

## SEISMIC PERFORMANCE OF SCHOOL BUILDINGS IN 2017 EZGELEH EARTHQUAKE, IRAN

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### ABSTRACT

Due to the high number of students and the possibility of a high death toll during an earthquake, school buildings are considered as highly important structures in most of today's seismic codes. The constituents of the structures of these buildings including the load bearing walls and the steel/ concrete components have to be designed so that they are at least capable of life-safety structural performance in the face of strong earthquakes. Meanwhile, due to their significant effects on the response of the structure, the performance of load-bearing and infill walls is particularly important. Observations from educational facilities after the Ezgeleh earthquake of November 12<sup>th</sup>, 2017 have revealed that the school buildings with unconfined load-bearing wall structural system located in near and far fields of the earthquake have sustained the highest level of damage. Schools with steel and reinforced concrete (RC) structural systems have fared much better in terms of seismic performance and damage. In this study, in addition to the specifications of the 2017 Ezgeleh earthquake, the structural systems and the infill walls used in the educational facilities in the earthquake – affected areas are introduced. Then, the performances of different school buildings with varying structural systems located in the far and near fields of the earthquake were investigated. The results obtained from field observations have been summed up and presented.

### INTRODUCTION

On November 12<sup>th</sup>, 2017 at 21:38 (local time), a huge earthquake with the moment magnitude of 7.3 on the Richter scale, an epicenter located near the Iraqi border (34.81 N, 45.91 E) and 130 km away from the city of Kermanshah and a hypocentral depth of 18 km took place (Figure 1a). This earthquake claimed the lives of 620 individuals, injured over 12000, destroyed thousands of buildings, and rendered tens of thousands of the inhabitants homeless.

Based on the geological reports, the earthquake occurred in the vicinity of the Zagros fold and thrust belt. At the location where the earthquake occurred, the Arabian plate moves northward relative to the Eurasian plate at a speed of about 26 mm per year. The fault in the region runs along the Northwest-Southeast direction, with reverse mechanism and a rightward strike-slip component. Investigations have shown that the movement of the slippage has been from the northwest to the southeast, i.e., from the epicenter toward the city of Sarpol-e Zahab (37 km southeast of the earthquake's epicenter) which has resulted in the majority of the damage and casualties being concentrated in this city. The earthquake gave rise to phenomena such as landslide and rockfall, and in some parts along the bank of the river traversing the city of Sarpol-e Zahab, liquefaction was seen [1].

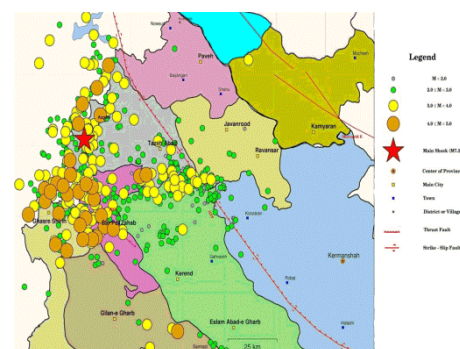
Approximately 43 minutes before the main earthquake struck, a foreshock with the moment magnitude of 5.4 on the Richter scale occurred. After the occurrence of the main earthquake, over 1800 aftershocks with magnitudes ranging from 2 to 5.5 on the Richter scale took place in the region. The distribution of these tremors is depicted in Figure 1b.

More than 110 seismographs in Iran recorded the acceleration of this earthquake. The Sarpol-e Zahab station (34.4598 N, 45.8686 E), positioned 39 km from the epicenter of the

earthquake, measured the ground movement. The effective duration of the earthquake was about 11 seconds.



(a)

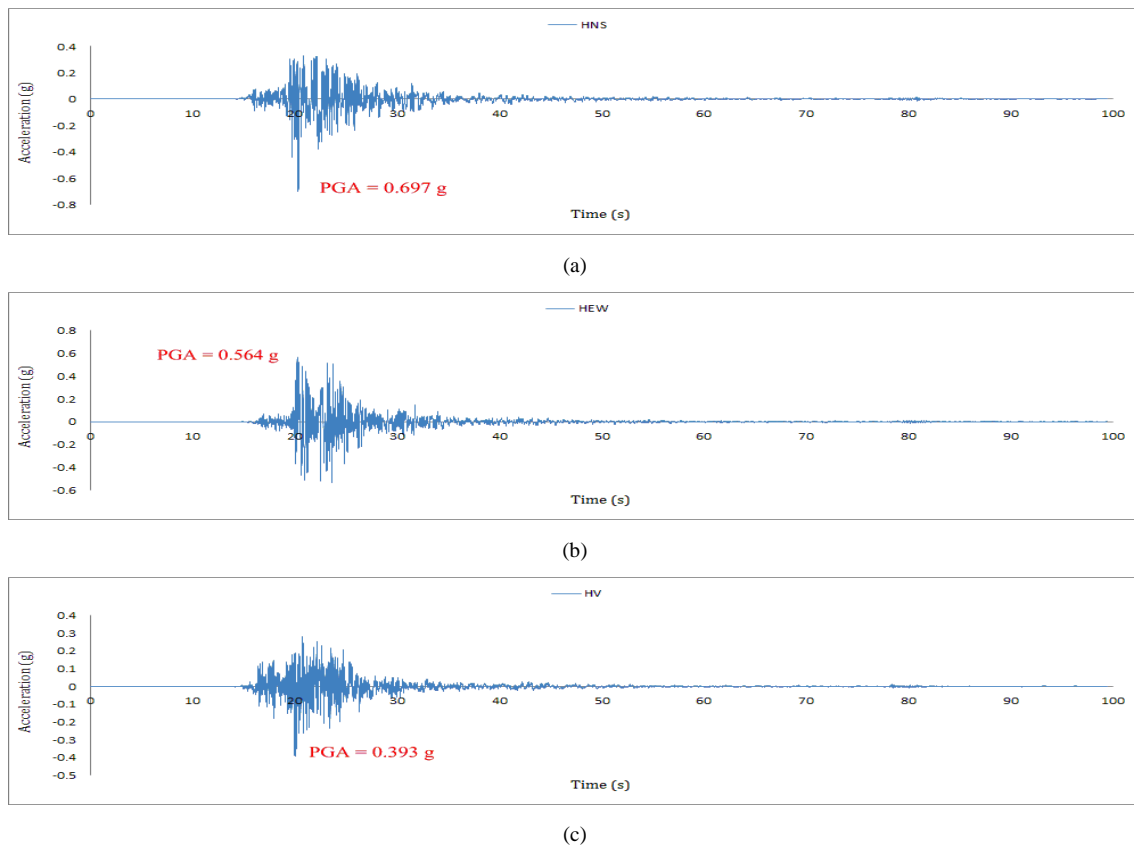


(b)

Figure 1: (a) Location of the epicenter of the main shock on November 12<sup>th</sup>, 2017. (b) locations of the aftershocks of the Ezgeleh earthquake [2].

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**Figure 2: Acceleration history recorded at the seismograph station nearest (about 39km) to the epicenter of the earthquake. (a) horizontal North-South acceleration (HNS); (b) horizontal East-West acceleration (HEW); (c) vertical acceleration (HV) [3].**

The maximum horizontal accelerations recorded by this station in the North-South and East-West directions were HNS= 0.697 g and HEW=0.564 g, respectively. Also, the maximum vertical displacement was measured at HV=0.393 g. These values show that the seismic excitation applied to the buildings was far greater than the PGA values recommended by the old and recent seismic codes (Figure 2).

An important aspect of this earthquake was the level of damage it inflicted upon the buildings located close to the fault and the epicenter of the earthquake, which was quite lower than the buildings in Sarpol-e Zahab, which is located 39 km away from the epicenter. This can be attributed to factors such as faulting type, earthquake orientation, the distance between the location of the structure and the fault, soil type, and the characteristics of the earthquake record including frequency content, duration, amplitude, and the dynamic properties of different structures.

The corresponding response spectrum of the three components, with 5% of damping is shown in Figure 3. The amplification region in the response spectrum diagram is between 0.1 to 0.5, which, for the predominantly short buildings of Sarpol-e Zahab city, is very critical.

Numerous reports have been reported on the performance of structures against past earthquakes and the post-earthquake observations have been presented. In a study, Dizhur et al. [4] evaluated the performance of unreinforced and reinforced masonry structure during the 2010 Darfield earthquake. In that study, a brief history of the city of Christchurch including information about the unreinforced masonry as a popular building material and also an estimation of the number of unreinforced masonry buildings in the Canterbury area were provided.

Then, an overall outlook of the observed collapse patterns in unreinforced masonry brick buildings and masonry rock buildings in the Christchurch area after the 2010 Darfield earthquake was presented. Case studies were carried out on the damage inflicted on 5 unreinforced masonry buildings that had not been retrofitted prior to the earthquake. Also, the performance of 8 retrofitted buildings, along with the detailings of the buildings and retrofitting techniques were explained. The case studies included moment resisting frames, steel strong backs and strapping, diaphragm anchoring, surface bonded fiber reinforced polymer (FRP) sheets, and cavity ties.

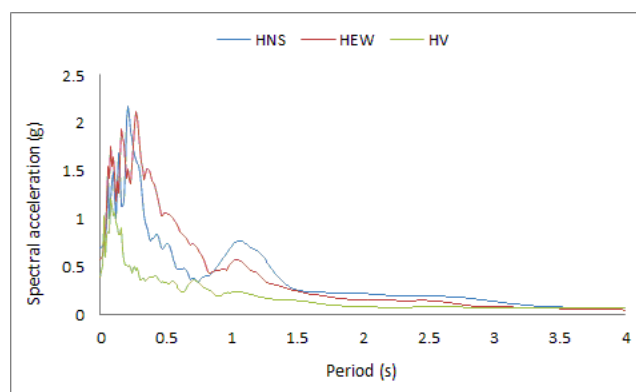
In another study, Bothara et al. [5] reported their post-earthquake observations after the 2009 Padang earthquake. Among the reported information were the occurrence time of the earthquake, the magnitude, casualties, and the destruction of public and governmental buildings. Then, a team of 10 reported their observations of the area and their evaluation of the safety of the buildings. The reports of this team were on the city of Padang and the other areas stricken by the earthquake. The study presents the observations and evaluations of the team regarding the reasons causing the collapse of buildings subjected to average and strong earthquakes.

Dizhur et al. [6] studied the performance of masonry buildings and churches after the Christchurch earthquake of February 22nd, 2011. The study contains the report of an international team of researchers on the documentation and interpretation of the damage sustained by masonry buildings and churches. The study focuses on failure patterns and collapse mechanisms. The details of the observations were on the performance and the defects that resulted in damage being sustained by 650 unreinforced masonry brick buildings, 90 unreinforced masonry rock buildings, 342 RC masonry buildings, 112 churches in the Canterbury area, and 1100 residential buildings

with masonry façades. Also, the details pertaining to the retrofitting techniques adopted prior to the February 22nd earthquake in the unreinforced masonry buildings in Christchurch were presented. Some brief recommendations regarding proper modification techniques for masonry rock buildings were provided as well.

The typologies and the failure states observed after the 2015 Gorkha earthquake in Nepal were studied by Dizhur et al. [7]. The study first presents the characteristics of the earthquake including the time of occurrence, magnitude, capital loss, casualties, and the destruction of public and governmental buildings. Then, a number of documents related to the observations after the 2015 Gorkha earthquake and its aftershocks were published. Also, the typologies of the buildings and the failure states observed at the time of inspection were also briefly reported by the authors. Afterwards, comparisons were drawn between the damaged unreinforced masonry buildings and the macro-element collapse states using multiple images and schematic examples. A brief investigation of temporary shoring techniques was also carried out.

In this study, using the data gathered from field observations after the 2017 Ezgeleh earthquake in Iran, the performance and seismic response of different school buildings were assessed. The studied structural systems include infill walls in steel or RC frames and load-bearing walls.



**Figure 3: Response spectrum of ground motion components recorded in the November 12th, 2017 Ezgeleh earthquake, Iran.**

### STRUCTURAL SYSTEMS USED IN IRANIAN SCHOOL BUILDINGS

In Iran, different structural systems are used in the design and construction of buildings. All buildings in Iran are designed and built in accordance with the Iranian seismic design code (the 2800 standard) [8]. School buildings in Iran are mostly constructed using steel or RC structural systems or the confined load-bearing wall. The Iranian seismic design code considers school buildings as “highly important”, with their construction processes being continuously supervised by engineers. The quality of the materials used in the schools is also controlled by material labs. The design and construction of school buildings in Iran are presided over by the ODRS (Organization for Development, Renovation, and Equipping Schools of I.R. Iran), which is a subsidiary of the Ministry of Education. The details of each of the structural systems are provided in the followings.

#### Load-Bearing Wall Structural Systems

Unconfined masonry structures have long consisted of a significant portion of the buildings constructed in Iran, especially in small cities. Unconfined masonry structures are composed of a series of walls with no vertical or horizontal RC confining elements. In these buildings, due to the absence of the confining elements, the walls and the ceiling are not connected and therefore cannot exhibit a monolithic behavior against lateral forces. Many of the schools in the areas struck by the

Two months after the Ezgeleh earthquake in Iran on November 12th, 2017, almost all of the school buildings (numbering 417 schools) in both urban and rural areas affected by the earthquake were visited and assessed. Reports of the field observations and the damage inflicted on the school building have been compiled and are available.

In these investigations, information such as the geographical location and coordinates of the schools, the distances between the schools and the epicenter of the earthquake, catalogued earthquake records, structural systems of the school buildings, age of the buildings, concordance of the design of the buildings with existing design codes, different types of damage caused by earthquake, etc. and also photographs were gathered and documented.

Finally, a report is presented on the seismic performance and damage sustained by school buildings located at different distances from the epicenter of the earthquake. The criteria by which the seismic performances of old (schools with the structural age of 25 years or more) and new (schools built after the introduction of the Iranian seismic design code) schools are evaluated are Life Safety (LS) and Immediate Occupancy (IO), respectively. To that end, some of the properties of the materials used in the schools and also their construction methods have been assessed.

earthquake lack these confining elements and have sustained considerable damage as a result.

With the advent and development of seismic design codes, the construction of a new type of reinforced masonry structure became prevalent. Based on the Iranian seismic design code, the load-bearing masonry walls in this type of building are confined on four sides by RC tie columns and tie beams. In this system, the masonry wall is responsible for transferring the gravity load from the ceiling to the foundation, and it also acts as the component withstanding lateral loads. Horizontal and vertical ties are the masonry wall’s restricting elements, and in addition to improving its strength and monolithic behavior, they prevent the total collapse of the wall during an earthquake.

The construction procedure of this type of structure is as follows: first, the lower horizontal RC confining element, which also acts as the foundation of the wall, is implemented. Before concreting the lower horizontal confining element, the dowel bars of the vertical confining element are prepared and placed at specific distances. Afterward, the masonry walls are constructed and the vertical confining elements are concreted. The upper horizontal confining elements and the ceiling slabs are then simultaneously concreted (Figure 4).

Confined masonry walls are generally used in one and two-story buildings. Height and story number limitations for these buildings are considered in many design codes. In Iran, the

height of the building is limited to 8 m, with the structure consisting of a basement and a maximum of 2 stories. This type of structural system is mostly used in rural schools or small urban schools.

Generally, the performance of these structures has been more or less desirable in many of the past earthquakes, and the collapse of confined masonry buildings has been predominantly due to different constructional deficiencies such as the inadequate implementation of confining elements and their faulty connection of the ceiling.

### Steel and RC Frame Structural Systems

These structural systems, which are commonly employed in large urban and rural school buildings, are designed and built using steel and RC frames. In school buildings with steel frames, beams and columns are responsible for gravity loads, and moment resisting frames, steel braces, and RC shear walls or a combination of them carry the lateral loads. In the RC frame structural system, as well, moment resisting frames, RC shear walls, or a combination of the two are used to withstand lateral loads (Figure 5).



*Figure 4: Schools with confined load-bearing wall structural system.*



*Figure 5: Schools with (a) steel and (b) RC frames.*

### Infill Walls in Steel and RC Structures

To parcel out internal spaces in a building or to separate the inner and outer spaces in steel and RC structures, infill walls are used. In these structures, infill walls are constructed after the complete implementation of the structure and the ceiling. Infill walls were previously built using masonry materials. The bricks used were perforated clay bricks which were employed to decrease the weight of the building (Figure 6a). The main deficiencies of these walls are the lack of monolithicity and brittle behavior which cause them to collapse during an earthquake. Today, new materials are used in the construction of infill walls. A new type of light wall prevalently used in educational buildings is the sandwich panel wall, known in Iran as “3D panels”. These panels include an expandable polystyrene core with the nominal density of  $15 \text{ kg/m}^3$  and a thickness of 40 to 100 mm. On each side of the core, a mesh of

welded steel wires with a diameter of 2.5 to 6 mm is on each side of the core. The meshes are connected to each other using shear absorbing wires (Figure 6b). After being installed inside the frames, the panels are covered with a layer of shotcrete (Figure 6c).

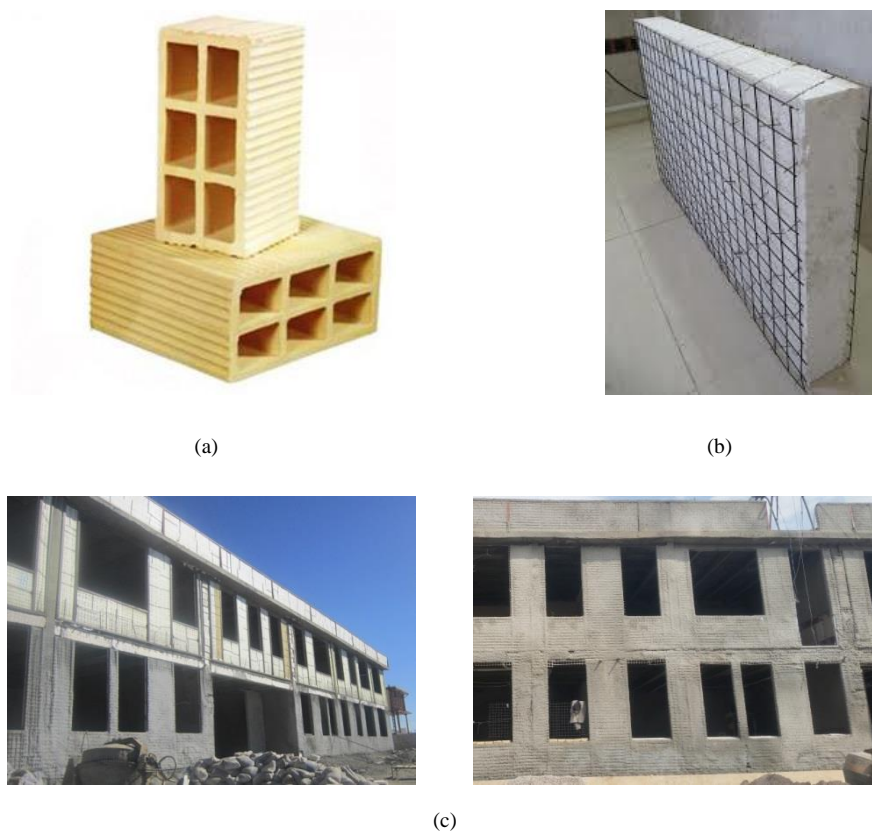
### Infill Walls and Their Effect on the Seismic Response of Structures

In RC or steel frames, the walls parceling out the inner spaces or the ones separating the inside of the building from outside can either be light (such as 3D panels, light plaster panels, etc.) or heavy (masonry). The types of materials used in infill walls notwithstanding, in most cases, design codes either do not take into account the effects of these walls or they only consider their influence on the period of the structure, without accounting for their global or local effects. Therefore, the structures are mostly

designed as a bare frame. Nonetheless, if the partition is made of brick and is connected to the frame, the behavior of the structure would be different from that of a bare frame due to changes in stiffness, strength, ductility, etc.

Studies on frames with infill walls in the past 50 years have revealed that the existence of infill walls, their connection to the surrounding frame, and the material from which they are built have important effects on the behavior of structural frames. In other words, stiffness, strength, ductility, and energy dissipation capability in a frame are severely influenced by infill walls [9 – 16]. Also, the presence of openings, their shapes and locations influence the response of the structure and the parameters affecting the behavior the frame [17 – 19]. The 2017 Ezgeleh earthquake in Iran once again showed that infill walls have an important role in the seismic response of structures.

Schools in rural areas are mostly single-story buildings, and in urban areas, they are built with two or three (at the most) stories. The structures of rural school buildings are generally made up of unconfined masonry, confined masonry, steel with welded connections, and in some cases, steel with connections fastened with bolts and nuts. In schools in urban areas, with the exception of old masonry schools, other schools are either concrete structures or steel structures with welded connections or connections with screws and nuts. In these regions, the seismically resistant systems considered for most of RC or steel framed school buildings are RC shear walls and Concentrically Braced steel Frames (CBF). In recent years, different materials such as solid clay bricks, perforated clay bricks, hollow light clay blocks, and sandwich panels (3D panels) have been used in the construction of infill walls in schools. Considering that design codes change over the years, in most cases, there is no anchorage or connection between the infill and the frame.



**Figure 6:** Types of material used in infill walls of school buildings: (a) perforated clay bricks; (b) sandwich panel (3D panel); and (c) instances of sandwich panel infill walls implemented in school buildings.

Observations from the damage caused by the earthquake have shown that factors such as the distribution of infill walls in the plan and along the height of buildings also has a significant effect on different types of partial and total failures. Partial failure mechanisms include horizontal and diagonal cracks in the wall, the separation between the infill wall and the frame, and the collapse of small parts of the wall. Total failure, on the other hand, constitutes the complete of the collapse of the infill wall. In this study, different educational buildings with different structural systems and infill walls located in the areas affected by the November 12<sup>th</sup>, 2017 Ezgeleh earthquake in Iran were investigated. The damage inflicted on the buildings were evaluated by considering the fault region and the distance from the epicenter of the earthquake.

### BRICK FAÇADES IN SCHOOL BUILDINGS

In Iran, depending upon the structural system of the building, brick façades are implemented differently. In school buildings

with the load-bearing wall structural system, perforated clay bricks with the dimensions of 220\*110\*6 mm are commonly used. The façade layers (built with perforated bricks) are implemented simultaneously with the load-bearing walls (built with solid bricks). The perforated bricks form the outer (façade) layer and the solid bricks are the inner layer of the wall. Thus, the façade is an integrated part of the load-bearing wall (Figure 4).

However, in buildings with steel or RC frame structural systems, the façade layers are built after the completion of the structure and the infill walls. Therefore, the façade layer needs to be properly fastened to the wall and the structure to prevent its collapse during earthquake. In these types of buildings, bricks with the dimensions of 200\*30\*10 mm are used to construct the façade layer. In most of the old school buildings, there is no connection between the façade layers and the walls behind them, which has led to their collapse during previous earthquakes.

There are guidelines in Iranian design standards explaining how the façade layer should be connected to the main wall. Among the methods introduced are the use of L shaped rebars or galvanized steel mesh between the brick rows of the main wall, to which the façade layer is attached. The façade layers in the new school buildings built in recent years have been implemented based on these guidelines. Field observations after the 2017 Ezgeleh earthquake revealed that in new school buildings, where the façade layers were properly implemented, damage were inconsiderable (Figure 7).

### ASSESSING THE DAMAGE CAUSED BY THE EARTHQUAKE IN SCHOOLS LOCATED IN FAR AND NEAR FIELDS FROM THE EPICENTER

#### Schools Located within 10 km from the Epicenter

The cities and villages with a maximum distance of 10 km from the epicenter of the earthquake are assumed to be in the near

field of the earthquake and are shown in Figure 8. An assessment of the damage caused by the earthquake in the school buildings in these areas is brought in the following.

Near-field earthquakes have characteristics that distinguish them from far-field earthquakes. The accelerograms of these earthquakes contain long period pulses with strong amplitudes which can often be found at the beginning of the earthquake record [20]. In the Fourier spectrum of the accelerograms of near-field earthquakes, the spectral domain is maximized within a small range or, in a way, within a specific period. Because of this, in near-field earthquakes, the behavior of the structure exits the modal stage, where one or multiple modes of the structure determine the overall behavior and takes on a wave state, in which the behavior of the structure is determined by the sum of the effects of the waves passing through it [21].



Figure 7: Damage caused by the earthquake in schools with brick facades.

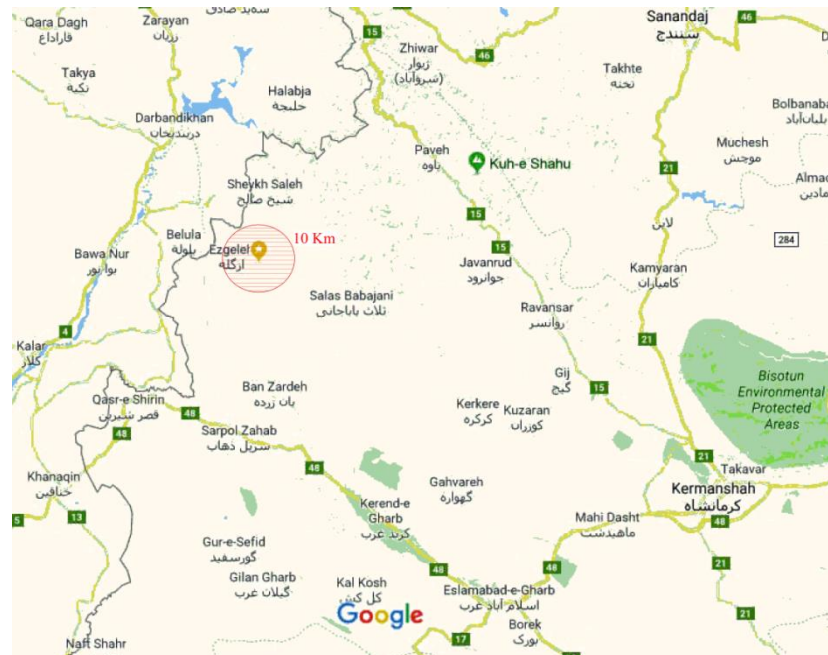


Figure 8: The near field of the fault within 10 km from the epicenter of the November 12th, 2017 Ezgeleh earthquake, Iran.



**Figure 9: Damage sustained by unconfined schools located within 10 km radius of the epicentre.**

The emergence of long period pulses with strong amplitudes at the beginning portion of the record points out a significant faulting-induced kinetic energy release in a short time period, which leads to a significant force being applied to the structure in a brief span of time. This is one of the most important characteristics of ground excitations in the near field of faults. This causes the materials used in construction to be subjected to impacts and the structure to display a more brittle behavior [22].

In the cities and villages close to the epicenter of the earthquake, due to the lower number of students, geographical conditions, and available materials, most schools are single or two-story buildings with the masonry brick wall structural system. Despite the old age of most of the schools in the region, the non-compliance of these structures by the requirements of new seismic design codes (the 2800 standard), the high intensity of the earthquake, and the particularly strong vertical component of the earthquake in the region, none of the schools went through total collapse. Therefore, the school buildings in this region have satisfied the Life Safety performance level. Most of the newly built schools have remained without damage. Some schools, however, had sustained considerable damage. The maximum damage in this area was inflicted on buildings with

the unconfined bearing wall structural system and also unconfined surrounding walls (Figure 9).

Most of the damage in unconfined school buildings located in the near field of the earthquake include diagonal cracks in the walls, separation of the brick rows and horizontal cracks in the walls, failure of the piers around the openings due to the short column phenomenon, slippage of the ceiling, and the separation of the ceiling from the walls.

Investigations carried out on the schools in the region have revealed that old school buildings (schools with the age of more than 25 years) that were horizontally confined and employed the load-bearing wall structural system, had sustained far less damage compared to unconfined masonry buildings. Schools with horizontal and vertical ties were either without or with little structural damage. In new schools built according to the latest design codes, the use of reinforcing steel bars in between the rows in the masonry wall, in conjunction with tie columns and tie beams fully connected to the walls, almost no damage was seen. Schools with steel structures and proper lateral anchorage and slightly-sloped ceilings satisfied the Immediate Occupancy performance level and had desirable performances during the earthquake, so much so that even the infill walls of these school buildings did not sustain any kind of cracking or damage (Figure 10).



Figure 10: Undamaged newly-built schools located within 10 km radius of the epicenter.

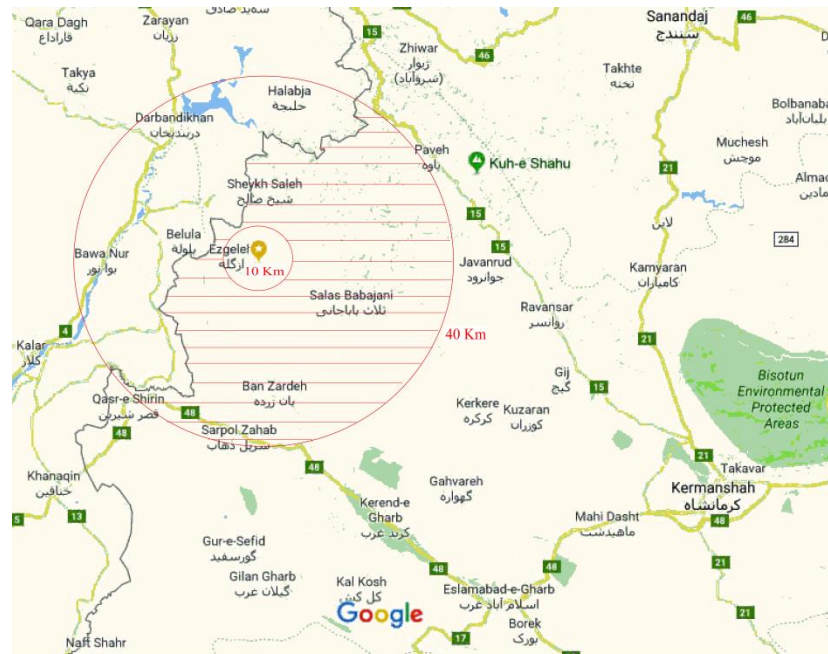


Figure 11: Area far from the fault located between 10 to 40 km from the epicenter of the November 12th, 2017 Ezgeleh earthquake, Iran.

### Schools Located between 10 to 40 km from the Epicenter

This area, assumed to be the far-field of the fault, includes cities adjacent to the epicenter of the earthquake such as Paveh to the northeast, Javanrud to the east, Salas Babajani to the southeast, Sarpol-e Zahab to the south, and Ghasr-e Shirin to the southwest (Figure 11). Investigating the obtained records from the accelerogram stations in the region showed that despite being obtained at a distance approximately equal to those of other cities from the epicenter of the earthquake, the record of the Sarpol-e Zahab city was significantly higher. This can be due to the orientation of the fracture from the north to the south, which was the cause of Sarpol-e Zahab suffering the most damage.

### Schools with Load-bearing Wall Structural Systems

In this region, also, unconfined single-story rural schools with the age of more than 25 years and the load-bearing wall structural system had sustained the most damage. Schools with only horizontal confinement (no vertical confinement) had

sustained relatively low damage. However, compared to the area near the center of the earthquake, the level of damage was quite higher.

Among the deficiencies that caused the collapse of so many schools are unsuitable structural system and the lack of horizontal and vertical confinement, which are mostly seen in schools with the age of more than 25 years. Some instances where school buildings with the same system that have not collapsed or have sustained trivial damage were also observed. Therefore, this system is capable of withstanding large earthquakes only if lateral resisting elements such as horizontal and vertical ties are considered and properly implemented.

Lightweight schools (schools built with light steel structures and sloped ceilings with the weight of less than  $100 \text{ kg/m}^2$ ) that are regular in their plan and height with a high level of relative wall (the ratio of the collective areas of load-bearing walls to the total area of the building) have sustained far less damage. Poor seismic performance was observed only in cases where defects in construction and design or material were

present. The same poor performance was also seen in cases with no vertical ties, discontinuous tie beams, improper connection of the diaphragm and unsuitable arrangement of the structural elements.

Among the most prevalent observed damage were shear failures, development of diagonal cracks in the corners of

buildings without tie columns, the combination of extended diagonal cracks and horizontal cracks in the wall's mid-height, and the separation of the wall from the other walls. These failure states are because of the stress concentrations in the upper and lower corners of the wall's panel. The poorest performance of these types of buildings was seen in regions for the weak soil, alluvium, and riverbanks (Figure 12).



*Figure 12: Damage suffered by schools located between 10 and 40 km from the epicenter of the earthquake.*

### Schools with Steel/RC Structures and Infill Walls

In Iran, buildings are often designed and modeled without taking into account the effect of infill walls. Experimental and empirical observations have often underlined the fact that the presence of infill walls increases the lateral stiffness of the frame and affects the response of the structure to ground excitation. The only recommendation of the Iranian seismic design code for structures with infill separators is to decrease the structure's period by 20%, which does not seem quite reasonable for different infill walls built from different materials. Therefore, the effects of infill walls have to be taken into account in a realistic manner.

In recent years, the most common structural system employed in the construction of schools in the areas affected by the earthquake is the steel structure. With the development of factories in remote areas of the Kermanshah province producing ready-mixed concrete and welded or bolted steel components, the efficiency and quality of construction has increased and as a result, steel structures have replaced buildings with the load-

bearing wall structural system. Therefore, the criteria recommended by new design codes are observed in the newly built steel or RC school buildings.

The performances of the steel or RC school buildings with infill walls in areas 10 to 40 km away from the epicenter of the earthquake have been highly desirable. Regularity of these buildings in their plans and along their heights, suitable and symmetrical distribution of the infill walls, and the appropriate anchorage of the infill walls are the reasons that are partly responsible for this desirable performance. In some parts of this area, particularly in the city of Sarpol-e Zahab and the surrounding villages (where the most damage has been inflicted), the least damage was sustained by the walls of the schools due to the in-plane and out-of-plane movements of the walls being prevented by the proper anchorage of the masonry infill walls. Another factor contributing to this low level of damage is the use of new materials such as sandwich panels (3D panels) and their proper connection to the structural elements.

In most of the schools with this structural system, despite the intensity of the earthquake, the infill walls either have remained intact or contain a few surface cracks, with some small parts having fallen off. However, no total cracking or collapse of the infill walls was observed. In addition, in schools under construction where sandwich panels (3D panels) were used with sufficient anchorage, almost no damage was seen (Figure 13).

Assessing the failure modes of the wall and the cracking pattern of the infill walls show that anchored infill walls, especially continuous infills such as sandwich panels (3D panels), due to their proper and complete connection to the frame, experience no separation from the surrounding structure and only contain surface cracks along the vertical, horizontal, and diagonal directions, which results only in the plaster covering to peel off (Figure 14).



*Figure 13: Steel and reinforced concrete school buildings with anchored infill walls located 10 to 40 km away from the epicenter of the earthquake.*



*Figure 14: Surface cracks on the anchored infill walls of schools 10 to 40 km away from the epicenter.*

#### **ASSESSING THE GEOGRAPHIC LOCATIONS AND DISTRIBUTION OF THE SCHOOLS WITHIN THE AFFECTED REGION**

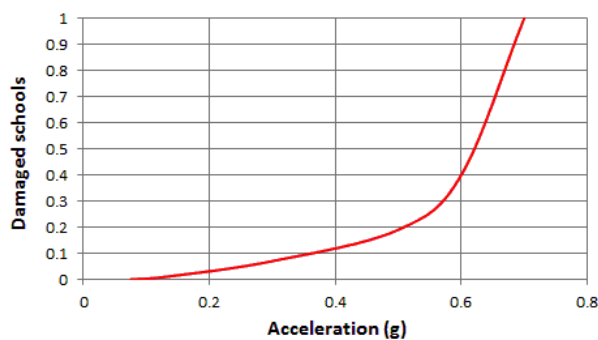
Figure 15a shows the location of the damaged schools that need to be demolished and reconstructed. This figure shows the distribution of collapsed school buildings and their distances from the epicenter of the earthquake. Figure 15b is a map of the faults in the region and the fault responsible for the earthquake.

A comparison between figures 15 (a) and 15 (b) shows that the schools damaged by the earthquake are predominantly located near the faults in the region. Since shear failures in short school buildings with load-bearing the structural system constitute the majority of the failures, long period pulses with strong amplitudes at the beginning of the earthquake can be cited as the reasons which are amongst the main characteristics of near field earthquakes.



**Table 1: Level of damage sustained by school buildings with respect to seismic acceleration.**

No.	Maximum acceleration (g)	No. of damaged school buildings in equi-acceleration regions	Total number of school buildings in the equi-acceleration regions	Ratio of the damaged school buildings
1	0.075	0	43	0
2	0.13	1	97	0.01
3	0.3	6	81	0.07
4	0.5	12	63	0.19
5	0.6	22	55	0.4
6	0.7	78	78	1



**Figure 17: The level of damage sustained by schools in terms of earthquake acceleration.**

### CONCLUSIONS

The November 12<sup>th</sup>, 2017 Ezgeleh earthquake in Iran brought about considerable damage to old and new buildings in the areas affected by the earthquake. Schools with different ages and structural systems, which comprised a sizable portion of the buildings, were affected by the earthquake and sustained different levels of damage.

The maximum acceleration of the ground motion in the response spectrum took place between the period range of 0.1 to 0.5 seconds, which resulted in short buildings and structures with load-bearing wall systems to sustain the maximum damage. In this earthquake, because of the faulting conditions, the orientation of the earthquake, and the geographical and geotechnical elements in the region, the city of Sarpol-e Zahab, 40 km away from the epicenter of the earthquake, has sustained the most damage. In this study, based on post-earthquake field observations, the performances of schools in the near and far fields of the earthquake and the damage they have sustained have been assessed.

- Assessing the damage inflicted upon the educational buildings showed that schools with the load bearing wall structural system have suffered the highest level of damage in both near and far fields of the earthquake. Among the deficiencies that were the cause of the collapse of many of these schools, were defective structural systems and lack of horizontal and vertical ties in most of the old schools (schools with the age of more than 25 years). Light school buildings with a regular geometry in both their plans and heights with a high level of relative wall have sustained far less damage, and poor performance was seen only in cases where no vertical ties were used, discontinuities existed in

tie beams, the diaphragm was not properly connected, and structural elements were poorly arranged.

- The performances of infill walls anchored to the main structure, especially sandwich panels (3D panels) that are properly anchored using angle profiles, have been quite desirable in both steel and reinforced concrete structures, so much so that in areas close to or away from the earthquake, damage were limited to surface cracks and peeled off plaster coverings. Therefore, employing continuous walls with proper anchorage to the main frame and considering their effects in the design of the structure can be taken as a beneficial recommendation in seismic zones.
- Assessing the areas with the same seismic acceleration showed that the collapsed school buildings are concentrated in the areas close to the center of the earthquake and in areas with the maximum acceleration. The level of damage inflicted upon the school buildings was at its highest in the acceleration range of 0.55g to 0.7g.

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