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Lessons of the 1990 Manjil-Iran earthquake

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ABSTRACT: On June 20, 1990, a strong earthquake occurred in Iran causing widespread death and destruction in one of the well developed areas of the country. Most of the death occurred due to collapse of adobe, unreinforced stone or brick masonry homes. The damage to modern engineered facilities was minimal and was in the form of cracking of reinforced concrete structures and in one case collapse of a major elevated water tank which probably had design deficiencies. Several poorly constructed 6-8 story steel and reinforced concrete buildings completely collapsed. Throughout the area, damage to unreinforced hollow infill walls and the equipment was widespread.

1 INTRODUCTION

The areas affected by the Manjil-Iran earthquake are shown in Figure 1. The quake measured 7.7 by the United States Geological Survey (USGS 1990). According to unofficial statistics (Zargar 1991), about 200,000 residential, commercial and industrial units were damaged where about 60,000 of them were totally demolished. About 400 hospitals and health units were damaged and 7500 classrooms were rendered useless. The initial monetary damage was estimated at 800 billion Iranian Rials (about 8 to 11 billion U.S. dollars).

The damage caused by the Manjil-Iran earthquake has been reported by A. Astaneh (1990), M. Ghalibafian (1991), M. R. Maheri (1991), M. Mehrain (1990), A. A. Moinfar (1990), M. Niazi (1992) and M.K. Yegian (1990) among others. The purpose of this paper is to summarize the earthquake engineering aspects of this major event and discuss the lessons that were learned and could be learned.

2 GENERAL EARTHQUAKE ENGINEERING ASPECTS

The Manjil earthquake occurred in a developed part of Iran affecting many modern and engineered facilities in urban areas as well as many remote villages with thousands of traditional adobe houses. Most of the non-engineered adobe or unreinforced masonry houses in the area were severely damaged or collapsed. Damage to the engineered facilities was in the form of extensive rock slides over the highways, collapse of portions of the tunnels, minor damage to abutments of modern bridges, some damage to a major dam, minor damage to a modern grain silo, some damage to foundations in a major power plant, extensive damage to equipment in many industrial facilities and damage to unreinforced hollow tile or concrete block infill walls in many buildings.

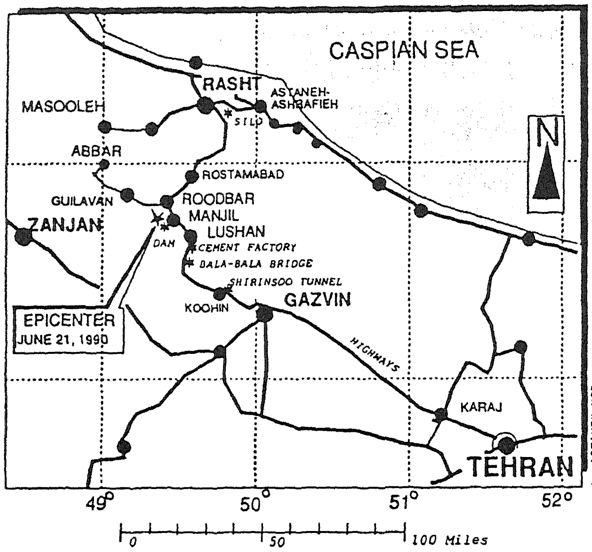
In the following sections more field data on the performance of man-made facilities are provided and lessons that were learned or could be learned are discussed.

3 NON-ENGINEERED TRADITIONAL CONSTRUCTION

In small towns and villages throughout the affected area, the majority of buildings were non-engineered one or two-story buildings with adobe and unreinforced stone or brick masonry construction. These buildings are usually built by local masons to resist gravity loads but with limited or no seismic considerations. The walls are usually load bearing masonry walls constructed by using sun-dried mud bricks, stone or brick masonry with mud, lime-mud, or sand cement mortar.

The roof of an adobe building is usually flat earthen roof built by mud layers placed on the wood mattings which in turn are supported on a series of round wood logs. The round wood logs are supported on the adobe walls. The roof structure in stone or brick masonry buildings consists of a series of steel I-beams spaced at about one meter intervals and ten centimeter thick brick jack arches span the two adjacent I-beams. On top of the brick arch light-weight gravel and about 2 centimeters of cement mortar and 2 centimeters of terrazzo tiles are placed.

The adobe and unreinforced masonry building have been built for many years in the rural areas throughout the central and eastern portion of the Alpine-Himalayan seismic belt. During past moderate or strong earthquakes, these relatively heavy, weak and brittle buildings have sustained heavy damage or completely collapsed killing thousands of



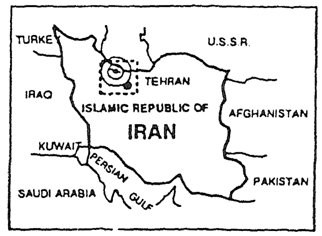


Figure 1. Map of the affected areas

their occupants in each earthquake. In Iran alone, over the last 30 years, more than 70,000 people have perished in these hazardous buildings.

However, brick masonry buildings that were seismically reinforced by using vertical and horizontal tie columns and tie beams have survived strong earthquakes including the Manjil earthquake. The survival of brick masonry buildings with seismic ties, even those with only horizontal ties, signifies the importance of tying the load carrying elements of the building to each other as well as ensuring that the walls will not fall apart.

The poor seismic performance of the adobe and unreinforced masonry buildings has been well known for many years and is not a new lesson to be learned. The frequent collapse of these buildings during earthquakes is related to several factors including the heavy weight, low natural period, existence of no continuous load path for seismic forces, brittleness, lack of ductility, relatively low strength to weight ratio of the material, lack of significant tension capacity of the elements and usually poor foundations.

Several studies on earthen and low strength masonry buildings (for example, Erdik 1987) have discussed seismic performance and have proposed technologies for improving seismic behavior of these hazardous buildings. However, actual implementation of these solutions appears to be a challenge. The adobe houses are mostly located in the remote villages and towns which are not easily accessible. The delivery of the material, equipment and technical man-power is very difficult and expensive if not impossible. Also, it appears that the volume of the buildings that need to be retrofitted is so great that the government agencies and communities involved are unable to provide the necessary financial support.

As a result, thousands of these "death trap" buildings are standing on the seismically active Alpine-Himalayan belt waiting for another fault to slip and thousands of lives to be perished.

4 PERFORMANCE OF ENGINEERED BUILDINGS

During Manjil earthquake, a few six to eight story, presumably engineered buildings in the city of Rasht, totally collapsed. The buildings had reinforced concrete or welded steel structures. Initial investigations of the wreckage indicated that poor performance of concrete structures was most likely due to the poor quality of the concrete and lack of proper seismic detailing in the joints. In steel structures, the cause of the collapse was related to the inadequacy and poor execution of fillet welds in the connections (Ghalibafian, 1991).

A lesson to be noted here is that due to the existence of factor of safety in design of structures for gravity loads, in some cases, poorly constructed structures can still withstand gravity loads. However, strong earthquakes push the structures to their limit and damage the poorly constructed areas of the structures. If these areas are critical to the overall stability and integrity of the structure, the damage usually results in partial or total collapse with tragic consequences.

Other than the few poorly constructed buildings that collapsed during the earthquake, the remaining engineered buildings in the affected areas performed very well. There was almost no critical structural damage. The quality of the design as well as construction of the modern engineered facilities, visited by the author, appeared to be good and in general compliance with the the currently available earthquake engineering technology. However, unreinforced infill walls and equipment inside the well-built structures sustained considerable damage during the earthquake.

The use of unreinforced masonry infill walls with hollow clay tiles or cement blocks was very common in the area. These walls usually were not reinforced and were not attached to the structure by any mechanical means. As a result, during the earthquake, these relatively stiff but brittle walls had failed. The falling debris resulting from the failure of the infill walls occasionally had caused serious damage to the nearby equipment. In most cases, due to cracking and partial failure of these walls, a number of buildings were evacuated and costly repairs were being undertaken.

Iran has a relatively modern seismic design code (BHRC 1988) that has been initiated in 1962 and is currently maintained by a committee of earthquake engineers at the Ministry of Housing and Urban Development. According to the law, compliance with the code is mandatory. However, most non-engineered and some engineered buildings do not fully comply with the code. Sometimes, particularly in the remote areas, the buildings do not have any seismic design considerations and are not subjected to rigorous construction inspections. As a result, during the earthquakes these seismically hazardous buildings are severely damaged or collapse.

5 PERFORMANCE OF MAJOR ENGINEERED FACILITIES

Numerous important residential, commercial and industrial facilities were located within the affected areas. Most of these facilities have been built during the last 30 years and were designed to withstand varying levels of seismic forces. In the following, a discussion of performance of these facilities and lessons learned are provided.

5.1 Geotechnical Aspects

In the town of Masooleh several boulders, approximately 3x3x3m in size, had been released from the mountains overlooking the town and rolled down the slopes. The boulders had completely demolished several homes and caused death of ten people and injuries to others. Some evidence of liquefaction was observed in and around the town of Astaneh-Ashrafieh where sand-boils had completely filled up some wells and several houses were unevenly uplifted and settled. According to Ghalibafian, (1991) major damage due to failure of soil was almost total burial of two villages built on the downslope due to landslides above the villages.

5.2 Bridges, Tunnels and Highways

Numerous rockslides were observed along the major highway between the cities of Gazvin and Rasht. The rockslides had closed the highway during the main shock and continued to do so during the aftershocks. The entrances to three tunnels on this highway had collapsed. A sixteen meter long segment of the Shirinsoo tunnel had collapsed twice, once during the main shock and again two days later due to the aftershocks. The bridges in the affected areas even in the epicentral areas had performed well. Two major steel truss bridges had no visible damage. Two major concrete bridges had sustained minor damage in their abutment and one bridge had a horizontal crack in one of its piers. Two old brick masonry bridges with multiple arch spans damaged and one had lost half of its deck width in one span.

5.3 Hospitals

A major hospital in Rostamabad, a town near the epicenter had totally collapsed during the earthquake as shown in Figure 2. The modern facilities had been completed only two years prior to the earthquake. The hospital complex consisted of several one story unreinforced concrete block masonry buildings where unreinforced walls and a number of steel columns were carrying the gravity load. Probably the collapse was due to sliding of the poor supporting soil and lack of seismic considerations in design and construction of such a critical facility.

5.4 Dams

The Manjil dam over the Sefidrood river, built in 1967, sustained some minor damage in the form of a horizontal crack and some hair cracks at the top of the dam and in the buttresses. According to Moinfar (1991) after the reservoir was drained, some cracks at the base of the dam on the upstream side were also observed. According to engineers at the dam site, the dam was designed for 0.25g horizontal equivalent static force. The operating facilities and staff housing near the dam were severely damaged or collapsed. The seismic behavior of this major buttress dam provides a unique and very valuable opportunity for seismic studies to advance the technology of earthquake engineering of major concrete dams.

5.5 Power plants and a cement factory

A major fossil-fueled power plant was located within 30km of the likely epicenter. The structures of the power plant, which were mostly reinforced concrete frames had very minor damage. The most important damage in this facility was collapse of a heavy non-structural exterior wall panel above the gate where the main power transmission lines were exiting the building. The falling debris has demolished the power line conduits making the power transmission impossible. Also, in this facility, the foundation of one of the generators showed uneven settlement of about 5cm.

The modern Khazar cement factory with 2000 ton daily cement production is located within the 15km of the likely location of the epicenter. The structures of this plant, which were reinforced concrete frames with shear walls, reinforced concrete silos or steel gable frames, had no significant visible damage. However, considerable damage had been inflicted on the equipment either due to failure of equipment supports or due to collapse of the adjacent non-structural walls on the equipment.

5.6 A major silo and water tanks

A major reinforced concrete grain silo with 120,000 ton capacity sustained some minor damage at the base of columns of its elevator shaft. The damage was primarily a horizontal crack developed at the construction cold joint. The grain-loading equipment at the top floor of the silo were displaced and damaged. the damage was easily repaired and operation of silo resumed in about a week after the quake.

An elevated water tank in the City of Rasht had totally collapsed and two others, which had just been constructed, Figure 4, were damaged. The quality of construction in these reinforced concrete water tanks appeared to be good. It is possible that the damage might have been due to deficiency in the seismic design. An older reinforced concrete elevated water tank in the town of Astaneh-Ashrafieh had also collapsed. In this case, the seismic design, detailing as well as construction appeared to be poor.

Studies of the behavior and causes of damage in these important structures, can provide very valuable information to improve their seismic design in the future as well as in the retrofit of existing ones.

6 SUMMARY

The performance of the man-made facilities during Manjil Iran earthquake and the lessons learned from this earthquake could be summarized as follows.

1. The non-engineered facilities or engineered facilities with poor construction collapsed or were heavily damaged causing most of the deaths and injuries. The large number of fatalities once again emphasizes an urgent need for practical and inexpensive retrofit systems that can be implemented to reduce the risk of collapse of these hazardous buildings.
2. The engineered facilities designed and constructed in accordance with the current earthquake engineering technology performed very well with minor structural damage. The good performance of these facilities emphasized the benefits of implementing sound earthquake engineering in the design of structures as well as the importance of quality control in construction.
3. Damage to the equipment in the industrial facilities was extensive indicating deficiencies in the seismic design and detailing of the supports of the equipment.
4. In some cases damage to the equipment was caused by the collapse of the structural or nonstructural elements on them.
5. The performance of unreinforced hollow clay tile infill walls was poor.
6. Finally, all buildings and other facilities that collapsed, without exception, were either not designed according to the current seismic code provisions or were poorly constructed.

An important lesson that one can learn from this earthquake is that in order to survive major earthquakes with minimum or at least tolerable damage, it is necessary that the structure, non-structural elements and equipment comply with at least the provisions of the current seismic codes and all components of a facility be constructed properly.

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