PERFORMANCE OF ESSENTIAL FACILITIES IN THE 2012 VARZAGHAN-AHAR EARTHQUAKES

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ABSTRACT

On August 21st, 2012 two earthquakes struck the northern part of East Azerbaijan Province, Iran with a magnitude 6.2 and 6.0. The earthquake affected three medium-size city centers; Varzaghan, Ahar and Heris. Most essential facilities in the stricken area had suffered minor or moderate structural damages combined with major non-structural ones. Facilities such as hospitals, gas and water systems, electricity network, and important governmental operation centers were damaged in these earthquakes. The major non-structural failure modes involved cracking and collapse of infill walls, separation of facades from back walls, and failure of suspended ceilings. Damage to exterior architectural elements and overturning of medical equipments were also observed in these events. Based on the experience gained from these events, it can be concluded that functionality of a given facility is highly dependent upon the performance of both the building structural system and the non-structural elements.

INTRODUCTION

Essential facilities are those buildings that support functions related to post-earthquake emergency response and disaster recovery. These facilities are considered “essential” since they provide lifesaving functions and render emergency assistance to communities when a disaster strikes (French and Olshansky, 2000). In another word, they includes all buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, snow or earthquakes (IBC, 2012). According to IBC (2012), they are including but not limited to:

- Surgery or emergency treatment facilities.
- Fire, rescue, ambulance and police stations and emergency vehicle garages.
- Designated earthquake, hurricane or other emergency shelters.
- Designated emergency preparedness, communications and operations centers and other facilities required for emergency response.
- Power-generating stations and other public utility facilities required as emergency backup facilities.
- Structures containing highly toxic materials.
- Aviation control towers, air traffic control centers and emergency aircraft hangars.
- Buildings and other structures having critical national defense functions.
- Water storage facilities and pump structures required to maintain water pressure for fire suppression.

Transportation networks, especially highways and bridges, can be also considered as part of these facilities. They play an important role in emergency management. Extensive damage to these systems would seriously impact emergency response and recovery operations (French and Olshansky, 2000).

THE EARTHQUAKES AND THEIR SEQUENCES

On August 21st, 2012 two earthquakes struck the northern part of this region with a magnitude 6.2 and 6.0 on the Richter scale. The first event had occurred about 17 kilometers west of Ahar in coordinate system 495/38 degrees in north latitude and 46/865 degrees in east latitude and had a maximum PGA of about 478 cm/s/s. Only 11 minutes after the first event, the second earthquake occurred about 10 kilometers of Varzeghan, 38/449 degrees north latitude and 46/731degrees for the east. The maximum PGA for the second event was recorded of about 534 cm/s/s (ISMN, 2012). Based on the recorded data, focal depths of 16 and 14 Km. are suggested for these events (Vasheghani and Zaré, 2014).

The main impacts were felt around the towns of Varzaghan, Ahar and Heris. It had been reported that more than 330 people lost their life. The significant amount of death toll was the results of the failure of adobe and non reinforced masonry buildings in rural areas (Miyajima et al., 2012). Furthermore, 4500 had been injured and 72,000 directly affected due to complete or partial destruction of their properties (Fallahi, 2013). According to the IFRC report (2012), 399 villages and five cities had been affected. Furthermore, around 18400 rural residential units had sustained 30% or more destruction, while only 9500 of those units sustained more than 60% or more destruction. In urban areas, from the total of 25700 residential units that affected by these events, around 4750 planned to be reconstructed (Housing Foundation, 2012). Moreover, a large number of animal sheds had been destroyed, whereas 8,000 cattle and sheep had been lost due to the collapsed structures (Gokgun and Mutlu, 2012). The amount of damage of this earthquake was estimated to be more than 403 million US Dollars (Mobaraki and Kashaniasl, 2014).

GENERAL DAMAGE OBSERVATIONS

Buildings in the stricken area experienced different levels of damage. In rural areas, most of the collapsed and damaged houses were adobe and unreinforced masonry buildings with wood lumbers covered by thick layers of mud in the roof. Confined masonry buildings that were constructed according to The Iranian Seismic Code - IS 2800 had sustained little or no damage. Most urban buildings in the stricken area had suffered minor or moderate structural damages combined with major non-structural ones. Failures of some steel structures due to the absence of lateral systems had occurred. Similarly, some structural damage had been observed in concrete structures. Government schools, health facilities and other commonly used buildings such as community centers and mosques had also been affected by these earthquakes. Detailed description of the behavior of different types of buildings is given by Miyajima et al. (2012).

HOSPITALS

In most earthquakes, structural failure is the most important factor that causes injuries. In Iran, the brittle nature of some traditional construction materials used in buildings, the heavy weight of these materials, and the breathing difficulties caused by the huge amount of dust produced by the collapsed buildings are the main reasons that increase the number of deaths and traumatic injuries during an earthquake. Because of the expected large number of casualties, the uninterrupted operation of hospitals is crucial in the aftermath of an earthquake. Therefore, damage to these facilities and any possible evacuation that follows may hamper the emergency response and compound the disaster by adding new casualties. This tape of events was repeated in the 2012 Varzaghan-Ahar Earthquakes.

In the present events; and due to the damage occurred to urban and rural medical centers, temporary hospitals had been established in tents and mobile clinics. Rescue teams had to transmit the injured people to the hospitals of the nearby cities (Razzaghi and Ghafory- Ashtiany, 2012, Gokgun and Mutlu, 2012). Hospitals in those cities took in many of the injured and they struggled to cope with thousands of earthquake survivors waiting to be treated.

The two main hospitals in the stricken area; Bagher’ol-oloum Hospital in Ahar city and Imam Husain Hospital in Heris, were highly damaged and were not active after the earthquakes. The Heris hospital building sustained different degrees of structural damage, while Ahar's hospital sustained no such damage. Furthermore, the two earthquakes did great damage to the non-structural parts and the facilities (IIEES, 2012). In both hospitals, the displacements and the fallings of medical equipments and oxygen capsules were among the main reasons led to the stoppage of their services.

The Bagher'ol-oloum Hospital in Ahar city is a two-storey concrete building that escaped structural damage but had received high damage in the non-structural parts and put out of commission after the earthquakes. In plane failure of infill walls, failure of suspended ceilings and overturning of medical equipment were the major failure mode of non-structural components in this hospital. Damage was more extensive in the upper floor compared to the ground floor (IIEES, 2012).

In Heris city, the hospital building consists of three blocks. It was built on a hill slope and the first block was in operation for one year before the 11 August 2012 events. Although, the city was located about 20 km away from the earthquake epicenter, performance of the hospitals was not acceptable and it was rendered out of service. The structural system of the two-storey hospital was RC moment-resisting frame with masonry infill walls. The building had experienced some structural damage as shown in Fig. 1. Plastic hinges had been developed in the columns of the ground floor. Furthermore, some of the columns experienced shear cracks next to the openings of the infill walls with diagonal cracks observed in some of the beams next to the column joints. An elementary check of the building carried out by Consulting Engineers of Fadak (2013) showed some deficiencies in the building's design that might led to some of the above mentioned shortcomings. In the author's opinion, the combination of stiff masonry infill walls, under-designed concrete columns, poor quality of concrete, absence of suitable frame-infill connection details, and the lack of measures to protect columns against shear failures had contributed to these kinds of damage.

In Heris, both structural and non-structural infill walls had been used in the hospital building. In regard to the structural infill walls, diagonal and horizontal cracking had been observed as shown in Fig. 2. The low resistance capacity of masonry against shear and tensile stresses and the absence of suitable frame-infill connection details were the main reasons that caused such failures. Non-structural infill walls had also been used in the first block of the building. The 10 cm thick non-structural walls were separated from both sides and attached to upper and floor beams. Furthermore, double angles were used at both edges of the wall, as shown in Fig. 3. In these events, many cracks had appeared near the frame-wall connection regions leading to spall of plaster there. This phenomenon was observed near the mid-span double angles as well, as shown in Fig. 3. The absence of gaps or the use of small gaps between walls and frames were the main reason for such a failure. Furthermore, the use of heavy masonry units and thick plaster coatings did great damage to the infill walls (Consulting Engineers of Fadak, 2013).

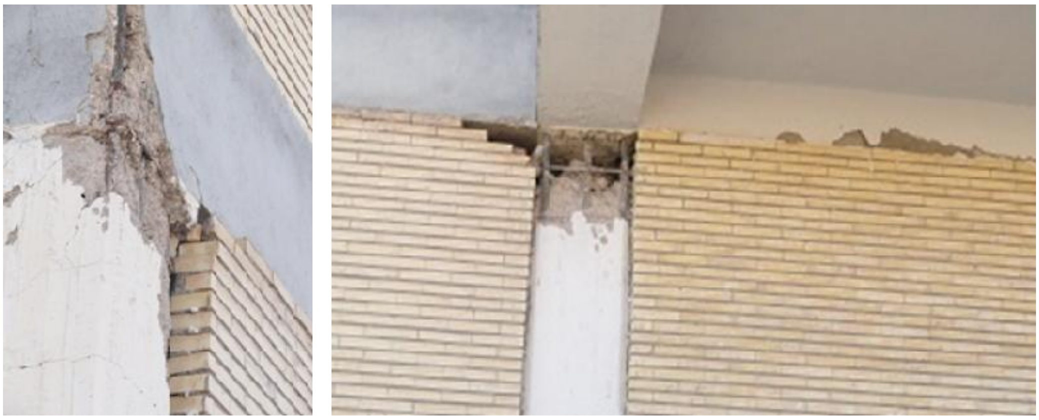

Figure 1. Shear cracks and plastic hinges in columns and cracks in beams due to the presence of infill walls

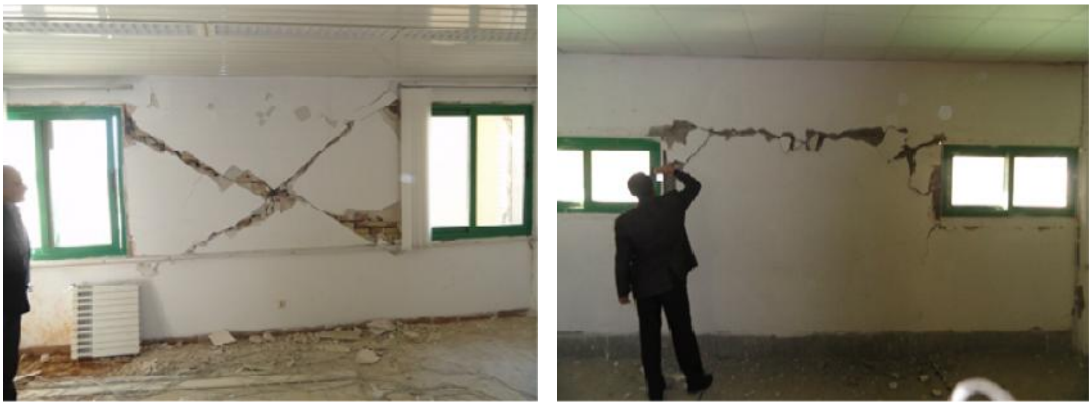

Figure 2. Typical cracks in structural infill walls

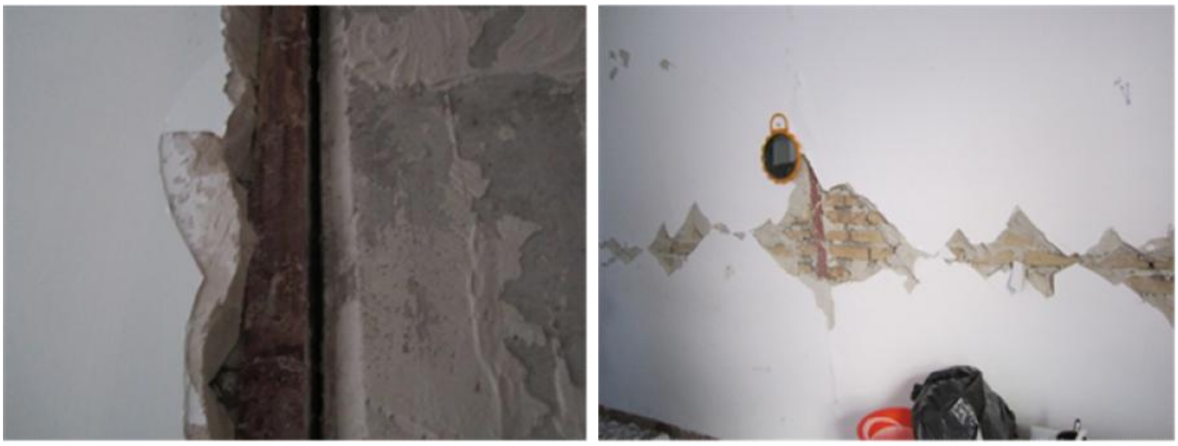

Figure 3. Double angles at the edge of non-structural infill wall (left) and spall of plaster at the middle of infill wall showing the mid-span angles used there (right) (Consulting Engineers of Fadak, 2013)

Regarding exterior non-structural walls in the hospital building of Heris, a special type of these walls in the form of U-shaped perimeter walls was used. These walls were constructed outside the frames but their wings were either connected to the columns or infill walls. As shown in Fig. 4, many deep vertical cracks had been observed in these walls. Despite the existence of general provisions for non-structural walls in the IS 2800, no official connection details were available for exterior walls and curtain walls. Providing such details was largely ignored by the engineering community, as well. Therefore, it can be concluded that the observed cracks were due to story drifts and lack of improper connections with the main structure.

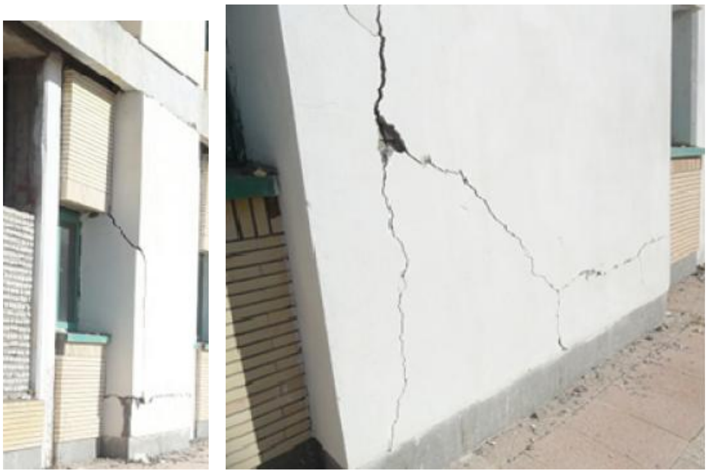

Figure 4. Typical cracks in non-structural external walls

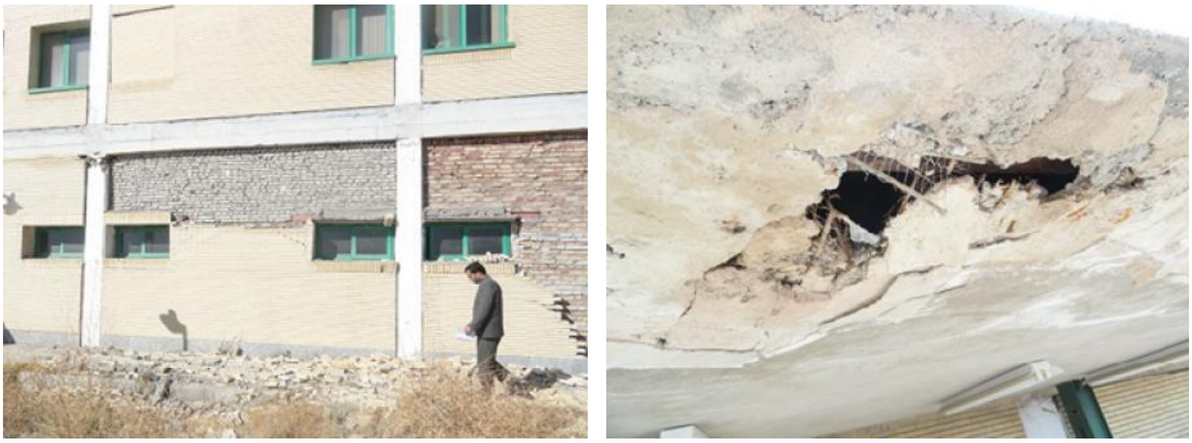

Figure 5. Failure of façade (left), and failure of metal meshes coated by plasters in a suspended ceiling (right)

Among other types of non-structural failures in the hospital building of Heris were those related to façade and suspended ceilings. Examples of such failures are shown in Fig. 5. On the other hand, none of the mechanical and electrical equipments found in the basement of the hospital was affected by the quake. In spite of the shortcomings observed in the restrained systems, all these equipments had met the required "Operational Non-structural Performance Level".

LOCAL GOVERNMENTAL BUILDINGS

There were many local governmental buildings in the earthquakes' stricken area. This section discusses only the performance of Varzqan's Governors Building. For more information on other buildings, reference is made to Razzaghi and Ghafory- Ashtiany (2012) and the IIEES report (2012).

The Varzqan's Governors Building was a steel moment-resisting frame with perforated clay blocks used as infill walls. The façade used in this building was connected to the masonry infill wall by steel bars with sheets of 2 to 3 cm of plastofoam used as insulation material between them, as shown in Fig. 6. Although the number of the bars used in this process was quite sufficient and the ends of these bars were mostly well embedded into facade, these bars had been separated from the walls during these events. Such kind of failures had been observed in other buildings in the earthquake stricken area. Thus, conclusions can be made on the necessity of using better construction details for such multi-wythe walls. On the other hand, the perforated clay infill walls were quite weak to withstand out-of-plane forces. This was due to the small contact area between mortar and masonry units, the poor quality of mortar, and to the lack of adequate restraints in the direction perpendicular to the infill plane.

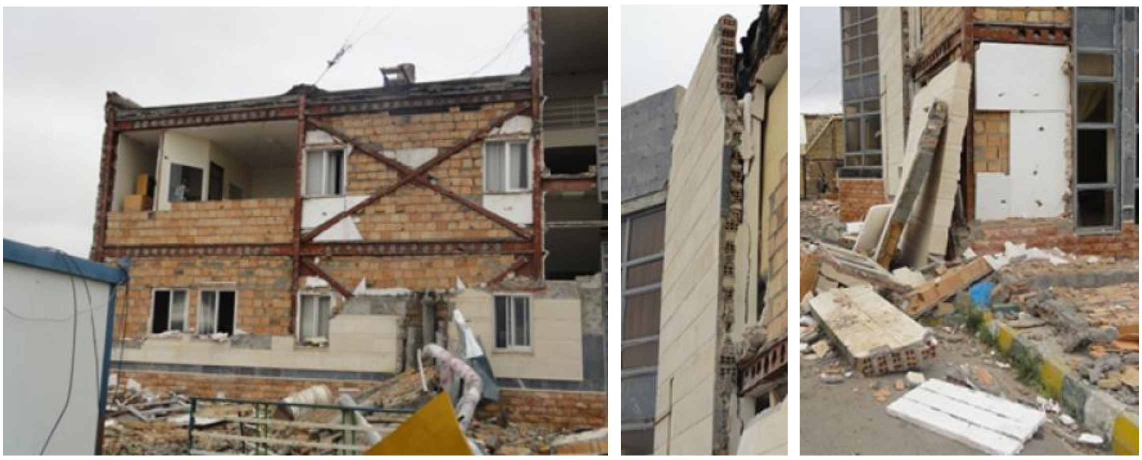

Figure 6. Collapse of infill walls and failure of façade due to out-of-plane forces (left**)**, and failure of façade caused by in-plane forces due to improper connections to the back wall (middle and right)

TELECOMMUNICATION SYSTEMS

Some Insufficiencies were reported in telecommunication antennas. There were some difficulties in phone contact to the earthquake stricken areas because of heavy traffic in calls (Miyajima et al., 2012).

ELECTRICITY NETWORK

Electricity network of 25 villages were totally damaged. The total damage in these villages had be estimated to be around 0.6 million US Dollars. As result of these events, some of electrical feeders were gone out of circuits and reconnected after half an hour. Furthermore, electricity towers located on fault has fallen but the rest of them in further distances from the fault remain intact (Miyajima et al., 2012).

GAS AND WATER SYSTEMS

Damage to gas distribution network had been reported in residential areas because of buildings collapse (Miyajima et al., 2012). Moreover, there were signs of seriously damaged gas valves as well (IIEES, 2012). Furthermore, it has been reported that some gas leakages caused fire in some villages of the area (IIEES, 2012 and Miyajima et al., 2012). The gas system of Ahar and Heris started working again after a couple of hours and in Varzaghan it took a day to be back in service (IIEES, 2012).

No structural damage was observed in the gas stations in the affected area. However, most of the CNG gas stations went under inspection in order to ensure their safe operation (Razzaghi and Ghafory- Ashtiany, 2012).

In these events, some problems in the water network had been also faced. The severity of the damage was more in villages due to topographic and soil conditions. However, the problems in water network were mostly fixed in the few days followed the events (Kalantari, 2012).

ROADS AND BRIDGES

Although some of the bridges in the affected area suffered structural damage, all of the observed bridges were fully serviceable after the earthquakes (Razzaghi and Ghafory- Ashtiany, 2012 and Miyajima et al., 2012). However, it was apparent that some bridges had suffered some soil settlement in both sides of these bridges. The reason for this is the poor compaction of the adjacent soil to the abutments (Miyajima et al., 2012). Furthermore, the pavement of some of the roads cracked due to the fault rupture and geotechnical instabilities but the roads was serviceable after the earthquake (Razzaghi and Ghafory- Ashtiany, 2012).

INDUSTRIAL PLANTS AND FACTORIES

Although the operation in some of the plants was partially stopped, no observable structural damage was reported in the industrial plants. In fact, most of the important industrial plants and factories (e.g. Petrochemical plant, refinery, cement factory, etc.) were located near Tabriz and Soufyan cities, more than 45 Km far from the epicenters of the main earthquakes. It is estimated that the PGA of the earthquake in this zone was less than 0.05g. (Razzaghi and Ghafory- Ashtiany, 2012).

ESSENTIAL FACILITIES AND SEISMIC CODES

Experience has shown that buildings that met the minimum code requirements have survived past earthquakes. However, non-structural damage remains a big vulnerability issue. Such damage can reduce the building effectiveness or even cause its evacuation. Past experience shows that for some essential facilities like hospitals, even very low shaking levels of S_{DS} 0.2 g to 0.4 g could be expected to cause non-structural damage resulting in significant disruption of their operations (FEMA, 2007).

The vulnerability assessment of essential facilities like hospitals with respect to non-structural building components is different from the assessment of potential structural damage. A significant emphasis need to be placed on the design and installation of non-structural anchorage and bracing, the construction need to be monitored and inspected regularly, and the potential for damage to infill walls, façade, partitions, ceilings, pipes, ducts, and other non-structural components should be estimated using a proper and acceptable charts. Even with the extraordinary measures taken in recent codes, the level of non-structural damage recorded indicates that the potential disruption of hospital operations can happen at shaking of about 50 percent S_{DS}. The shaking above 80 percent S_{DS} would most likely result in non-structural damage that would require immediate closure and total evacuation of the hospital (FEMA, 2007).

Based on the above discussion, it can be concluded that current code requirements are not always adequate, especially not for essential facilities. Most essential facilities require special attention, in addition to compliance with building code requirements, in order to be able to sustain their operations after a major disaster. Thus, a need to adhere to a performance-based approach is necessary to define the required performance level for such facilities.

CONCLUSIONS

In past earthquakes, it was common practice to blame the non-engineered buildings for most of the losses. In these events, this also was the case. However, and since these earthquakes had stricken urban centers, the safety of infrastructures and essential facilities become a major concern for the society. As shown in the present paper, buildings that remained structurally sound after the earthquakes lost their operational capabilities due to damage to their non-structural components. The stoppage of services in the main hospitals in the region had caused an increase in the number of fatality in this earthquake. Based on these events, it can be concluded that functionality of a building is highly dependent upon the performance of all systems and subsystems, in particular both the building structural system and the non-structural elements and equipment installed in the building. The poor performance of non-structural components has been caused mainly by improper construction and installation practices. Furthermore, the lack of clarity of the present specifications, and the lack of sufficient level of supervision were among the other reasons that led to many of these deficiencies.

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