EVALUATION OF BEHAVIOR OF BUILDINGS IN CHANGUREH—AVAJ EARTHQUAKE STRICKEN REGION

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ABSTRACT

The Changureh earthquake of June 22, 2002 shocked the northwestern region of Iran. Over fifty villages are totally or partially collapsed due to this earthquake. Most of the buildings in this rural area are non-engineered ones and made of adobe. The engineered buildings in this area are the unreinforced masonry, which is constructed according to the Iranian Seismic Building Code (ISBC) and steel structures with simple joints and bracing system. The main earthquake records of this earthquake are processed and its characteristics are tabulated. The most of non-engineered buildings are collapsed mainly due to poor building materials and lack of structural integrity between their members. In this study by visiting the earthquake stricken region the damage of buildings are evaluated. The causes of building collapse are listed for different types of buildings.

INTRODUCTION

On June 22, 2002 at 7:28 a.m. (local time), the M_w 6.3 earthquake hit the northwestern region of Iran causing significant damage and casualties to mountainous towns and villages in the area. This earthquake was felt as far as Tehran, which is approximately 290 kilometers east of the epicenter. The latest reports indicate that the death toll was 261 and the number of injured exceeded 1,300 people. In addition, over 25,000 people are were left homeless as a result of this earthquake. Figure 1 shows the map of the

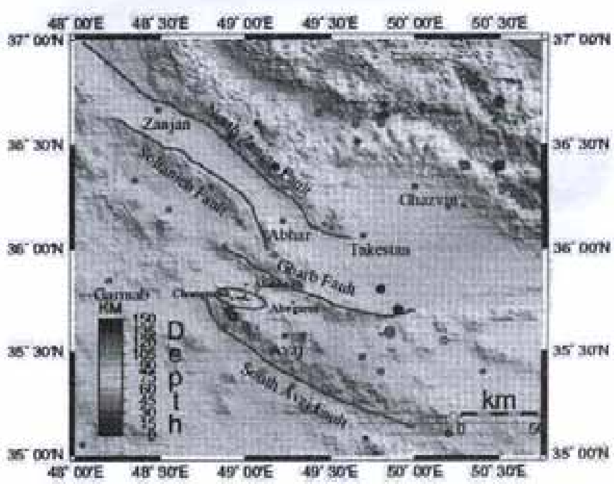

Fig. 1: Map of epicenter of the earthquake and faults around affected area

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region with the epicenter and the location of major faults.

As reported by Institute of Geophysics of Tehran University, the coordinates of epicenter were 49° 4' 48" E and 35° 51' 00" N. Focal depth was estimated to be 10 kilometers.

This paper reviews the seismological aspects of the region, strong ground motions and evaluates the non-engineered and engineered buildings subjected to this earthquake.

SEISMOLOGICAL ASPECTS

Iran is located on the Alpine-Himalayan earthquake belt and is very often subjected to relatively strong earthquakes. The plate tectonic map of Iran is shown in Figure 2. As illustrated, Iran is placed at the intersection of two plates; Arabian plate and Eurasian plate. The Qazvin region is prone to earthquakes with its most recent event occurring 39 years ago. The earthquake was disastrous for Booeen Zahra region. The history of seismicity of this area is shown in Figure 3.

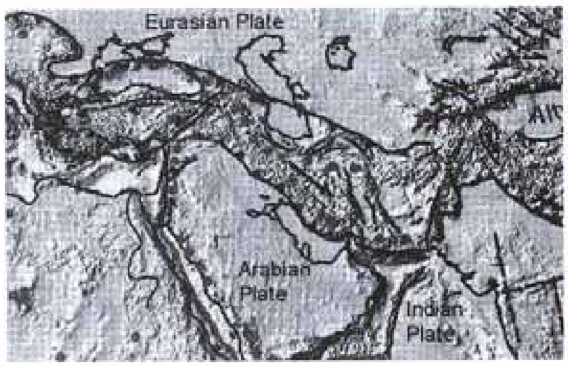

Fig. 2: Iran plate tectonic map

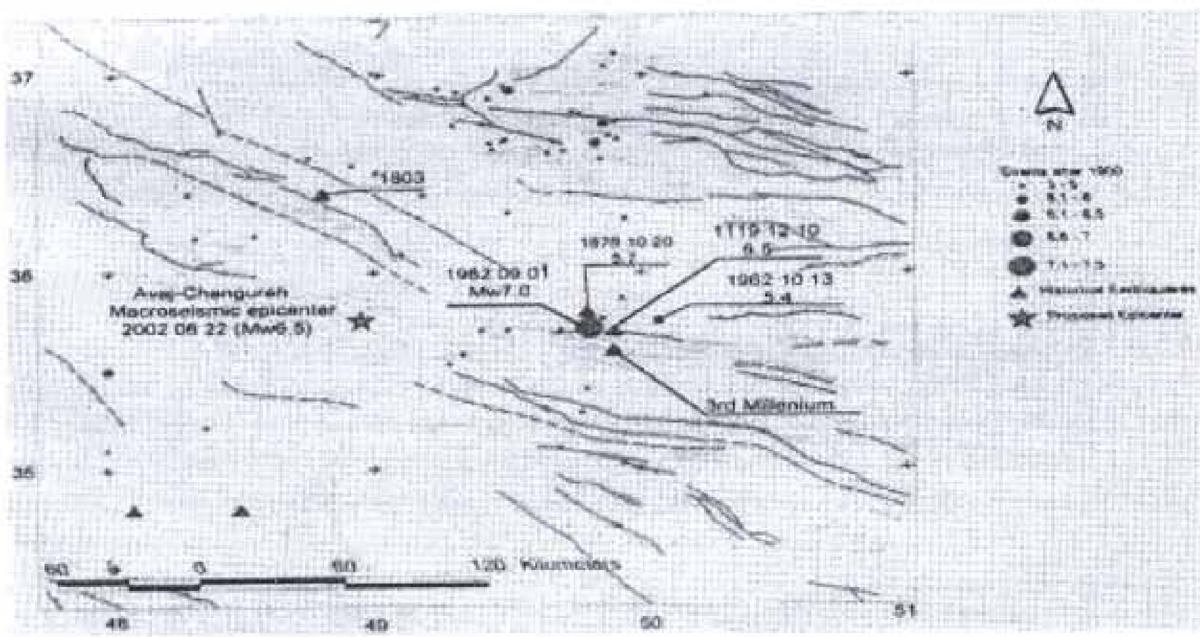

Fig. 3: Past sesimicity of the area

STRONG GROUND MOTIONS

This earthquake is mainly recorded by 25 digital accelerographs. Table 1 describes the main earthquake parameters in some stations.

Table 1. Main earthquake parameters

Station	PGA (cm/s²)		PGV (cm/s)		PGD (cm)	
	L	T	L	T	L	T
Avaj	452.8	419.2	25.0	15.9	2.5	4.0
Abegarm	116.9	126.4	13.3	09.9	4.4	2.4
Razan	162.8	187.5	10.9	09.6	1.7	1.2
Kabodarahang	083.9	148.0	04.8	05.2	1.2	0.9

The uncorrected peak ground acceleration (PGA), which is recorded in Avaj station, is equal to 0.5g, which is along longitudinal component. This station has recorded the maximum vertical acceleration of 0.27g. Ground accelerograms recorded in this station are shown in Figure 4. These accelerations in Razan station are 0.27g and 0.14g respectively. In Abegarm, peak horizontal acceleration recorded along transverse direction is 0.13g. The maximum vertical acceleration in this station is 0.05g. These three accelerographs are the nearest ones to the focal center of the earthquake.

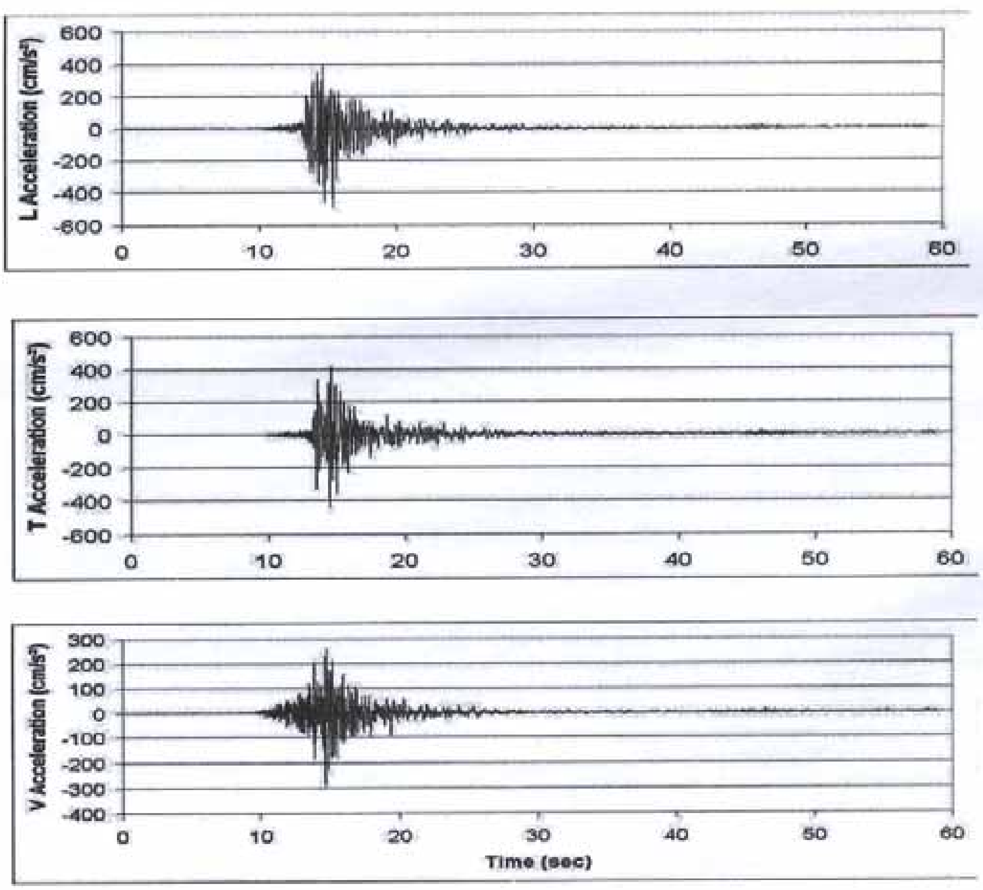

Fig. 4: Accelerations recorded at Avaj station

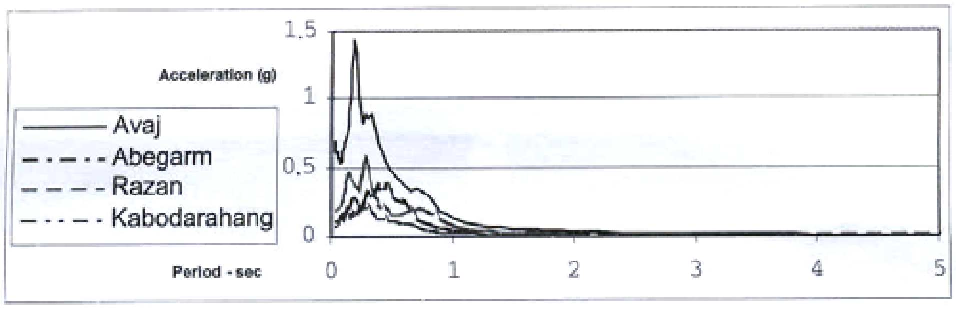

Fig. 5: Longitudinal response spectra

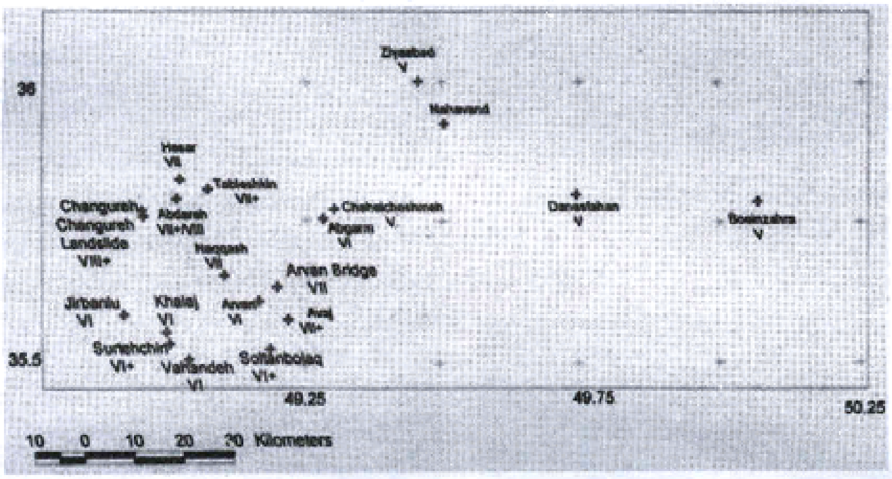

Fig. 6: Modified Mercali Intensities

Longitudinal component response spectra of these stations are shown in Fig. 5. Modified Mercali Intensities in some locations are shown in Fig. 6.

DAMAGE ON THE BUILDINGS

Although there is an updated seismic building code in Iran and it is comparable to the most of the seismic codes of different countries; in practice, the implementation of this code is limited primarily to the larger cities of Iran. In villages, there is typically no control over the seismic design and the construction of buildings. Villagers tend to build their own houses at minimum cost, so they can not able to use standard materials in their buildings; as a result, these buildings may not stand the strong ground motions which usually occur in most part of the country.

The structural damage to rural buildings was in a region mainly restricted by Avaj to the south, Abegarm to the east, Shirinsoo to the west and Abhar to the north. Most of the buildings were single story and made up of adobe and masonry materials. They were mostly structures without engineering considerations; therefore, they could not withstand seismic forces. The structural failure and collapse resulted from weak connection between walls, lack of structural integrity, lack of proper lateral resisting system, and the use of non-ductile materials. Structural collapse was widespread in Changureh and Abdarreh. Electrical local network was disrupted and it was partially restored after 8 hours. Water and irrigation systems were damaged severely in the meizoseismal zone.

Building types existing in this region can be divided into two categories: non-engineered buildings and engineered buildings.

Fig.7: Complete failure of adobe buildings in Abdarreh

Fig. 8: Complete failure of adobe buildings in Changureh

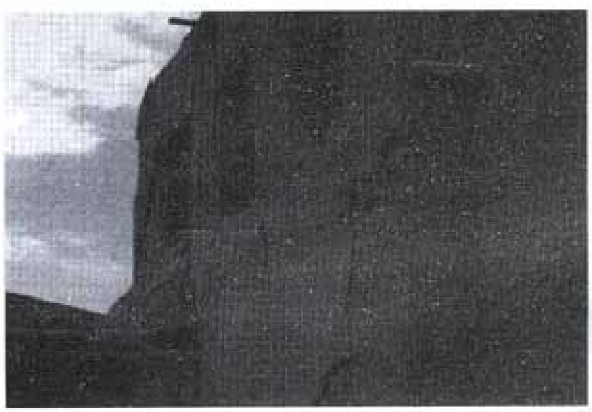

Fig. 9: Partially damaged adobe building

Fig. 10: Collapsed non-engineered buildings beside engineered ones

Fig. 11: Damaged brick masonry building

Fig. 12: Failed jack arch roof

NON-ENGINEERED BUILDINGS

Most of existing non-engineered buildings are made of mud adobes. This type of building system is highly vulnerable due to material weakness. Foundations are traditionally placed in low depth and because of site slope and material weakness, do not work as a continuous member. The main defect in tall adobe walls, which can lead to complete collapse, is moment generation in them resulted from load eccentricity or earthquake excitation. This causes tensile stresses to develop in the section. The material used in these walls is extremely weak in tension and cracks immediately. This leads to general wall collapse, as the earthquake loads are reversal. The major failure causes of adobe buildings in this region are listed below.

- Lack of ties in walls
- Weak connection between orthogonal walls
- Walls directly erected on natural earth without foundation
- Thick and heavy roofs
- Very tall or very long adobe walls
- Openings placed near building corner
- Large openings or openings close to each other
- Insufficient support length for roof beams or lintels
- Constructing 2-story or more buildings using adobe and mud
- Using adobe in composition with other materials like brick, stone or block

Figures 7 and 8 show complete collapse of this type of buildings in Abdarreh and Changureh villages. A two-story adobe building that did not completely fail is shown in Figure 9. This may be a result of the soft soil the building is constructed on, which reduces the energy transferred to the structure. Figure 10 shows these buildings adjacent to some engineered masonry buildings that did not collapse.

A non-engineered brick masonry building is illustrated in Figure 11, which failed due to weak materials, large openings, absence of ties and non-symmetric stiffness distribution in plan. Figure 12 shows a destroyed jack arch roof of a masonry building. Insufficient bracing and weak mortar can be the causes of this defect.

ENGINEERED BUILDINGS

In this region, buildings that are completely or partially constructed using engineering codes and requirements are of different types: unreinforced masonry system, steel frame system, and composite system of steel and masonry.

Practical requirements for constructing unreinforced masonry buildings are considered in 3rd chapter of Iranian Seismic Code. Based on this code, concrete or steel lateral and vertical ties should be placed in the walls in regions of high seismicity. The main sources of vulnerability of these structures are listed below.

- Weak connections between horizontal and vertical ties
- Widely spaced stirrups in concrete vertical ties
- Insufficient reinforcement anchorage length through connections
- Insufficient connection between walls and ties

- Large openings or improperly placed openings
- Lack of relative structural wall in each of building directions
- Insufficient anchorage of non-bearing walls (partitions) at two ends
- Using mud mortar instead of cement

Most of steel frame buildings are unbraced ones and connections are built using single angle profiles without stiffeners. In such conditions the frame has no lateral resistance. Moreover, infill walls are not connected sufficiently to structural elements. The main reasons for failure of these buildings can be as follows.

- Simple frames without bracing
- Weak beam-column connections
- Using strong beams with weaker columns
- Lack of connection between infill and structural elements
- Absence of bracing rebar in jack arch roofs

Fig. 13: 3-story steel frame building damaged due to high torsional forces

Fig. 14: Collapsed simple steel frame building

Fig. 15: Collapsed simple steel frame building

Fig. 16: Changureh entrance bridge

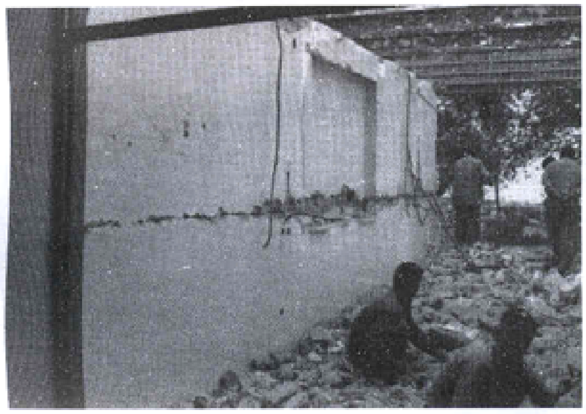

Fig. 17: Cracked wall due to construction discontinuity

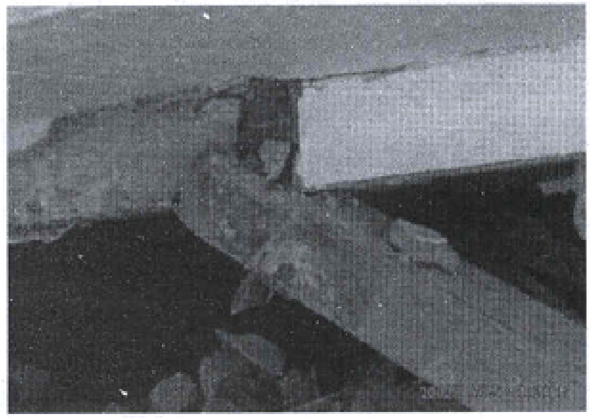

Fig. 18: Weak connection between beam and column

Weak connection between beam and column Composite buildings consist of bearing walls around their plan and steel internal columns on single footings. No lateral resisting elements are placed in these buildings. The main problem, which reduces the seismic strength of these buildings, is that the ductility of surrounding walls does not conform to steel columns.

Figure 13 shows a 3-story steel building in Avaj, which is severely damaged due to large torsional forces generated during the earthquake. The system is non-symmetric both in plan and in elevation. Some completely collapsed buildings are illustrated in Figures 14 and 15. Their system was simple steel frames without bracing.

Figure 16 shows the entrance bridge to Changureh that is damaged along with, a nearby temporary road is constructed for transportation. Figure 17 illustrates a wall, which is cracked horizontally because of construction discontinuity. Failure of a weak beam-column connection is shown in Figure 18. In this connection, the continuous beam is crossed through the column and a single angle profile on each side serves as a seat for the beam.

RECONSTRUCTION AND REHABILITATION

Over 14,000 buildings were damaged from 50% to 100% and are to be reconstructed by the Housing Foundation of the I.R. Iran. Other buildings with less than 50% damage are to be repaired.

The aluminum truss system shown in Figures 19 and 20 is one of the building types used for rehabilitation after Booeen Zahra (1962) earthquake. This system is very light and can be an acceptable system, if architectural requirements are met.

Different building systems are being used in this construction, such as steel frame system, masonry system with concrete ties or bolted steel ties, and sandwich panel system. Some of these systems are shown in the following figures (Figures 21 and 22).

CONCLUSION

The following points are clear from the field investigation:

Fig. 19: Aluminum truss roof system

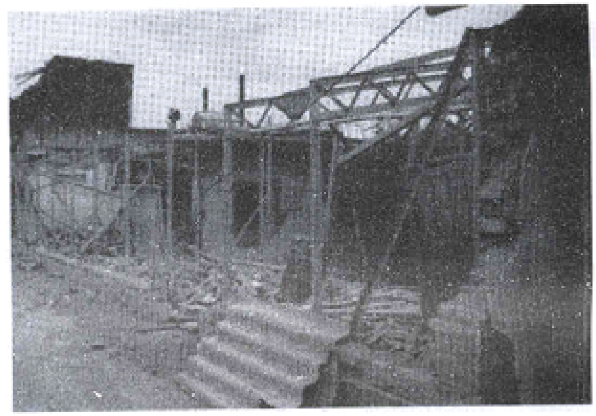

Fig. 20: Aluminum trusses

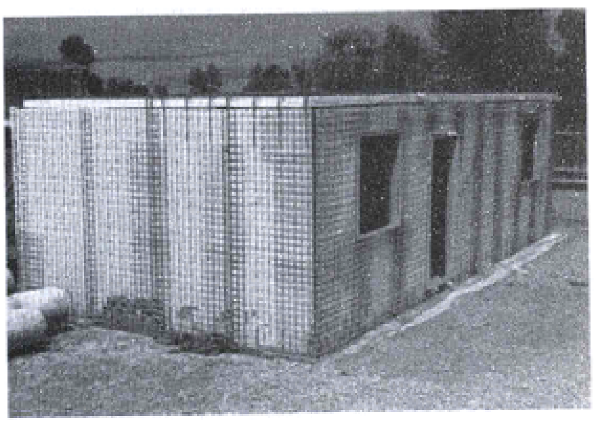

Fig. 21: Sandwich panel system

Fig. 22: Storage of steel ties used in masonry system

The non-engineered buildings in the region are completely collapsed due to poor building materials and lack of integrity between structural elements. The steel buildings are severely damaged mainly due to weak connection between columns and beams and ignoring the use of lateral bracing system. The unreinforced masonry buildings in the region are partially or totally collapsed due to weak connection between the horizontal and vertical ties, using non-standard mortar in bearing walls, and lack of roof integrity. If proposed buildings are constructed according to the engineering criteria, the seismic behavior of these systems can improve in future probable earthquakes.

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