

The Manjil, Iran Earthquake of June 21, 1990

We have two contributions towards the report on this earthquake. There has been minimum editing for consistency, and some of the data ought to be considered preliminary, particularly the details of the earthquake source and its causative fault.

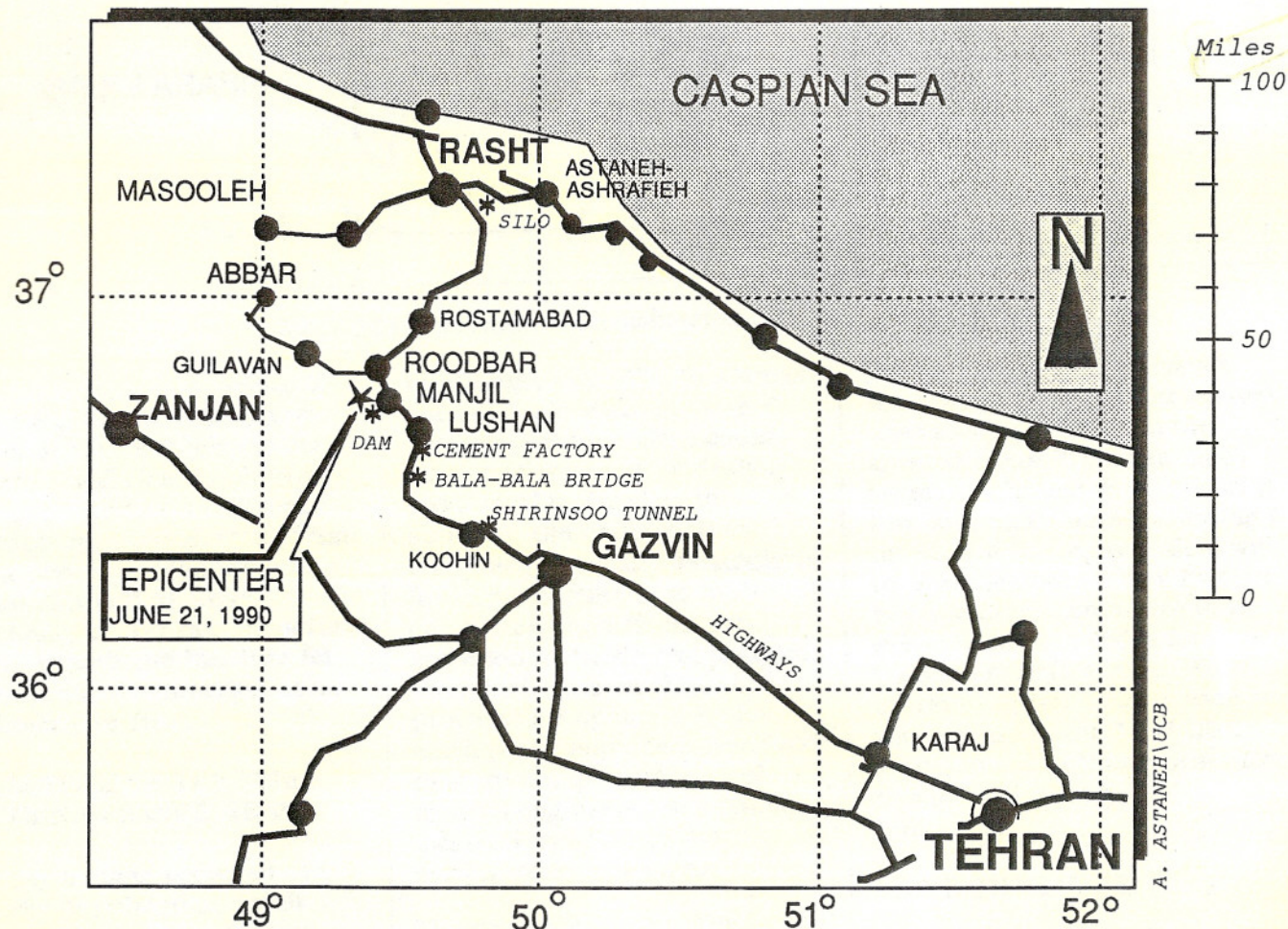
Contribution by Abolhassan Astaneh, EERI Reconnaissance Team Leader, USA, and M. Ghafory Ashtiani, Head, IIEES, Iran.

INTRODUCTION

On June 21, 1990, at 12:30 a.m. local time, a major earthquake occurred in the northern central region of Iran. The M7.3 quake (the USGS magnitude is 7.7) caused heavy casualties and damage to modern structures, their non-structural elements, and equipment. More than 35,000 deaths and 100,000 injuries are reported. Two days after the quake an EERI reconnaissance team traveled to Iran and investigated the quake. The team consisted of U.S. and Iranian researchers and

earthquake engineers. This report is a summary of their observations.

Team members were Abolhassan Astaneh, Associate Professor in the Civil Engineer-

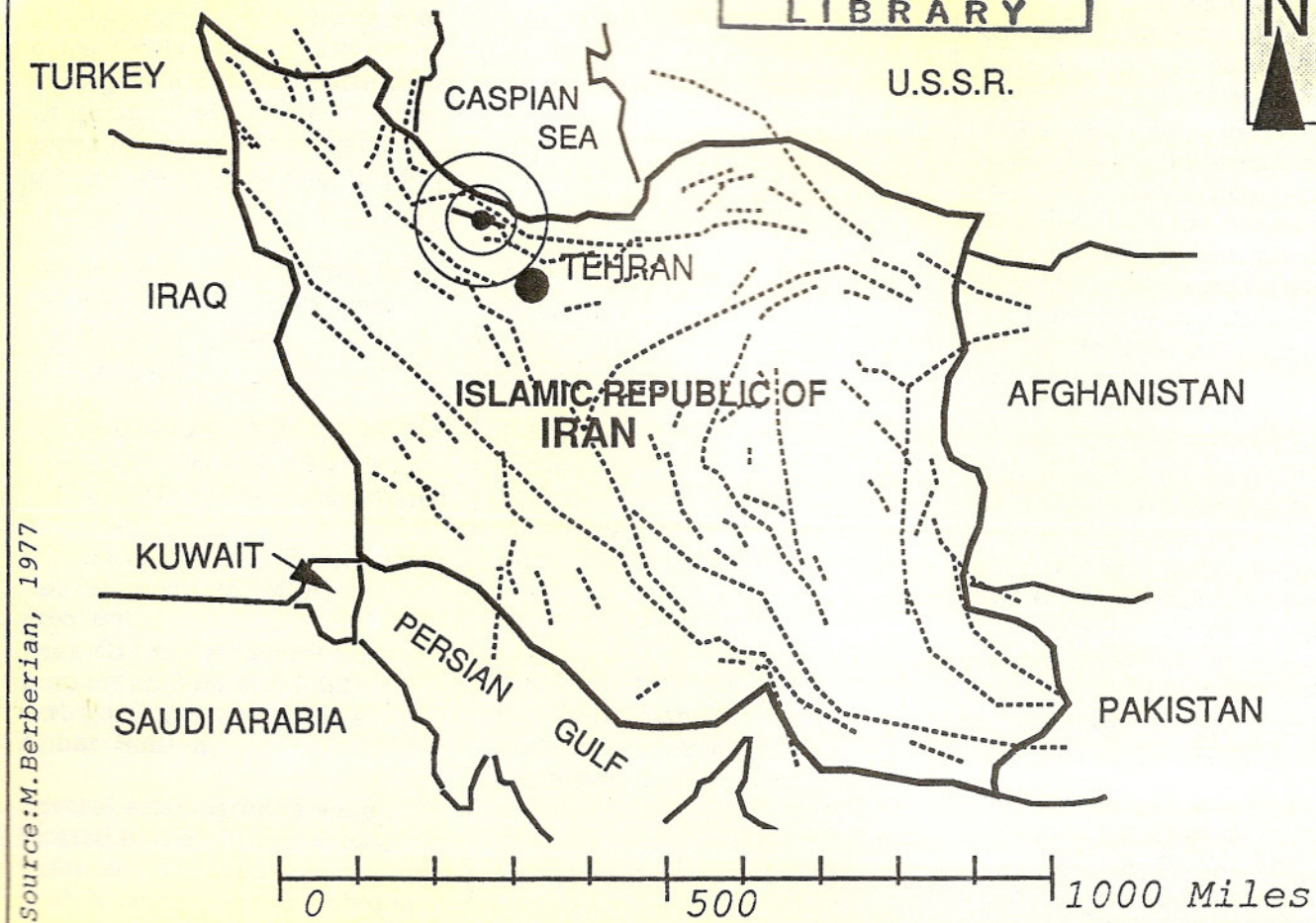


Epicenter of the earthquake and affected areas.

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Major faults in Iran² and epicenter of June 21, 1990.

ing Department and the Earthquake Engineering Research Center at U.C. Berkeley (team leader), Saïd Bolourchi, Principal engineer with Advanced Engineering Consultants of San Francisco, and Mohammad Mehdi Ahmadi of Sharif University in Tehran, structural engineer with the Institute for Earthquake Engineering and Seismicity of Iran.

OBJECTIVES OF THE EERI RECONNAISSANCE TEAM

The earthquake occurred in a densely populated and well developed area and affected many major engineered facilities. The facilities included modern dams, tunnels, roads, bridges, silos, power plants, elevated water tanks, and

residential and office buildings. Most of these structures were designed using modern codes similar to the seismic design codes used in the U.S. In addition, the construction technology in Iran, particularly for major facilities, is quite comparable to western construction methods and practices. Therefore, this earthquake provided an opportunity for earthquake engineers worldwide to study the performance of modern engineered structures located very close to the earthquake's epicenter.

The main objective of the reconnaissance tour was to join forces with Iranian earthquake engineers, learning lessons that can be used not only in Iran but worldwide to reduce earthquake

hazard. The reconnaissance team was in Iran for almost two weeks with one week in the affected areas. The team had several technical meetings with Iranian researchers, including a meeting of the team leaders with several members of the Iranian Seismic Code Committee to re-evaluate current codes for possible modifications. The current Iranian seismic code is very similar to the 1988 UBC with some additional provisions to address local types of buildings.

THE EARTHQUAKE

Iran is located on the Mediterranean-Himalayan seismic belt. This belt stretches in the east-west direction from the Himalayas to the Mediterranean Sea.

Historically, Iran has been a very active seismic region. Earthquakes of M6 and smaller are very common in the region. From 1900 to 1979, on the average, Iran had an earthquake with magnitude greater than 6 every 1.5 years and an earthquake greater than magnitude 7 every 6 years¹.

At the time of this writing the following information was available about the earthquake^{5,6}.

Magnitude: 7.3 - 7.7
 Epicenter: 36.96N, 49.41E
 Depth of Hypocenter: Estimated 10-30 km
 Intensity: Felt over 600,000 sq. km. (intensity III (MSK) or greater).
 Peak Ground Accelerations: horizontal, 0.65 and 0.62; vertical, 0.52 g; recorded at Abbar Station.

Several seismographs were located in the affected areas. Reference 5 provides maximum peak accelerations recorded at 15 stations within 200 kilometers of the epicenter.

GENERAL DAMAGE

The earthquake area was one of the most agriculturally and industrially developed regions of Iran. Several major and modern industrial facilities and a major concrete buttress dam are among the facilities within 20 miles of the epicenter. The cities of Manjil, Roodbar and Lushan were heavily damaged with very few buildings standing in Roodbar. According to government figures, an estimated 100,000 adobe houses, mostly in villages, had collapsed or sustained such severe damage that they had to be demolished. The number of casualties is estimated to be at least 35,000 and possibly as high as 40,000. Most of the casualties occurred when adobe houses collapsed on

residents. Some lives, specially in cities, were spared due to the fact that many people were up and outdoors watching world soccer games on television.

Generally, the observed damage to engineered facilities was in the form of rock slides over highways, collapse of portions of tunnels, building collapses due to liquefaction, minor cracks in a major dam, minor damage to a modern grain silo, extensive damage to equipment in many industrial facilities including a major cement plant, some damage to a power plant, and damage to nonstructural elements in residential and office buildings.

GEOTECHNICAL DAMAGE

Along the major highway from Gazvin to Rasht there were numerous rockslides. The entrances to three tunnels in

this area had collapsed. The Shirinsoo tunnel near Kuheen had collapsed twice, once during the main shock and again two days later due to aftershocks. In the resort town of Masooleh, with a population of 2500, several rocks approximately the size of a passenger car were released from the mountains above the town and rolled down the slope. These rocks had completely demolished several houses in their path, resulting in 10 deaths.

Some evidence of liquefaction was observed in the town of Astaneh-Ashrafieh where sand boils had completely filled up 8-10 meter deep water wells. Also, due to liquefaction, several houses were unevenly uplifted, or sunken resulting in severe damage. Further evidence of liquefaction and sand boils was observed under the Bala-Bala bridge.



Damage to exterior of the hotel Bozorge Guilan



Damage to exterior of the hotel Bozorge-Gullan.

DAMAGE TO ADOBE AND TRADITIONAL BUILDINGS

The majority of houses in villages in the affected areas were adobes with sun-dried mud bricks or stone walls. When the adobe buildings were subjected to earthquake forces, the heavy mass of the roof and walls developed relatively large inertia forces, and since buildings lacked even minimum continuity, they collapsed.

MODERN RESIDENTIAL AND OFFICE BUILDINGS

Most engineered buildings in Iran are of steel construction. In the areas affected by the earthquake, steel structures of 3 to 8 stories were very common. The design of steel and concrete structures in Iran is generally based on the AISC specification and ACI code respectively. Some provisions of German and French codes are also used. Damage to modern residential and office buildings designed according to governing codes, in most cases, was limited to cracking or complete failure of non-structural walls and partitions. Iran has a long history of construction of buildings to last. Examples of

buildings and bridges several hundred years old abound. However, during the 60's and 70's a number of modern buildings were built by profiteering developers without due application of seismic codes and proper construction methods. Otherwise, the quality of construction of engineered buildings is in general similar to that of the US and Europe. During the earthquake, eight buildings of up to eight stories totally collapsed in the city of Rasht. According to city officials these buildings apparently were built by

developers and not designed and constructed according to governing seismic codes.

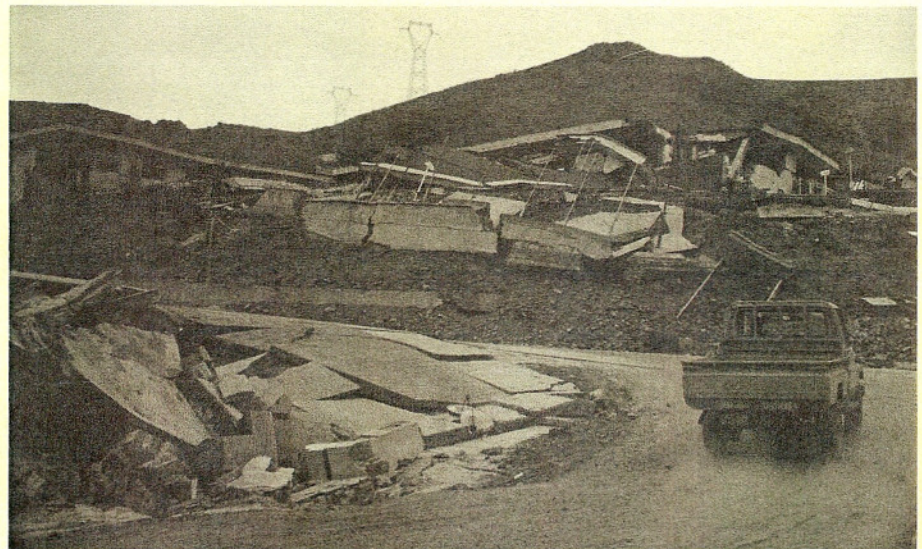
There was no engineered building that had observable structural damage. One steel building in Rasht was under construction at the time of the earthquake. Concentric diagonal braces were being added to the building to reinforce the original design to withstand earthquakes. The half-completed structure swayed laterally and caused cyclic buckling of the bracings and tearing of connections.

Damage to several other engineered buildings was in the form of cracks in interior partitions and cracking and spalling of exterior nonstructural facades. Also, equipment in the mechanical room had some damage to fittings and pipes.

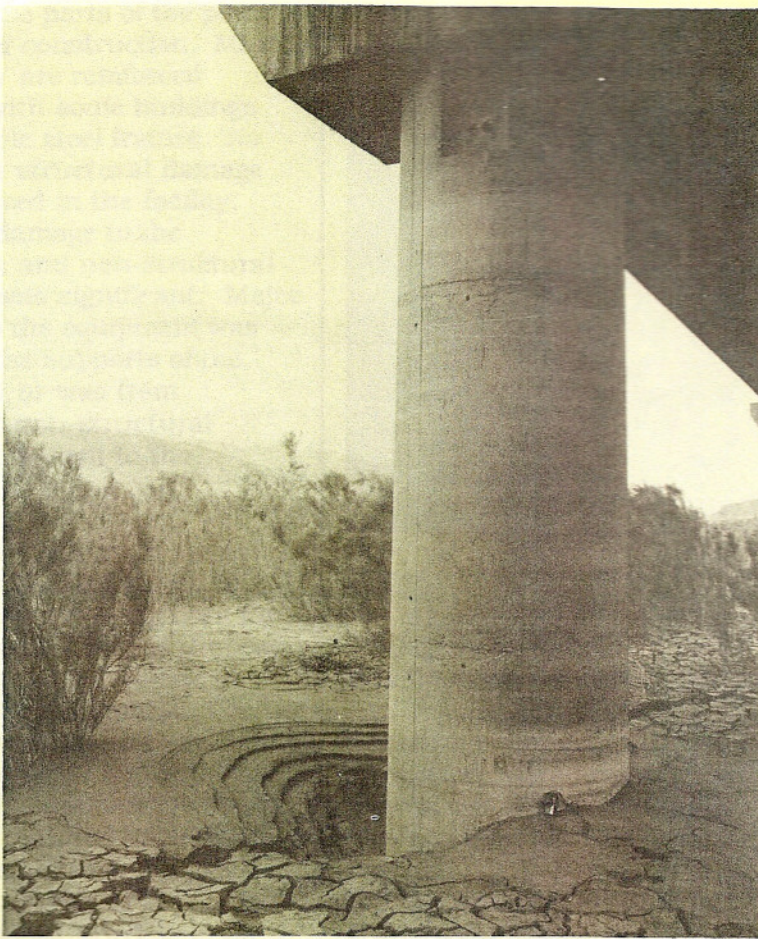
A major hospital with several one-story concrete masonry buildings in Rostamabad had completely collapsed, possibly due to sliding of the supporting soil.

DAMAGE TO HIGHWAY BRIDGES

There were three types of bridges



Collapse of Rostamabad Hospital, (about 15 miles from the epicenter).

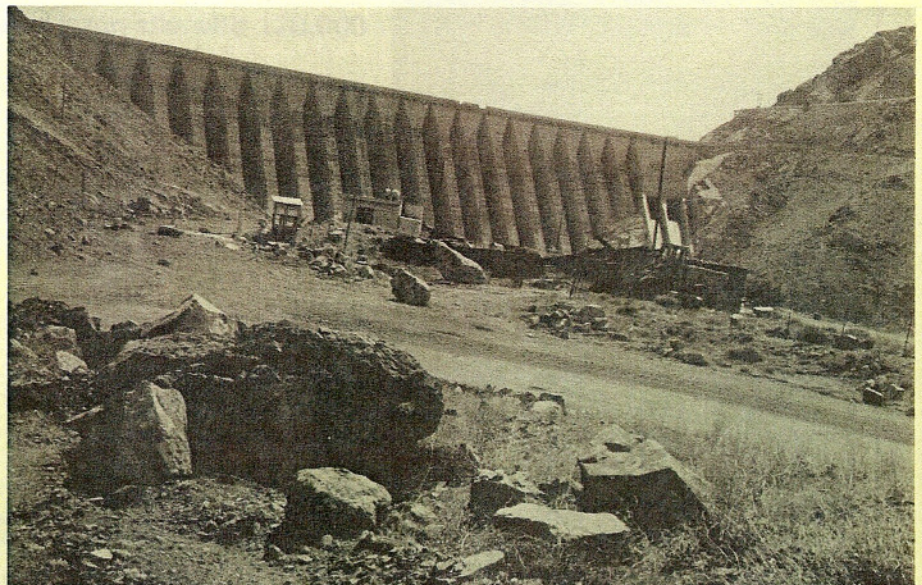


Soil liquefaction and sand boils under Bala-Bala bridge.

in the affected area: steel truss bridges, concrete bridges and old brick masonry arch bridges. Steel bridges had no damage. Two of the old arch bridges located within 15 miles of the epicenter had severe damage, resulting in closing one of two lanes. Damage to three major concrete bridges in the area within 20 miles of the epicenter was limited to pounding of longitudinal stringers against each other or against abutments, causing minor concrete spalling in structural members and major damage to non-structural sidewalks. At least one of the piers of the Bala-Bala bridge had a horizontal crack about 5 feet from the top of pier. The drybed of the river underneath the bridge showed numerous sand boils and a major subsidence of about 6 feet.

DAMAGE TO DAMS

The Sefidrud dam is a major concrete buttress gravity dam located only a few hundred



Sefidrud Dam which sustained minor damage.

meters from the causative fault. The construction of the dam was completed in 1967 and was designed for 0.25g horizontal equivalent static force. The dam is 106 meters high and at the base has a width of about 100 meters. The length of the dam at the top is 425 meters. The dam sustained minor damage in the form of horizontal cracks developing at the highest construction joint. Apparently this joint was about 9 meters below the water level at the time of the earthquake. After the quake, the water was drained, and the water level was below the crack line 4 days after the quake, when the EERI team visited the dam.

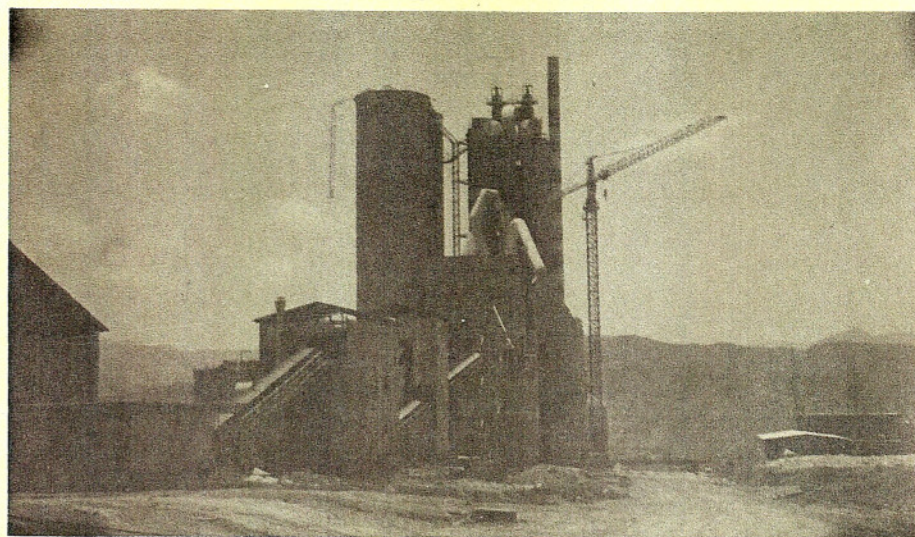
The one-story concrete office buildings, and power transmission equipment around the dam, sustained severe damage. One transmission tower collapsed and several transformer stations were damaged.

CEMENT FACTORY DAMAGE

The Lushan cement factory with 2000 ton production is located within 10 miles of the epicenter. The facility is a modern factory designed and built in the last 15

years. Some parts of the plant were under construction. Most structures are reinforced concrete with some buildings having gable steel frames. No significant structural damage was observed in the facility. However, damage to the equipment and non-structural elements was significant. Major damage to the equipment was failure of the supports of the equipment or was from collapsing non-structural elements adjacent to the equipment.

Three of the four main steel containers that were used to store and feed raw material for cement production had dropped down about 10 inches due to failure of their supports. The supports in some cases had instrumentation, and acted as load cells to measure the weight of the raw material to be fed to the production line. The load cell supports did not appear to have sufficient provisions to prevent horizontal movement of the container. As a result, the supports had collapsed in an overturning manner causing these large and heavy containers to drop. Even though the containers did not seem to have been damaged, the impact had buckled diagonal bracing of the supporting structure and had



Part of the Lushan cement factory.

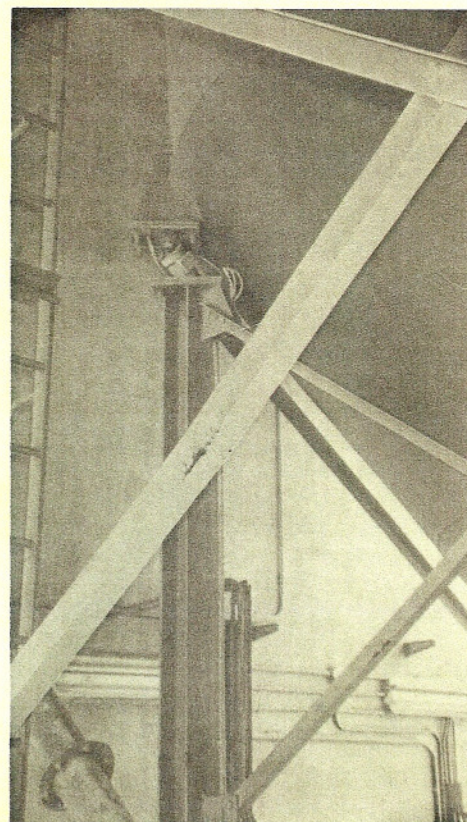
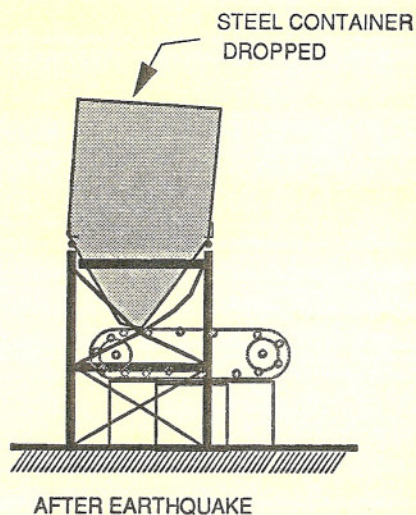
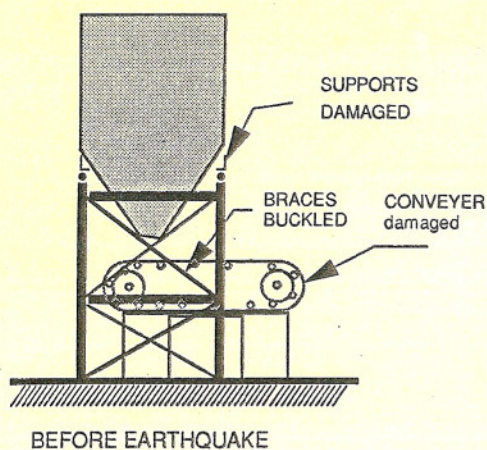
damaged the equipment below and the conveyer belt system.

Sensitive equipment such as computers, data acquisition and control systems, as well as modern laboratory equipment, were damaged. Damage was due to the impact of falling debris either from collapsed non-structural walls or collapsed false ceilings. The non-structural walls in this factory were generally hollow cement blocks with cement mortar and no reinforcing steel.

ton capacity located in the city of Rasht was also visited. The silo was completed only three years ago. The quality of construction of the silo appeared to be very good. The silo, which is about 50 miles from the epicenter, had performed well with only minor concrete spalling and a rebar buckling at the base of two columns of its

DAMAGE TO A MAJOR SILO

A major grain silo with 120,000



Collapse of support of main containers at Lushan cement factory.

elevator structure. In addition, all around horizontal cracks were visible at the location of two lower cold joints at the base of this tower.

POWER PLANTS

Iran does not have nuclear power plants. There were two major fossil fuel and gas burning power plants in the vicinity of the epicenter, one within 20 miles. The structures of the power plant had very minor damage. However, the reinforced concrete structural frames supporting the main power generators had sustained some damage. The most important damage was collapse of the heavy concrete non-structural walls on top of the main power transmission lines, where these lines were exiting the building. Even if the power generating equipment were operational, it would have been impossible to distribute power to the users.

WATER TANKS

There were three almost similar elevated reinforced concrete water tanks in Rasht. One tank was operational but totally collapsed during the earthquake. The two other tanks were under construction and horizontal cracks developed near the base of the main supporting pipe along the top of the opening.

SUMMARY OF OBSERVATIONS

Damage to modern engineered structural elements during the June 21, 1990 Iran earthquake was very limited. However, damage to equipment in industrial facilities was extensive and had resulted in decommissioning of some facilities.

The most important observation was that in most cases damage was caused by the collapse of



Empty R/C elevated tanks developed cracks, while full tank collapsed.

structural or nonstructural elements onto equipment. Similarly, sometimes movements of structural frames had caused severe damage to expensive non-structural elements.

Another important preliminary finding is that almost all engineered structures designed according to modern seismic codes and constructed well performed extremely well with almost no significant structural damage. The structures included buildings of up to 10 stories, bridges, a major cement factory, a major power plant, a major

dam, and a major grain silo. However, four reinforced concrete tanks did not perform satisfactorily.

It appears that an initial lesson one can learn from this earthquake is that in order to survive major earthquakes with minimum or at least tolerable damage, it is not sufficient to design structures properly or to attach equipment or non-structural elements to the structures properly, but one should consider the interaction of structures, equipment and non-structural elements. More research in this field is needed.



Soil liquefaction and sand boils under Bala-Bala bridge.

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ACKNOWLEDGMENTS

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Contribution by M. K. Yegian, Professor and Chairman, C.E. Dept., Northeastern University, and V. G. Ghahraman, PhD Student, C. E. Dept., Northeastern University.

INTRODUCTION

Between August 21 and August 29, 1990, the authors travelled to Iran at the invitation of the Ministry of Housing and Urban Planning of the government of Iran. The purpose of their trip was to assist Iranian engineers and government personnel in observations and evaluations of the damage caused by the Manjil, Iran, earthquake; and to share the experience they have

gained from their active involvement in earthquake evaluation and reconstruction in neighboring Armenia. Both northwest Iran and Armenia are located in the same tectonic region and experience similar seismic activity.

This report presents a summary of the authors' evaluations of the observed damage and the plans for reconstruction of the devastated regions in Iran.

THE EARTHQUAKE

The earthquake occurred on June 21, 1990 shortly after midnight, local time. The magnitude has been estimated to be between 7.3 and 7.7 on the Richter scale. Although official estimates indicate that 35,000 people lost their lives, it is believed by many that the toll most likely is greater than 50,000. The epicenter of the earthquake is inferred to be at or near the town of Manjil. A possible fault rupture has been observed that extends in the NW to SE direction through Manjil having a likely length of about 80 km. The fault is believed to be a right lateral thrust fault similar to that observed in Armenia.

GROUND MOTION

Fortunately, within the damaged region a number of strong-motion accelerographs successfully recorded the ground motion. In the vicinity of the fault, horizontal peak ground acceleration of 0.65 g has been recorded. At about 75 to 100 km from the fault the peak ground acceleration ranged between 0.07 g and 0.19 g.

STRUCTURAL DAMAGE

Because of the rural nature of the populated region within the earthquake zone, the earthquake damaged primarily one or

two-story single family houses. These structures traditionally have been constructed of unreinforced brick or masonry having little resistance to lateral earthquake-induced forces. The damage statistics compiled by the Ministry of Housing indicate that a total of about 75,000 rural housing units and about 16,000 urban housing units suffered more than 30% structural damage. Such unreinforced structures have been known to be extremely vulnerable to earthquake-induced damage or collapse.

The exception to the above observation was in Rasht, 70 km from the epicenter, where 9 engineered structures (5 to 8 stories) were heavily damaged or collapsed. Many other similar structures also in Rasht performed well. Examination of photos of the collapsed structures suggests that poor construction, especially the poor quality of welds in the steel structures that collapsed, was the most likely cause. The city of Rasht is founded on deep alluvium (possibly between 150 to 200 meters thick). The amplifying effect of the alluvium probably increased the ground accelerations to a level that strength demands exceeded the capacities of these inherently weak structures, thus causing their collapse. The structural design needs to be thoroughly investigated before a definitive cause for their collapse can be identified.

GEOTECHNICAL RELATED DAMAGE

Landslides and liquefaction of foundation soils also have played a significant role in the destruction of one and two-story residential and commercial buildings. A number of landslides completely buried small villages. But the most dramatic observations relate to the wide-

spread liquefaction and liquefaction-induced damage. Seventy to eighty kilometers from the epicenter, in and around the Astaneh-Ashrafieh region, over 30 villages and towns have suffered from liquefaction of loose saturated sands. Similar observations were also made near and around Sowmeah-Sara, also about 70 km from the fault. In Loshan, 20 km from the epicenter, widespread liquefaction occurred along the banks of the Sefid Rud River. In this region observations of a dike failure, slope failure and failure of the foundation of a steel trestle were made. Surprisingly, the Bala-Bala bridge located in this liquefied region survived with no damage even though the ground soil near the surface and around the large diameter piers had experienced 20 to 30 cm settlement and 40 to 50 cm lateral movement.

The widespread liquefaction observed during the Manjil earthquake raises an important concern regarding reconstruction and future development of the northwest region of Iran. This region has been and will continue to be seismically active. Furthermore, all along present and past river beds there are vast deposits of loose sands as evidenced during the Manjil earthquake. It is important to perform a comprehensive field geotechnical and geologic investigation to identify the presence, extent, and density of these susceptible sands to mitigate future earthquake damage in the region.

RECONSTRUCTION

Plans for reconstruction of the devastated region have already been formulated by the Ministry of Housing and Urban Planning. The experiences the government has gained from the reconstruction of war zones has been most useful in adopting a basic prin-

ciple regarding the role of the central and provincial governments in reconstruction. Previous experience has shown that the central government cannot fulfil people's economic, technical, social and cultural needs during reconstruction. It is recognized that participation of the affected people is extremely important during reconstruction from war, flood or earthquake disasters. The role of the government has been defined to provide field and site investigation, proper design specifications, infrastructure including roads and utilities, and construction loans. It has been decided that people will be responsible for reconstruction of their own units and generally in the same location as their previous dwellings. The government believes that the existence of villages in their present locations for decades and even centuries must have had a reason. These communities will not be relocated unless necessitated by technological considerations regarding the adequacy of the site with respect to future earthquake hazard mitigation.

In Armenia, unlike in Iran, the Soviet and Armenian government agencies have assumed complete responsibility for reconstruction of the earthquake devastated areas. Reconstruction progress in Armenia has been very slow and inefficient, and has been plagued with controversies and concerns by the local people such as decisions related to the relocation of cities and towns. Thus, the difficulties that are being encountered during the reconstruction of Armenia suggest that there may be significant merit in the Iranian plan for reconstruction, where the government has limited and well-defined participation together with the participation of the people who have suffered from the earthquake.