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Structural damage from Manjil-Iran earthquake of June 1990

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ABSTRACT: The Manjil-Iran earthquake (M 7.3) of June 20, 1990 caused widespread structural damages covering an approximate area of 30,000 km^2, resulting in about 37,000 life losses, and 137,000 building failures leaving more than 400,000 people homeless. This earthquake severely damaged many engineered and non-engineered structures. Although a number of geotechnical failures and local site effects contributed extensively to the destruction in this earthquake, but the main cause of damages was poor performance of structures. In this paper, the behavior of some of these structures and the modes of failures have been discussed. Only important structures, which were designed against seismic loads, performed well. But most of conventional structures lacked aseismic considerations and failed. Structural failures were mainly due to the use of brittle building materials, lack of proper lateral-load-resisting system, and poor workmanship.

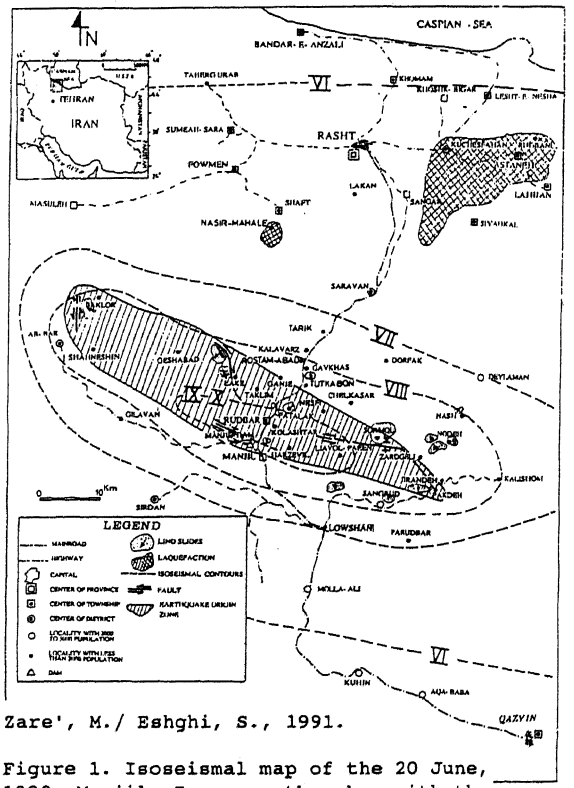
1 INTRODUCTION

On June 20, 1990 at 21:00 GMT (00:30 June 21, 1990 local time), a Richter magnitude 7.3 earthquake struck the northern central region of Iran. The earthquake inflicted devastating damages to three cities and more than about 300 villages in a populated urbanized region of Iran. It caused widespread structural and geotechnical damages covering an approximate area of 30,000 km^2 resulting in 37,000 life losses, 60,000 injuries, and 137,000 building failures leaving 400,000 people homeless.

The main event, centered at near the city of Manjil (36:49:00N,49:24:51E) with a focal depth of about 20 km, propagated along a number of previously unmapped faults that caused widespread ground failures. Numerous landslides as well as soil liquefaction occurred during this earthquake in a relatively vast area as shown in Figure 1.

The Isoseismal map of the 20 June, 1990 Manjil, Iran earthquake based on MSK scale, with the principal geotechnical failures and the earthquake origin zone for this event is shown in Fig. 1. Intensities ranging from VIII to X occurred in an about 200 km^2 of the imprinted area.

In this paper, after a description of the severity and distribution of damage over the devastated area, the structural damages due to the earthquake are reviewed. Finally, the implications of these damages for the aseismic design of structures are presented.



Zare', M./ Eshghi, S., 1991.

Figure 1. Isoseismal map of the 20 June, 1990 Manjil, Iran earthquake with the principal geotechnical failures and the earthquake origin zone.

2 SEVERITY AND DISTRIBUTION OF DAMAGE

Ground motions were recorded at 20 sites during the earthquake. The main shock was followed by numerous strong aftershocks for several months. The maximum recorded Peak Ground Acceleration(PGA) was at 0.56g and 0.47g in horizontal and vertical directions, respectively, at Ab-bar station about 40 km far from the epicenter. Figure 2 illustrates the acceleration time history and response spectra of the main shock. The spectra have their peaks at the period around 0.2 to 0.3 seconds.

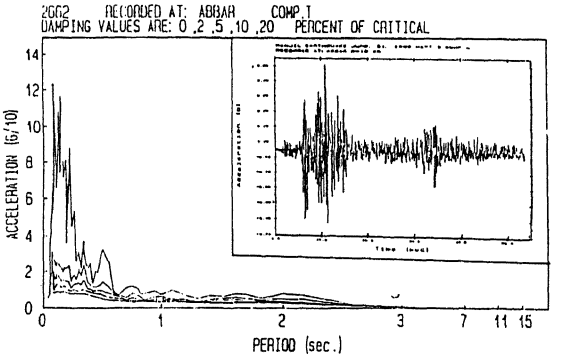


Figure 2. Acceleration time history and response spectra of the Manjil earthquake of June 20, 1990, recorded at Ab-bar station.

The epicenter was in the vicinity of Manjil and Rudbar and therefore these two cities almost totally destroyed. Ground motions in the epicentral region were quite severe, ranging up to 60% of gravity. Motions greater than 20 to 30 percent of gravity were detected over a wide area. Since these levels of motion, regarding aseismic design codes such as: ISIRI,1988), one might expect to see in these areas some significant damage to engineered structures, especially to older ones, designed to lower force levels. However damage in these areas with few exceptions concentrated in unreinforced masonry, timber, stone and adobe building structures. Other, relatively modern types of engineered structures such as steel and concrete bridges and also a large concert dam generally survived the motions in the epicentral region without serious damage (Eshghi,1990,1991).

Rasht city, 60km from the epicenter, was hit by the far-field, long-period ground motions during the earthquake with a maximum acceleration of about 0.1g. Figure 3 shows a distribution of damage to residential buildings and three water towers in Rasht, demonstrating that most of the damaged buildings and the collapsed tower were concentrated around the estuary of a river, where soft soils were deeply deposited.

Generally, the damage rate was comparatively high for the buildings of 5 to 8 stories made up of steel and reinforced concrete structures(Figs.4,5). The city was underlain by saturated alluvial deposits more than 60 m thick,consisting of alternating sand and clay layers. Predominate period of the ground was approximately 0.7 seconds(ISIRI,1988). This fact suggests that a resonance of structures and soils may be a major cause of damage, considering that the natural periods of the mid-rise buildings in the city were in the vicinity of 0.7 seconds(Eshghi,1990).

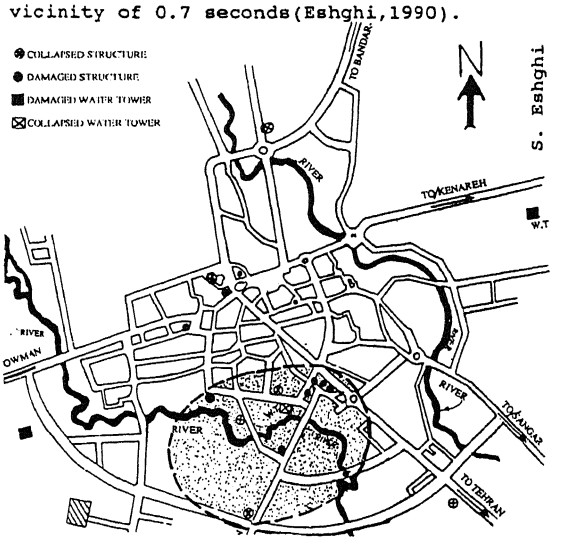


Figure 3. Damage distribution in Rasht.

In the town of Astaneh, located about 50 km east of Rasht, soil liquefaction occurred during the quake and damaged several blocks of one-story buildings made up of steel skeleton with brick infilled panels. Many building settled up to 1.m in the liquefied soil and suffered major damage as a result of uneven settlements and also severe tilting. Most of these buildings only had shallow spread footing foundations(Fig. 6).

During Manjil earthquake, soil effects clearly had a dominant influence on the unusual severity and distribution of damages to rural structures. Soft or loose soils are more disadvantageous than firm of dense soils. Furthermore, it experienced that the depth of alluvial deposits has an important effect upon the extent of damage.

3 DAMAGE TO NON-ENGINEERED STRUCTURES

Non-engineered buildings including rural dwellings and urban buildings (houses, shops), experienced substantial structural damage and/or total collapse during this earthquake(shown in Fig. 7,8,9). The damage was particularly widespread in the earthquake origin zone (Fig. 1) and was responsible for the great majority of life loss associated with this event(Eshghi,1990, Nateghi,1991).

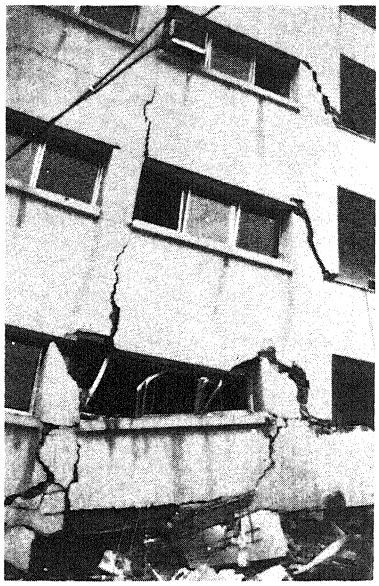


Fig. 4 Failure of an eight story steel structure in Rasht.

Fig. 5 Corner building collapse of a typified apartment building in Rasht.

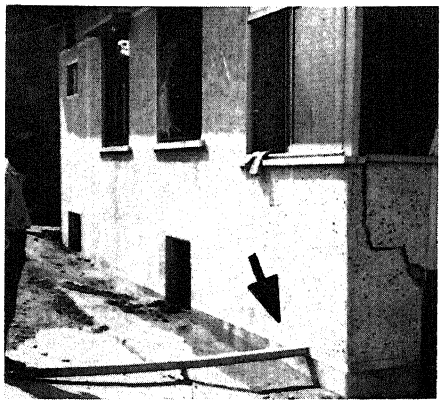


Fig. 6 Uneven settlement due to liquefaction

Fig. 7 Total collapse of a rural dwelling.

Fig. 8 Total collapse of urban buildings in Manjil.

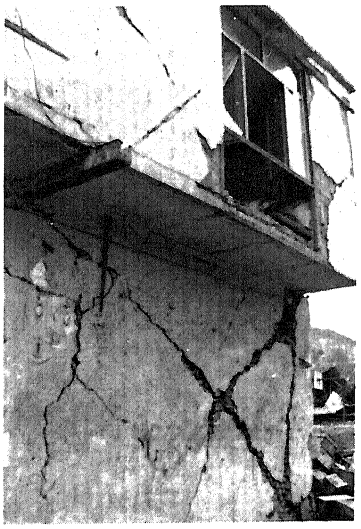


Fig. 9 X cracking in an URM wall.

3.1 Rural dwellings

During the quake, damage to rural building structures was excessive.In general, a rural dwelling was made up of URM (unreinforced masonry) bearing walls or a timber-framed structure, which covered with a lightweight wooden truss or heavy earthen flat roof.

In the affected rural areas, masonry bearing wall buildings were constructed with adobe (sun-dried mud bricks), rubble stone masonry in mud mortar; and also fired brick and concrete block in poor quality cement-sand mortar. Many masonry rural structures with heavy flat roofs suffered partial or total collapse, resulted in killing many of their occupants. During the event, a wide variety of damage types investigated, with corner damage, out-of-plane wall collapse and wall-to-wall separation predominating.

Timber-framed buildings were made up of pitched roofs, diagonal cross battening on a masonry plinth. In this earthquake, many timber-frame structures performed more resilient than masonry structures, but some of the older and weaker timber collapsed. Tiles and heavier roofing materials were shaken from the pitched roofs and many frames were severely distorted. Well-built structures, remained intact despite heavy cracking.

3.2 Urban buildings

Urban buildings were mostly built up to three stories and had three different load carrying systems: URM bearing walls, non-engineered steel and (R/C)reinforced concrete structures with URM infilled walls. They were not designed in accordance with building codes. These buildings generally performed unsatisfactory (Fig. 8).

In URM bearing wall buildings, brick walls supporting either lightweight roof systems, or brick infilled steel (jack-arch) roof system(Fig. 10), and lacked any lateral load resisting mechanism. In Manjil and Rudbar,the extent of damage to URM building was such that only a few building,which had ring beams (concrete beams poured on top of walls) remained standing. The typical damages and modes of failure were: shear failure of bearing walls (Fig.9); separation of supporting walls due to tension cracks; and cracks due to out-of-plane bending of wall and shear failure of spandrel wall between opening.

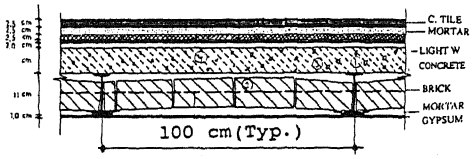


Fig. 10 Jack-arch flooring system.

non-engineered steel and R/C structures with URM infilled walls were constructed without proper engineering design, based on the experience of local masons. In most cases, such constructions suffered many deficiencies (IAEE,1986) resulted in total collapse of them in Rasht (Fig. 4). Collapse of infilled masonry walls was a common characteristic of structural failure.Modes of failure are summarized in sections 4.1,4.2.

4 DAMAGE TO ENGINEERED STRUCTURES

Many engineered structures were severely shaken by the June 20, 1990 Manjil-Iran earthquake. A brief survey of structural damage to steel and reinforced concrete structures (shown in Figs. 12-16) as well as to special engineered structures(shown in Figs.17,18) will follow.

4.1 Steel structures

Most of the mid-rise(4 to 10 storyed) buildings in the affected area were constructed using steel structure. As shown in Fig.11, columns were typically battened steel sections and main girders consisted of two I-beams. In the direction perpendicular to the main girders, beams supported jack-arch flooring system (Fig. 10), and lateral loads were resisted by bracing system. Sometimes solid URM infilled walls were used as shear walls.

During the earthquake, extensive damage was experienced in many steel structures including several cases of total collapse(Figs.4,5) most of them due to the lack of lateral load resisting system,poor welded connections and poor performance of beam-column connections. Figs. 12,13 show structural failures. Damages observed were dislocation and crushing of URM infilled walls, sidesway of the entire building and pounding.

4.2 Reinforced concrete structures

Reinforced concrete (R/C) structures performed unsatisfactory during this earthquake. A few number of reinforced concrete structures were totally collapsed, while others suffered severe structural damages(Figs.14,15).A large number of R/C structures had only a simple moment resisting frame for supporting gravity loads.

Lack of a proper ductile moment resisting frame, using plain reinforcing bars instead of deformed ones, not meeting the development and overlapping requirements, and low quality of concrete can be named as major contributing parameters in poor performance of these structures. Damages occurred were, crushing of column ends, short column effects(Fig. 14) diagonal cracking of beam-column joints.

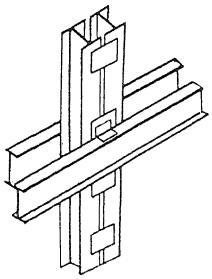


Fig.11 Typical beam-colunm connection.

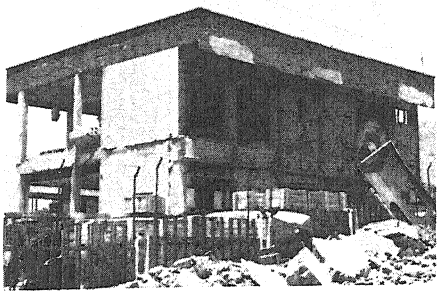


Fig. 15 Damage to a R/C building (Manjil Telecom Center).

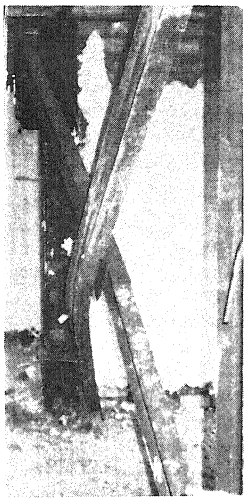


Fig. 12 Buckling of a bracing system.

Fig. 13 Buckling of a battened column.

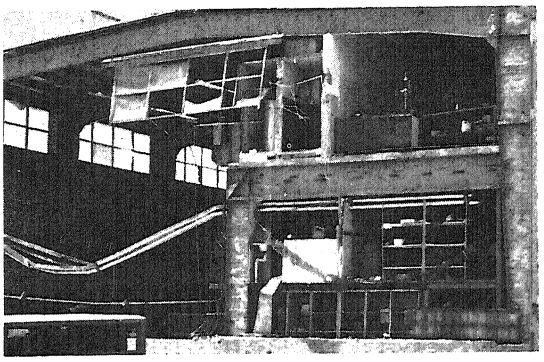


Fig. 16 Damage to industrial structures.

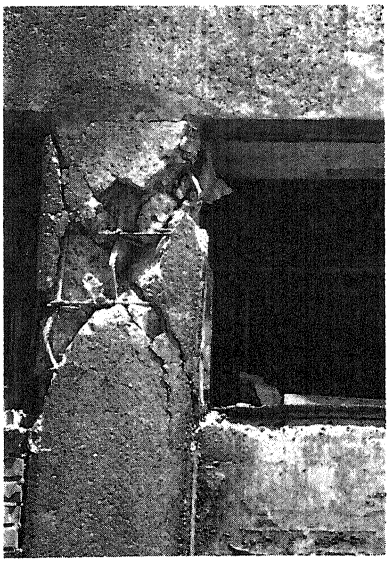


Fig. 14 Shear failure in a column which was shortened by interaction with the spandrel walls.

Fig. 17 Manjil large dam, which sustained only minor damage.

Fig. 18(a) Total collapse of R/C water tower in Rasht.

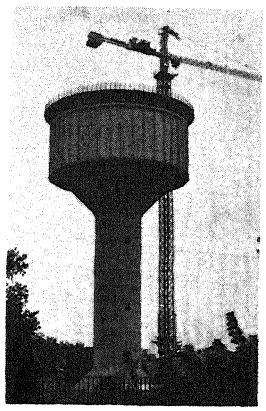


Fig. 18(b) Damage to an empty water tower also in Rasht.

4.3 Special engineered structures

Special engineered structures such as industrial structures(Fig. 16), steel and concrete bridges, silos, steel water towers and also a large concert dam(Fig.17) generally withstood the motions in the epicentral region with minor damage.

A R/C water tower with 1500 m^3 capacity in Rasht collapsed(Fig.18),Two more water towers with 2500 m^3 in Rasht of the same type as the collapsed one, sustained cracks in the perimeter of the shaft near the base(Fig.18). These towers did not collapse since they were empty at the time of the quake. The main factors contributed to the damage of these R/C water towers were as follows: high response amplification because of low natural frequency of the towers, local site effects in city of Rasht, and unsuitable structural form and detailing to withstand seismic loads

The only dam that suffered some structural damage was the Manjil Dam, located less than one km from the causative fault. The dam was the most important structure in the affected area. The dam was of the buttress type with a height of 106 m and crest length of 425 m. The reservoir was almost full at the time of earthquake. This dam experienced longitudinal crack at the interface of the crown and buttress tops, horizontal and diagonal cracks at the top of some buttresses, but remained stable.

5 CONCLUSION

With a magnitude of 7.3 the Manjil earthquake had a significant regional impact and provided a wealth of information on the seismic response of a wide variety of structures over a large metropolitan area. Many engineered and non-engineered structures were damaged severely during this earthquake. Based on the investigations made,it can be concluded that:

Although a number of geotechnical failures and local site effects contributed extensively to the destruction in this event, but the main cause of damage was poor performance of structures.

In general, structural failures were mainly due to the use of brittle building materials, lack of proper lateral-load-resisting system, poor workmanship and inefficient system of authorized supervision.

Most of the spectacular structural damage was suffered by precode buildings, principally of the unreinforced masonry type; which once again proved to be the most hazardous form of building construction.

Reinforced concrete structures performed poorly during the earthquake, and sustained substantial damage. Lack of a ductile moment resisting frame, using plain reinforcing bars instead of deformed ones, not meeting the development and overlapping requirements, and low quality of concrete can be named as the main causes of damage.

Lack of a proper lateral-load-resisting system,unavailability of large steel sections for columns, and poor quality of welded connections can be named as the main causes of unsatisfactory performance of steel structures during this earthquake.

Well-engineered structures performed well, Amongst them, steel and R/C bridges performed relatively well. The 106 m high Manjil dam, located within 1 km of the epicenter and subjected to very intense ground motion, appeared to sustain little damage. R/C water towers had unacceptable performance.

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