagonal sliding mode that is consistent with the result concluded by calculations. It should be noted that there are signs of sliding shear failure mode in this pier, indicating that the value of V_{bjs} is close to the value of V_{dt} and consequently vme equals 0.1 MPa approximately.

8. Conclusion

Performance of masonry buildings in the November 2017 earthquake in Sarpol-e Zahab - Ezgeleh (M_W 7.3) is investigated in the current paper. All of the presented data are based on field observations of earthquake damages assessment team of IIEES. Based on observations, unreinforced masonry (URM) and confined masonry (CM) buildings are the most common type of masonry buildings that were used in earthquake affected area. Official regulations of design and construction of masonry buildings in Iran do not permit the URM buildings to be used in the zones with high and very high relative hazard of seismicity; however, the URM buildings were used widely in earthquake affected area (which categorized as the zone with high relative hazard of seismicity) especially in rural areas and caused a lot of economic and financial losses. Moreover, defects in design and construction of masonry buildings such as inappropriate use of openings, utilization of unintegrated and weak roofs, failure to comply with the regulations of connection between roof and supporting walls, failure to comply with the regulations about confining elements, the utilization of inadequate amount of bearing walls, inappropriate extension of existing buildings and the use of poor quality materials were responsible for damages, which are investigated in this paper. Most of the mentioned defects are the result of poor construction by uneducated workmanship and the lack of proper monitoring of building construction by officials. It should be noted that in many cases of well-designed CM buildings had an acceptable performance and the use of these types of buildings should be considered instead of the use of detail-sensitive structures such as steel and concrete moment resisting frames in low rise rural and urban structures.

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