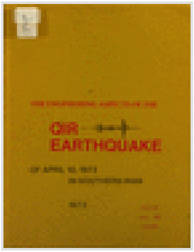


Engineering Aspects of the Qir Earthquake of 10 April 1972 in Southern Iran: A Report to the National Science Foundation (1973)

Pages
163

Size
8.5 x 11

ISBN
0309342228

Razani, Reza; Lee, Kenneth L.; Committee on Natural Disasters; Division of Engineering; National Research Council; National Academy of Engineering

THE ENGINEERING ASPECTS OF THE QĪR EARTHQUAKE OF 10 APRIL 1972 IN SOUTHERN IRAN

A Report
to the
National Science Foundation

Prepared
by

Reza Razani
Associate Professor in Structures
Department of Civil Engineering
Pahlavi University
Shiraz, Iran
and
Kenneth L. Lee
Associate Professor
Department of Mechanics and Structures
School of Engineering and Applied Sciences
University of California
Los Angeles, California

for the

Committee on Natural Disasters
Division of Engineering-National Research Council
National Academy of Engineering

Published by the
National Academy of Sciences
for the
National Academy of Engineering
Washington, D. C.

1973

NATIONAL ACADEMY OF ENGINEERING

COMMITTEE ON NATURAL DISASTERS

Ray W. Clough, Chairman
Jack E. Cermak
Alan G. Davenport
George W. Housner
Nathan M. Newmark

Nelson T. Grisamore, Executive Secretary
Joan M. Sieber, Administrative Secretary

This is a report of work done by the National Academy of Engineering under Contract No. NSF C310, Task Order 115, between the National Science Foundation and the National Academy of Sciences.

Table of Contents

Appendix

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This is a report of an inspection of the Qīr, Iran, earthquake of April 10, 1972, which was made for the Committee on Natural Disasters of the National Academy of Engineering. Participating in this inspection were Professors Reza Razani and Kenneth L. Lee. Professor Razani is a faculty member of Pahlavi University in Shīrāz, Iran, currently on sabbatical leave at the University of California, Berkeley. Professor Lee is a faculty member of the University of California, Los Angeles.

The members of this inspection team left California on April 18, 1972. One day was spent in Teheran and two days in Shīrāz obtaining maps, letters of introduction, and logistical support prior to leaving for the remote earthquake zone. A total of seven days was spent in the earthquake zone itself, after which the team returned to Shīrāz to draft the report. Professor Lee returned to California on May 3, 1972. Professor Razani remained in Shīrāz for an additional four days and in Teheran for one day to obtain from various government agencies the necessary permits and additional information, maps, and drawings for the report. He returned to California on May 9, 1972. During his stay in Shīrāz, he met with and briefed Professor Ray Clough, Chairman of the Natural Disasters Committee of the NAE, on the Qīr earthquake. Professor Clough came to Shīrāz to attend the first Iranian National Congress of Civil Engineering.

One of the purposes of this inspection trip was to determine whether or not a more comprehensive or specialized inspection mission should be organized, and one of the purposes of the meeting in Iran with Professor Clough was to make a decision on this matter. It was decided to recommend against sending an additional inspection team from the United States.

The NAE inspection team was joined in the field by Mr. Arthur Grantz of the United States Geological Survey and by Mr. James Dewey of the National Oceanic and Atmospheric Administration. They also met a UNESCO-sponsored inspection mission in the earthquake zone headed by Professor N. N. Ambraseys. These meetings led to a valuable cooperative exchange of information.

SYNOPSIS

On April 10, 1972, at 5:37 a.m. local time, a destructive earthquake of magnitude 6.9 occurred in the mountainous region of southern Iran near the town of Qīr, shaking an area about 400,000 km^2, virtually leveling the town of Qīr and the neighboring villages, especially those located on the alluvial valleys of Qīr, Karzin, and Afzar. Of the eighty villages affected by the earthquake, some fifty were totally destroyed and the rest received various degrees of damage. Earthquake effects on lands, soils, and foundations were not significant. Only small cases of ground and pavement failure, numerous rock slides, and some slope instability of the banks of the rivers and irrigation canals were observed. The earthquake disastrously affected structures, especially adobe and masonry dwellings. About 3,200 buildings were destroyed and some 5,300 people, or about 23% of the population of the area, were killed by the falling debris. Only a few engineered buildings were involved, the most important ones being a 10-span reinforced concrete bridge and an elevated steel water tank. Both survived the earthquake with insignificant damage. The few engineered masonry buildings in the area collapsed because of engineering and constructional shortcomings. Failures of adobe and masonry buildings with steel beams and shallow brick arch roofs, and with heavy flat timbered roofs were caused mainly by the poor quality of construction material and workmanship, the shear destruction of their load-bearing walls, the separation of connections between roofs and walls, and the disintegration of their non-rigid roofs. These defects prevented the structures from behaving as strong, rigid boxes. Wherever the roofs had tie beams and were monolithic, and wherever there were some undestroyed load-bearing elements such as steel columns, no roof collapse occurred. Rescue and relief operations were effective and satisfactory. The people are presently living in tent villages, awaiting the inauguration of the government's rehabilitation plans, which call for abandoning the small villages and creating a few modern rural centers under cooperative management.

In this report the seriousness of earthquake risks and the problem of earthquake hazard minimization in Iran are discussed and the urgency of enforcing a seismic building code for urban construction is pointed out. Various recommendations for improving the seismic strength of structures and for carrying out necessary research, education, organizational and legislative activities in Iran are given.

ACKNOWLEDGMENTS

The authors are indebted to Professor Ray W. Clough, Chairman of the Natural Disasters Committee of the U.S. National Academy of Engineering, for initiating and organizing this mission to Iran, and for his many helps and encouragements in carrying out this mission and in preparation of this report.

The authors also wish to acknowledge the assistance of:

Officials of Pahlavi University in Shīrāz, Iran, in particular, the Dean of the College of Engineering, for providing transportation facilities for the authors while in the earthquake area;

Officials of the Red Lion and Sun Organization in charge of relief operations, in particular, Messrs. Jahanmir and Amuzegar and General Dadsetani, for providing information and needed facilities;

Cultural attache of the U.S. Embassy in Teheran and head of the Iran-America Society in Shīrāz;

Mr. Khādam, head of the Iranian Geological Survey, for providing necessary maps and introductory letters;

Drs. Forati, Javandel, Khojasteh-Bakht, Mostaghel, and Poorshasb, members of the faculty of the Civil Engineering Department of Pahlavi University for providing needed information and for assisting the authors while in Shīrāz;

Dr. Thomas V. McEvilley of the Earth Science Department at the University of California at Berkeley for providing information of the earthquake and its aftershocks and on geology and tectonics of the area;

Mr. Fadaei Razavi, Ministry of Housing and Development of Iran, for providing construction drawings of the Qīr Clinic and the school of the village of Marand and for supplying some necessary photographs used in this report;

Mr. Davazdah-Emami of the Technical Bureau of Fārs Province for providing construction drawings of the Qīr elevated steel water tank.

Finally, the authors wish to acknowledge with pleasant gratitude the benefit and enjoyment they received from personal associations in the field with members of other investigating teams, each of whom went their separate ways in the daytime, but shared food, facilities, and information at a common tent-camp in the evenings near a small stream

1. INTRODUCTION

The earthquake occurred at 5:37 a.m. local time (02:06:53.2 GMT) on April 10, 1972. Early reports set the location of the epicenter some 60 miles west of the town of Qīr, close to the city of Jahrom. However, the major area of damage was centered around Qīr, and it seems that this early report of the epicenter location was somewhat in error. Based on information received from other seismological stations around the world, the location of the epicenter, as later corrected by NOAA, was 28.40° N latitude and 52.80° E longitude. This location is more in line with the damage intensity observed in the area. The surface wave magnitude of the earthquake was registered as 7.0 at the Pasadena seismological station, 7.1 at Berkeley, and was set officially at 6.9 by NOAA. A small single foreshock occurred hours preceding the main shock and was recorded at the Shīrāz seismological station (SHI). Hundreds of aftershocks occurred and were recorded at Shīrāz during the first few days following the main shock. Some of these aftershocks had a magnitude greater than 5.0.

The disaster area was located in the southern part of Iran, some 160 km south of Shīrāz between the principal cities of Jahrom, Firūzābād, Lār, and the coast of the Persian Gulf, as marked by the shaded zone in Figure 1.1. The main shock was felt in an area of about 400,000 km^2 within a radius of about 400 km around the epicenter. It was felt relatively strongly in Shīrāz, where the intensity was about III on the MM scale. There were reports that some poorly constructed houses in Shīrāz received minor damage. It was also reported that a few masonry walls of the top stories of the modern, one-year-old, 12-story Cyrus Hotel cracked and some window panes were broken, possibly due to far-reaching long-period effects of the earthquake. The earthquake was felt more strongly in Jahrom, about 75 km to the east of the epicenter, and in Firūzābād, about 65 km to the northwest. In Jahrom five weak buildings and a few walls collapsed and may others sustained minor cracks. However, no casualties were reported. The earthquake intensity in Jahrom was estimated to have been about V on the MM scale. A similar situation existed in Firūzābād. The intensity of the main shock in the

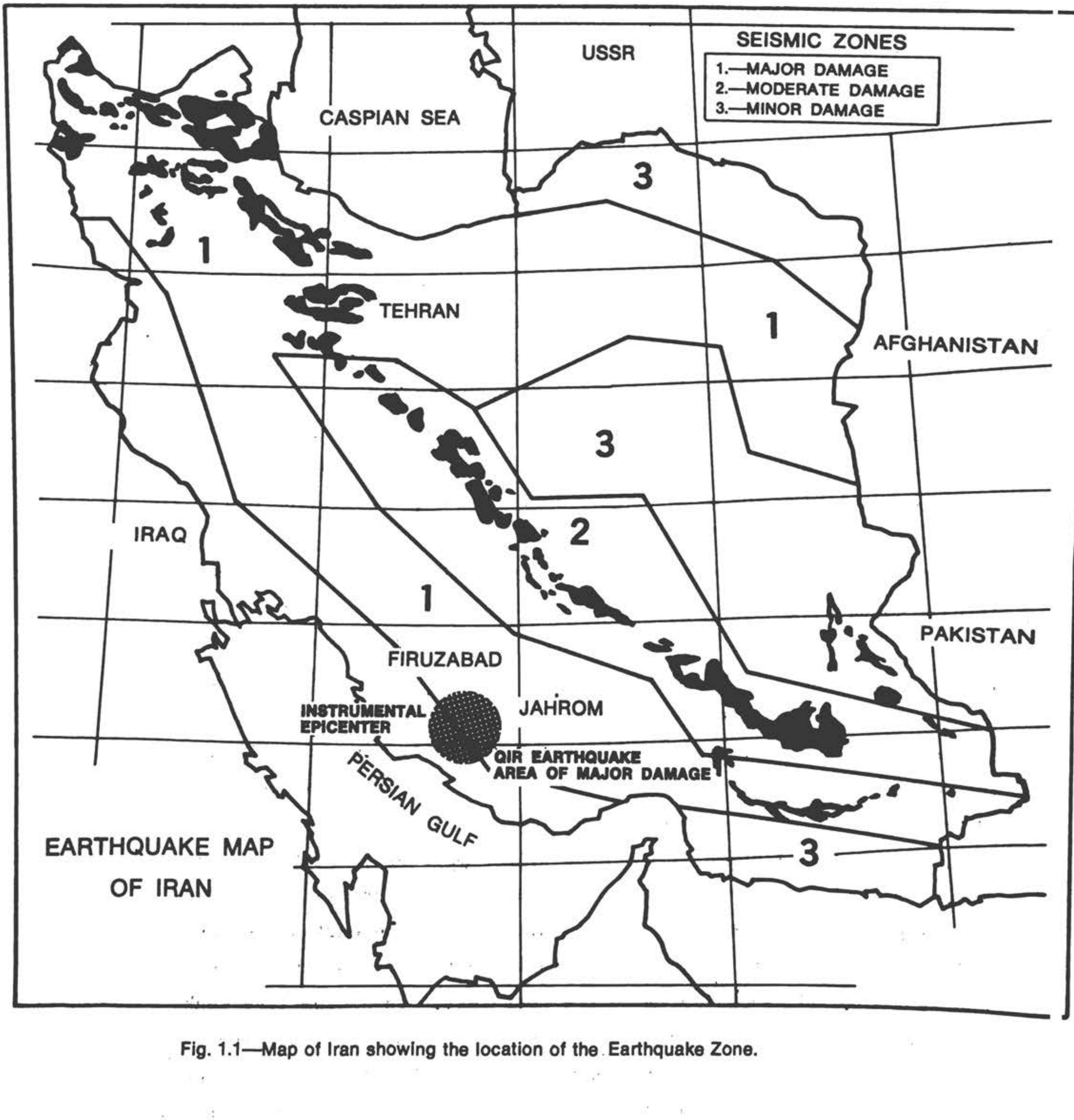


Fig. 1.1—Map of Iran showing the location of the Earthquake Zone.

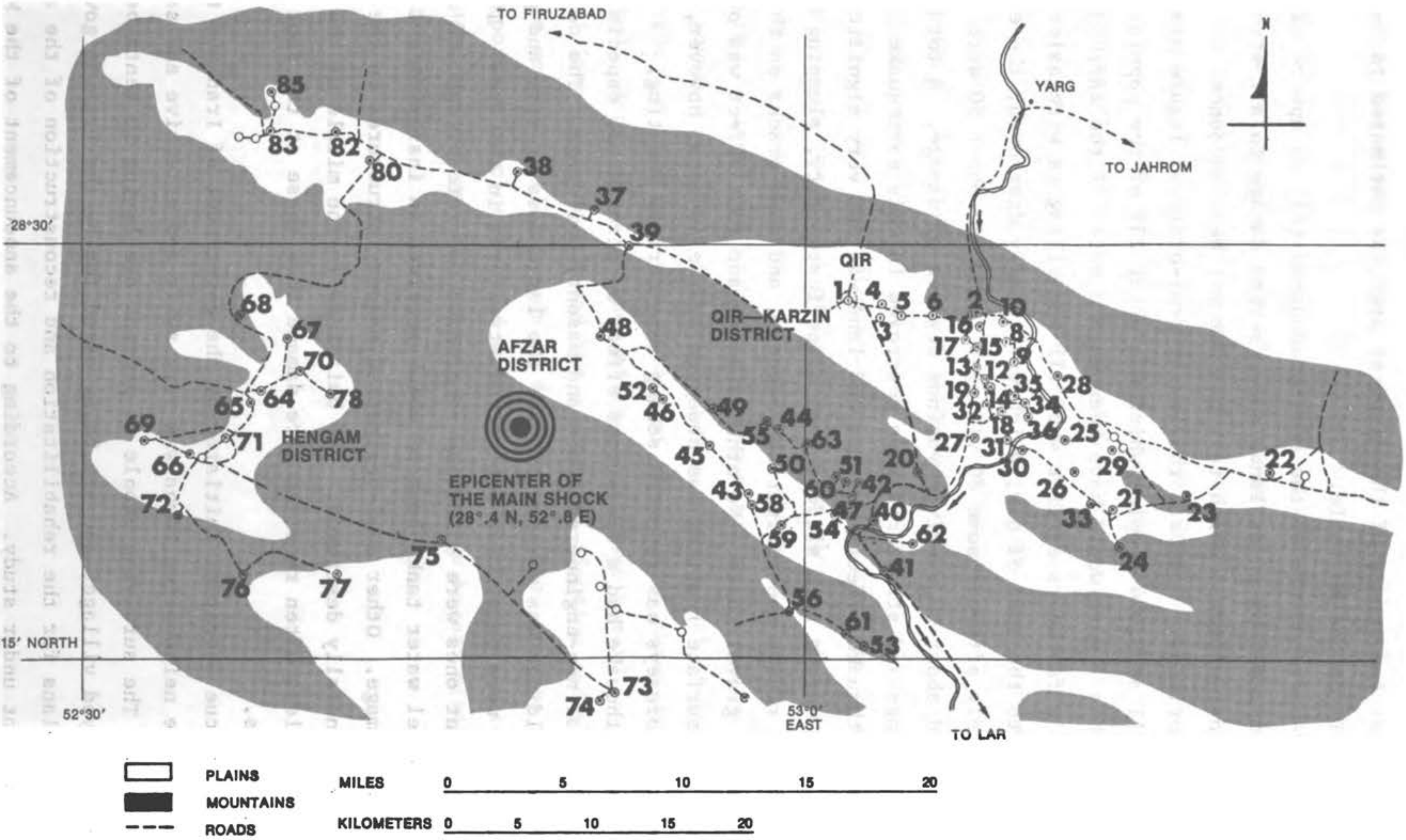


Fig. 2.1: Location Map of the Towns and Villages in the Disaster Area.

town of Qīr at the center of the disaster area was estimated to be not less than VIII on the MM scale.

Early reports described the estimated death toll as upward of 4,000 people, accompanied by major landslides, severe damage to all structures, etc. The final official death toll has not yet been announced by the Iranian authorities. However, the latest semi-official figure has put the death toll at 5,374 people, which was about 23% of the population of the area. This figure would have been much greater if the earthquake had occurred a few hours earlier when all the villagers were asleep. In addition to the town of Qīr, which was totally destroyed, the earthquake seriously affected some 80 villages, of which about 50 were totally destroyed and about 30 received various degrees of damage. A total of 3,160 buildings and structures were destroyed in this earthquake.

The earthquake effect on soils and land was not very significant except for numerous rock slides, some slope instability, slumping on the banks of rivers and irrigation channels, and some cracks on the shoulders of gravel roads. No other significant soil effect was observed. No surface faulting was observed by the authors; however, Professor Ambraseys has reported seeing some surface faulting.

The earthquake had a disastrous effect on structures, especially on traditional non-engineered adobe and masonry buildings. The collapse of these buildings was responsible for the large loss of life and property. There were only a few engineered structures in the area. The most important ones were a 10-span reinforced concrete bridge and an elevated steel water tank, both of which received an insignificant amount of damage. Other semi-engineered masonry structures in the area were generally destroyed. The buildings in the middle of the alluvial valleys often received more damage than those at the foot of the mountains.

The rescue operation initiated by the government of Iran and the people of the neighboring towns was very swift and effective and saved many lives. The surviving people at present are living in tents beside their destroyed villages and are being cared for by the Iranian government. The plans for the rehabilitation and reconstruction of the area are at present under study. According to the announcement of the Ministry of Cooperative and Rural Affairs of Iran, the preliminary plans seem to call for the abandonment of the concept of small villages, and, instead, recommend building four larger towns or rural centers in the four separate valleys which lie in the disaster area.

In the following Section of this report, the geography, geology, tectonics, seismicity, and other aspects of the earthquake-stricken area are discussed. The seismic history of the Fārs Province in southern Iran is described in detail, and the seismicity and seismo-tectonics of this area are also discussed in this Section. In Section 3 the engineering aspects of the earthquake effects are discussed. The general nature and extent of earthquake damage and other related information are described. Then, the local construction materials and methods are briefly described and a detailed discussion of the earthquake effect on various types of engineered, non-engineered, and traditional types of structures in the area is given and their failure modes and weaknesses are shown. Also, in this Section the effect of earthquakes on slopes, soils, foundations, and pavements is presented. In Section 4 the human aspects of the earthquake are discussed and problems of rescue and relief operation and future government plans for rehabilitation and renewal of the area are described. In Section 5 the summary of results and observations is presented. Here, the magnitude of the earthquake hazard in the urban areas of Iran is presented and the urgency of adopting and enforcing a suitable seismic building code is described. Also, in this Section some important conclusions and recommendations with regard to the Qīr earthquake and the general aspects of earthquake hazard minimization in Iran are given.

2. THE EARTHQUAKE-STRICKEN AREA

2.1- Geographical Setting

As shown in Figure 1.1, the affected area is a vast mountainous region in southern Iran within the province of Fārs. The area most severely damaged consists of the towns and districts of Qīr, Karzin, Afzar, and Hangam, located between three main cities: Jahrom in the northeast, Fīrūzābād in the northwest, and Lār in the southeast. The destroyed town of Qīr is located about 100 miles south of the historic city of Shīrāz, which is the capital of Fārs Province.

The topography of the area consists of numerous mountain ranges which are part of the Zagros range that covers a large region of western, central, and southern Iran. These mountains have an altitude of about 4,000 to 5,500 ft and are formed by sharply folded layers of limestone which all strike in a northwest-southeast direction. Within these mountain ranges there are high plateaus and talus slopes which in some areas level off into rich, level alluvial sandy silty valleys.

An indication of the relative orientation of towns, plains, and mountainous areas is illustrated in Figure 2.1. The principal town in this area is Qīr, which before the earthquake had a population of over 5,000. In the outlying areas, there are some 80 or more lesser towns and villages. These are identified by number in Figure 2.1. The names, population, and other data for these towns or villages in the affected earthquake area are listed in Table 1.*

The area is reached by one of three roads leading from principal towns or cities outside the area. From the north, roads lead in from Jahrom and Fīrūzābād. From the south, the area can be reached by a road from Lār. All these roads are dirt. The road from Lār is a newly constructed grade with a major reinforced concrete bridge crossing the Qara-Aqaj River at the village of Shāhābād (No. 40 in Figure 2.1) and numerous reinforced concrete and stone masonry arch culverts crossing streams and gullies. All other roads leading into the area, and from place to place within the zone, are unimproved dirt trails which ford the streams and change location from time to time, depending on local

---

*All tables are included in the Appendix.

conditions. The locations of the roads shown in Figure 2.1 are, therefore, only schematic.

Lack of good roads in the area made the reconnaissance somewhat difficult. Because of the high level of the Qara-Aqaj River, it was not possible to ford across it and reach the villages on the other side. Other investigating teams visited these villages by a long detour outside of the area, and the information reported herein for that zone was obtained from their observations.

2.2- General Condition of the Area

The climate is semi-arid with an average rainfall of about 10 in./yr. The mountains are almost completely bare except for thinly distributed shrubs and grass which grows in the springtime. This year was a particularly wet spring, with rainfall, thus far, about two times the long-term average. As a result, the one major river, Qara-Aqaj (or Mande), and the small streams were running high, and the mountains were lush with vegetation. Date trees were very abundant in the area; also, lemon, orange, tangerine, sweet lemon, and a kind of grapefruit (locally called toranj) grow in most village gardens. The principal crops are dates and various types of lemons, wheat, barley, rice, and other types of grains, and cotton. As water is scarce, irrigation is highly developed. Virtually every spring and stream is tapped and the water carefully regulated. In some areas they also use the ancient system of qanats to tap underground water for irrigation, but this is not so extensively used as in the north of the country.

In spite of the normally harsh conditions, the area supports a large population. Almost all of the people reside in numerous small towns and villages on or near the level alluvial valley floors and make a living from cultivating the rich land. The people living in the villages are relatively wealthy as compared with villagers in most other areas of Iran. Their language is a very pure dialect of Persian.

On the higher rocky plateaus, talus slopes, and lower portions of the mountains, village shepherds and the nomadic Qashqa'i tribes (who are of Turkish origin) graze flocks of sheep and goats. These nomadic tribes come to this area at the end of fall and stay in the area until the middle of spring, when the temperature becomes very warm. At this time they migrate to the cooler northern provinces. At the time of the authors' visit, many of these nomads were in the process of migrating to the north.

Using the statistical data shown in Table 1 and scaling off areas from a map, it would appear that the average population density over mountains and plains combined is at least 15 people per sq mile. Considering that most of the population is limited to the level plains, the average population density in those areas is about 100 people per sq mile.

2.3- Historical Aspects

The province of Fārs has been one of the highly developed areas of Iran, dating back to ancient times. It was the cradle of the Persian Empire between the sixth and fourth centuries B.C. The city of Estakhr and the royal palace of Persepolis, whose ruins are approximately 40 miles northeast of Shīrāz, were the capital and the center of administration of the Akamaenian Dynasty, one of the largest empires in the world, extending from India to Greece during that period. The condition of the southern region of Fārs Province during that period is not clearly known. However, as part of an advanced region of the world, it can be assumed that it enjoyed a high level of development at that time. The city of Firūzābād (originally called Gour), about 65 km northwest of the town of Qīr, seems to have been an important and prosperous city at the end of this period, but it was destroyed by Alexander the Great of Macedonia about 331 B.C.

The next available information about the area is from the period of the Sassanid Dynasty (226 A.D. to 651 A.D.) and indicates that the province of Fārs had regained its importance during that period. There exists much archeological evidence, such as roads, remains of bridges, fortresses, and fire temples, from this period which indicates the existence of a high degree of development and civilization in the area. The city of Firūzābād seems to have again become an important center at this time.

Many early Moslem geographers and historians have visited Fārs

Province and have recorded the condition of the area in their books and chronicles. Their observations indicated that the earthquake-stricken zone and its surrounding areas up to the eleventh century A.D. was advanced, prosperous, and well-developed, with most of the present cities existing. In this period the town of Qīr was surrounded by protective walls. The town also had a strong old fortress (probably on the top of the existing mound where the ruins of the fortress of Parnian is now located, which is approximately 2 km from the present town of Qīr). The irrigation water of Qīr came from the springs which flowed from the mountains. Karzin (now a village called Biān, No. 15 in Figure 2.1) was the most important town in the region. Its population and size were about one-third of the city of Estakhr (probably about 10 to 15 thousand people). There were walls around the town and a very strong fortress existed inside the city walls. The water for its irrigation came from the Qara-Aqaj River (at that time it was called the Sakan River). Karzin was the administrative center of the country of Qobad-Khoreh and there were many dependent villages around it. It was located on the major caravan route between the city of Shīrāz and the port of Siraf. This port was one of the most important commercial and military ports on the Persian Gulf during the early Islamic period. It was destroyed by an earthquake in the year 978 A.D.

Another relatively important town in the area was the town of Abzar (or Afzar) which was the administrative center of the region with the same name. At the present time in this region no town with such a name exists. However, the region is presently called the district of Afzar, which consists of many villages within the neighboring valley southwest of Qīr. The most important villages of this district are Marand, Baghenow, Mozaffari, and Haftasiab, shown by numbers 58, 44, 59, and 63 in Figure 2.1, respectively. Most of the irrigation water of these villages comes from the Qara-Aqaj River.

The earthquake-stricken region seems to have lost its economical and social importance about the early twelfth century A.D. While possible frequent earthquakes may be blamed for some periodical destruction of the area, the main reason for the decline of this region was the weakness of the centralized government resulting from the general political instability of Iran at that time and after the Mongol invasion.

Immigration of non-Persian nomadic tribes to the area and oppressive exploitation of the farmers and population by local feudal and war lords have also contributed to the decline of the area. The existence of these conditions up to the past decade has reduced these old cities to small towns and villages. Lack of good roads, hot temperature during more than half of the year, lack of sufficient water with periodic drought, and remoteness from major cities or centers are also among the important causes of the slow growth of the area.

2.4- Geology and Tectonics

The earthquake area is one of tightly folded northwest-southeast-trending mountains in the Zagros range, which extends the length of the country on its southwest border along the gulf. The mountain peaks reach an average of about 1,000 m above the valley floors. The valleys are generally less than 10 km wide, elongated northwest-southeast, fairly flat, with elevations 500 to 1,000 m above sea level. Villages and roads are naturally located in the valleys, the mountain slopes being very steep at the valley edges.

Takin (1972), in summarizing Iranian geology, considers the Zagros folded belt along the southwest part of the country to be completely different in geological history and tectonic development from the rest of Iran. The Zagros region remained relatively stable with conformable sedimentation from Cambrian to Pliocene time, attaining its folded nature through the late Tertiary Zagros orogeny. The section is predominately carbonate, with some salt diapirs. Parallel anticlines and synclines trending northwest-southeast characterize the Zagros range, the folded complex being clearly separated from the interior mass by the long, deep Zagros thrust zone.

Earthquakes in the Zagros region are primarily shallow, but occasionally occurring at depths greater than 200 km in the central sector. Near Lār, toward the southern end of the region, focal depths range mainly from 0 to 100 km, with very few shocks deeper than 100 km.

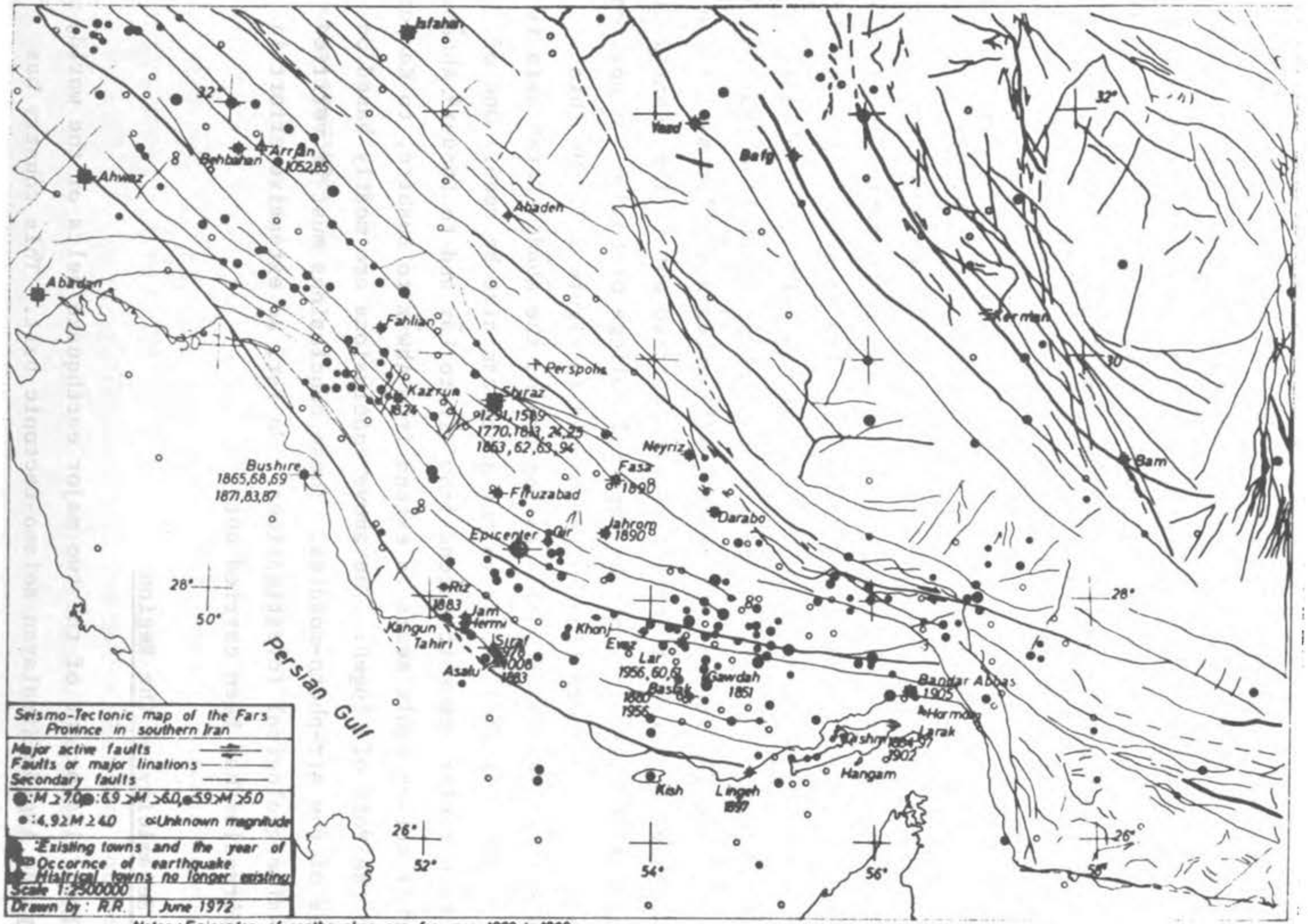
Nowroozi (1971, 1972) studied earthquakes in the Zagros belt, inferring the earthquakes in the Lār area to define a slab nearly 60 km thick, dipping northward at 10° to 20°, the subduction zone accommodating, at least partially, the relative motion of Arabia towards Persia. Fault plane solutions in the Lār area indicate horizontal compression normal to the fold axes and the thrust zone.

Mapped faults shown on the British Petroleum Company map of southwest Persia do not show any major throughgoing fault on the surface. The large percentage of earthquakes with focal depth around 50 km in the area, plus the first motion studies of Nowroozi (1971, 1972) indicate the dominant mode of strain release to be through relatively deep reverse faulting.

Wellman (1965) has mapped the fault patterns of Iran, using air-photo-mosaics. He has concluded that along the Zagros mountains there is an active dextral fault which is wrench-type in character and is the continuation of the Anatolia fault. He has also found many parallel faults between the Zagros fault and the Persian Gulf, but the indications of fault movement are more numerous on the Zagros fault line than on the parallel adjoining faults. Banisadr (1971) gives a similar map of the faults, based on air-photo-mosaic studies carried out in the Department of Engineering Seismology of the Imperial College of London. A portion of his map for Southern Iran is reproduced in Figure 2.2. On this figure the active Zagros fault passing around the Ābādeh-Darab axis is shown. Other parallel faults to the south can also be seen. One of the active faults seems to extend from Qīr to Lār and to Bandar ʿAbbās. The other active fault seems to extend from Ahwāz to Bushire, to Kangun, and to the Port of Lingeh. The above conclusions are mostly based on studies of the air-photo-mosaics. These conclusions must be verified by on-site geological investigations. So far, no extensive effort in this direction has been carried out.

2.5- Seismicity of the Region

Iran lies on one of the two major earthquake belts of the world, namely the Alpide-Himalayan seismo-tectonic belt. This country has experienced many destructive earthquakes in its recorded history [Ambraseys (1968) and Wilson (1930)]. During the past two decades alone, more than 30,000 people have lost their lives in three major earthquakes and numerous minor earthquakes.



Notes: Epicenter of earthquakes are for year 1900 to 1969
Fault lines & epicenters are reproduced from the Thesis of Banisadr (1971)

FIGURE 2.2 Seismo-Tectonic Map of the Fars Province in Southern Iran.

The province of Fārs in southern Iran has also experienced many destructive earthquakes in the past. While no record of earthquakes before the Islamic period (651 A.D.) is available, some records of the destructive earthquakes in the past 1,000 years in various chronicles, historical books, and manuscripts have been recorded. The information in these sources is mostly concerned with the events in or around large cities. The ancient city of Arrjan (see Figure 2.2), whose ruins are located near the present city of Behbahan, was damaged by earthquakes in the years 1052 and 1085. The historic port of Siraf near the present port of Tahiri, approximately 140 km south of the town of Qīr, was destroyed by earthquakes in 978 and 1008.

The city of Shīrāz has been the center of culture, trade, and government of Fārs Province for most of the past 13 centuries. It has a relatively well-recorded history which shows that it was destroyed or damaged by earthquakes in the years 1291, 1588, 1769, 1824, and 1853. Because of the lack of detailed records from these old dates, it might be presumed that many past strong earthquakes are unrecorded. However, in more modern times, beginning with the nineteenth century, the appearance of newspapers, the existence of well-kept records, and the general development of commercial, political, military, and socio-cultural activities in southern Iran have led to a better record of earthquake history.

Wilson (1930) mentions that earthquakes are not infrequent in southern Iran, but he finds little reference about them in current literature. As an indication of the occurrence of destructive earthquakes in the area, he cites that of all the massive bridges built from the Sassanid period onward, often of great beauty, solidity, and strength, not a single one remains. He concludes that seismic movements rather than abnormal floods or operation of decay and neglect have possibly been the major cause of their destruction. He observes that the steady diminution in the number of pillars noted as standing at Apadana Hall at Persepolis by successive travelers suggest that earthquakes have been frequent but not excessively severe. The construction of these pillars is so massive as almost to preclude destruction by any other agency. There were originally 72 pillars in this hall when it was constructed in 512 B.C. The reduction in number standing, as reported by various travellers, is shown in Figure 2.3, until today, only 13 remain.

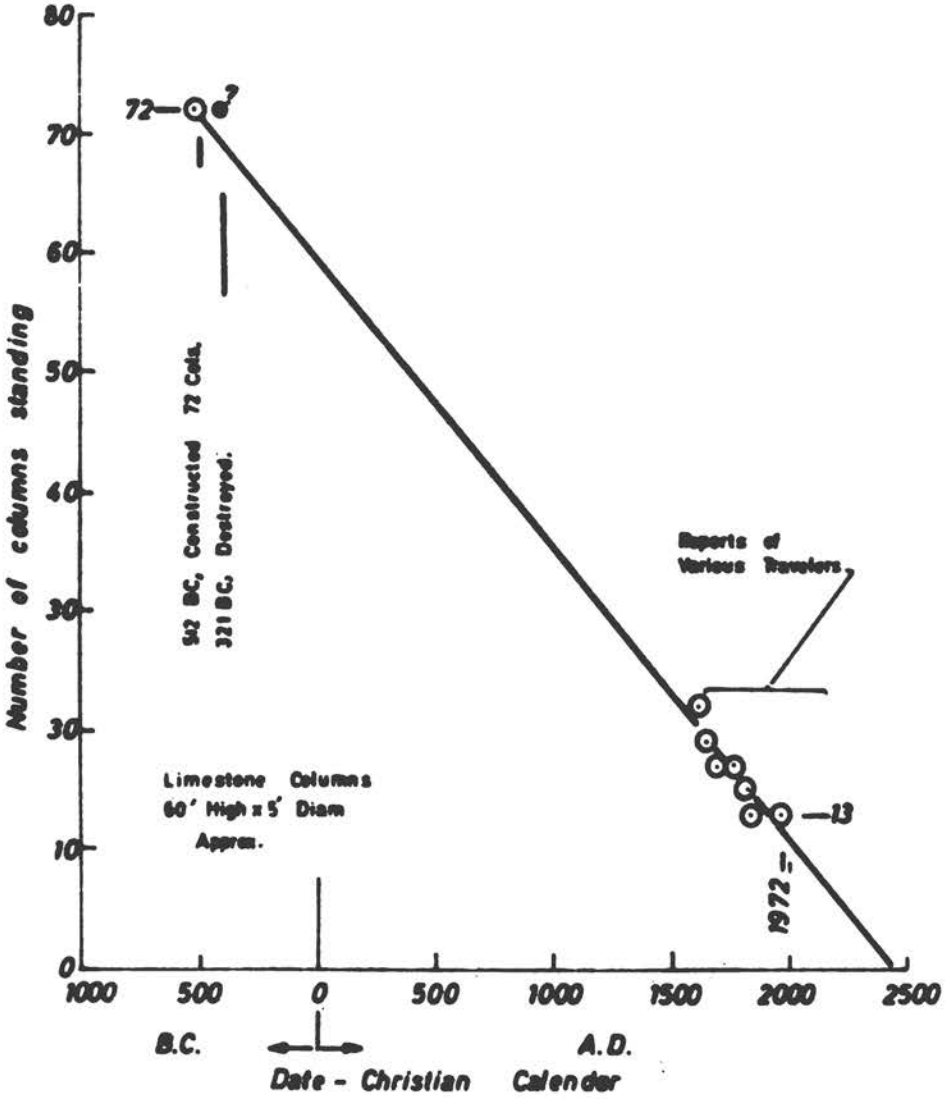


FIGURE 2.3 Diminution of the Number of Columns Standing at the Apadana Palace, Persepolis, Iran, During the Past Centuries.

Apparently, some earthquakes have caused sections of certain pillars to rock without tipping over. The traveller today can see some columns where the topmost stones have been rotated some 30 to 40 degrees and are displaced from their original position, and overhang the edge of the parent-pillar, as shown in Figure 2.4.

Although historical and archeological evidence indicate that the Qīr-Karzin-Afzar area has been continuously inhabited since the beginning of recorded Persian civilization, it seems that no major cultural center in this region has ever been developed, and hence, no historical records of the past earthquakes seem to exist.

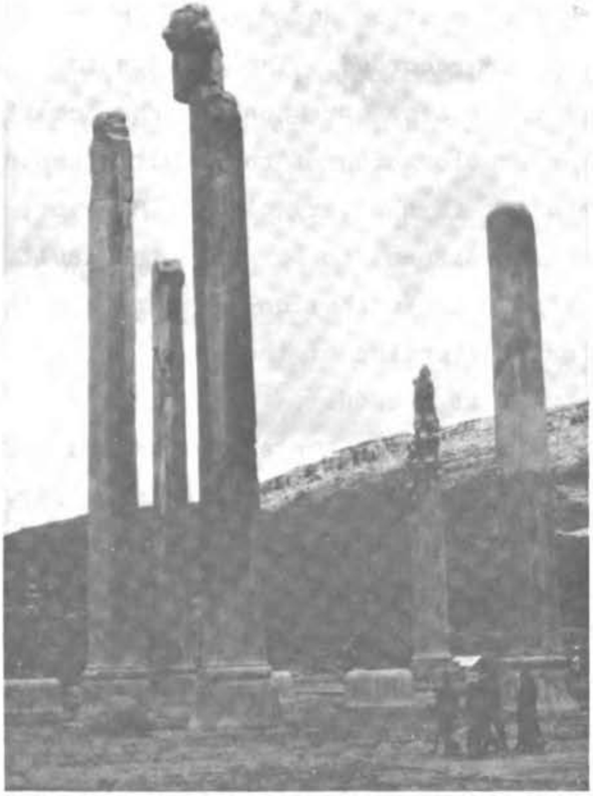


FIGURE 2.4 Displacement and Rotation of the Top Portion of a Column at Persepolis, Iran, Possibly Due to the Past Earthquakes.

Passing through the area, one finds many remains of old adobe brick and rubble stone villages which may well have been destroyed and abandoned due to past earthquakes. The old people in the area, while recalling many small earthquakes, did not recall any destructive earthquake in or around Qīr during their lifetime or as told by their fathers. There were some reports that Qīr had been damaged or destroyed by an earthquake about 102 years ago, but the authors could neither verify these reports nor find their source.

A detailed list of the historical earthquakes in the province of Fārs is given in Table 2. At the end of this table are given a list of the recent destructive earthquakes and also a description of other miscellaneous historical earthquakes whose accuracy have not yet been verified by the authors. In addition, all earthquakes in the area recorded for the years 1900 to 1970 having a magnitude greater than 4.0

are listed in Table 3. The epicenter of these earthquakes and of similar earthquakes in the neighboring regions is shown in Figure 2.2.

On this figure the location and date of the historical earthquakes discussed in Table 2 are recorded. The correlation between the location of the epicenter of the recent earthquakes, the location of the historical earthquakes, and the location of the fault lines obtained from the air-photo-mosaic studies is not very clear. However, the general trend of the seismic activities seems to be along the fault lines shown. For more accurate results, much further on-site investigation of the fault lines and statistical correction of the location of the epicenters of the recorded earthquake is needed.

During the past two decades there has been an extensive amount of seismic activity in the region around the city of Lār, with major shaking in 1956, 1960, and 1961. During the earthquake of April 24, 1960, the city of Lār was destroyed and more than 1,500 people were killed. The description of these earthquakes is given in Table 2.

On the basis of the seismic data available for different regions of Iran during this century (from 1900 to 1970), Moazami-Goudarzi (1971) has made a statistical study of the seismicity of the Iranian Plateau. He has estimated the return period of the earthquakes with different magnitudes for various regions of Iran and for the entire country. According to his studies, the return period of earthquakes in Iran are:

one earthquake of $M \geq 5$ every 8 months;
one earthquake of $M \geq 6$ every 3 years;
one earthquake of $M \geq 7$ every 20 years.

For the region between 28° to 30° N latitude and 51° to 54° E longitude, which includes the Qīr and Shīrāz areas, the return periods are:

one earthquake of $M \geq 4$ every 2 years;
one earthquake of $M \geq 5$ every 6 years.

For the region to the west of the earthquake zone, above the city of Lār, between 28° to 30° N latitude, and 54° to 57° E longitude, the return periods are:

one earthquake of $M \geq 4$ every 4 years;
one earthquake of $M \geq 5$ every 8 years;
one earthquake of $M \geq 6$ every 57 years.

These statistical studies are very useful and indicate the seismicity of the area. However, as these studies are based on a period of observation which is short in geological time-scale, they may exclude the long period major events and the geological and tectonic effects. Therefore, the accuracy of these statistical studies, when possible, should be improved by reference to the historical data of many past centuries and the geological and tectonic factors. In the absence of detailed historical information from earlier centuries, the frequent seismic activity of the nineteenth and twentieth centuries can be taken as being representative of the general seismicity of the region.

3. ENGINEERING ASPECTS OF THE EARTHQUAKE EFFECTS

3.1- General Nature and Extent of Damage

With very few exceptions, all of the observed earthquake effects were limited to adobe or stone masonry buildings and walls. Certainly all the deaths, injuries, and almost all of the property damage were related to the complete or partial collapse of this class of structures.

In Table 1 the names, numbers (for identification of the locations of the villages in Figure 2.1), population, number of buildings before the earthquake, number of people killed and injured, number of buildings left standing after the earthquake, and the percentage of population killed in each village are given. Figures 3.1 and 3.2 show the appearance and type of buildings of two undamaged typical villages far from the epicenter. The first village is located at the foot of the mountain and the second village is in the middle of the alluvial valley. The type of construction in the area and the detailed description of the damage will be discussed in Section 3.2. It was not possible to obtain any pre-earthquake views of the town of Qīr.

FIGURE 3.1 A Typical Village Located at the Foot of a Mountain.

FIGURE 3.2 Another Typical Village Located in the Plains.

Figures 3.3, 3.4, and 3.5 show the degree of destruction and some typical views of this destroyed town after the earthquake. It is seen that only a few walls remain standing. According to the data of Table 1, 67% of the people of this town, which had a population of 5,399, were killed by the earthquake.

FIGURE 3.3 Destruction in the Town of Qīr.

FIGURE 3.4 Destruction in the Town of Qīr.

FIGURE 3.5 Destruction in the Town of Qīr.

Figures 3.6 and 3.7 show the degree of damage and destruction and some typical post-earthquake views of the villages of Sekehravan (No. 4 in Figure 2.1) and Baghe-Now (No. 44 in Figure 2.1). The former village was located in the middle of the alluvial valley and a large portion of the latter village was at the foot of the mountain. The percentage of deaths in these villages was 24% and 15%, respectively.

FIGURE 3.6 Destruction in the Village of Sekehravan.

FIGURE 3.7 The Village of Baghe-Now.

Figures 3.8 and 3.9 show the degree of damage and the post-earthquake view of the lower and upper zone of the village of Liferjān (No. 10 in Figure 2.1). These two zones were very close together; the upper zone of the village was located at the foot of the mountain, the lower in the valley.

FIGURE 3.8 Destruction in the Lower Liferjān Village (Located in the Valley).

FIGURE 3.9 The Village of Upper Liferjān (Located on the Foot of the Mountain).

All the buildings in this village were destroyed or extensively cracked; however, the percentage of total collapse in the upper zone was much less than that in the lower zone. This can also be seen from the comparison of the above figures. In most cases, it was observed that the villages at the foot of the mountain, in comparison with neighboring villages in the middle of the alluvial valleys, received much less damage and death.

Many additional factors influenced the percentage of deaths in any particular village. The most important ones were the distance from the epicenter, type of buildings, density of population in the villages due to the proximity of the buildings, the number of stories of the adobe houses, etc. It was observed that in the villages where buildings were very close to each other or where there were many two-story adobe buildings (as in the town of Qīr), a much higher percentage of earthquake fatalities occurred, which may not necessarily have been due to a much higher earthquake intensity in those villages.

While traveling through the area and interviewing the surviving villagers, the investigating team decided that perhaps the most convenient basis for assessing the relative degree and extent of significant shaking was the death toll in the particular village. Although scarcely any adobe structure in the area escaped minor damage, there was often a definite, discernable difference in the degree of damage from place to place, and this difference appeared to be reflected by the relative number of persons killed. Thus, since time did not permit a more rigorous analysis, this was used to indicate extent of strong shaking. This index is particularly valid for comparison of earthquake intensity in small villages where most structures were single-storied and relatively separate from one another.

Data from Table 1 has, therefore, been plotted in Figure 3.10 to illustrate the relative degree of destruction of the earthquake from place to place, as well as the extent of strong shaking. Also in this figure, it can be seen that in most cases the villages at the foot of the mountains had less fatalities.

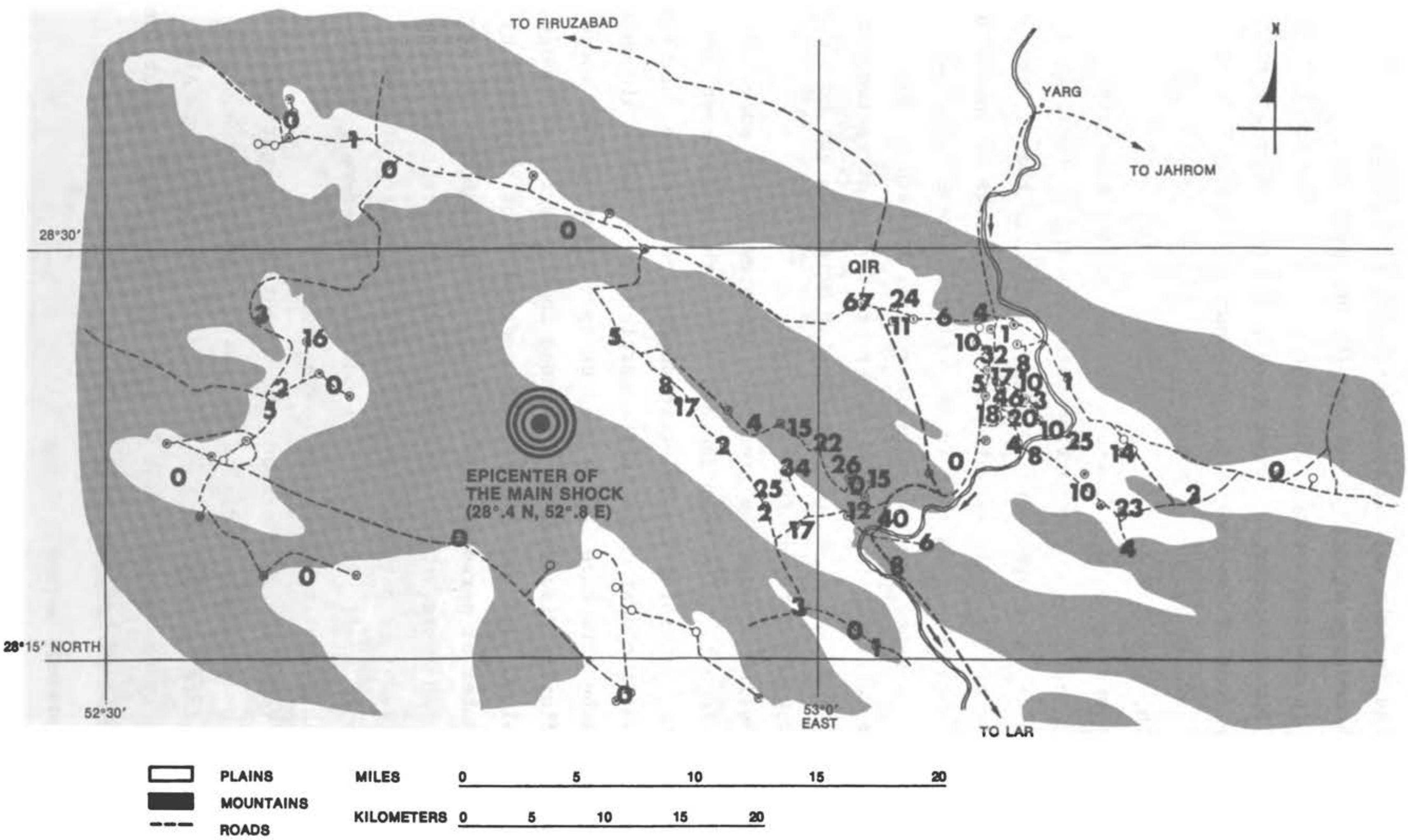


Fig. 3.10: Percentage of Earthquake Fatality In Each Village. (Use This Figure With Figure 2.1 and Table I)

3.2- Effect of Earthquake on Structures

Fortunately, the Qīr earthquake did not seriously affect any large city; otherwise the loss of life and destruction would have been many times greater than it was. Most of the structures in the earthquake zone were of traditional adobe type construction. There were only a very few engineered structures or even non-engineered brick masonry structures in the area. While detailed study of the engineering aspect of the destruction of these local structures seems to be irrelevant to the engineering practice and construction in the U.S., the destruction of these types of construction is the major cause of death during earthquakes in Iran and in many developing countries. In Iran alone more than 30,000 people have lost their lives under these types of buildings during the past two decades. Replacement of these structures with earthquake resistant structures using modern material and technology will be economically and technically very difficult to achieve even in decades to come. Designing feasible earthquake resistant structures with local material, methods, and construction technology is the most challenging task confronting the engineers in these countries. It is the opinion of the authors that the engineers and researchers of advanced countries should use their expertise to help in finding a solution for this problem. For this reason, in this report the effect of the earthquake on these types of structures is discussed in some detail.

In this Section, local construction materials, methods of design, and methods of construction are discussed first. This is followed by a discussion of the effect of earthquakes on the engineered structures, non-engineered modern structures, and non-engineered traditional masonry and adobe type structures. A few case studies of the failure mode and seismic behavior of each type of construction are also given.

3.2.1- Local Building Materials and Methods of Design and Construction

3.2.1.1- Local Construction Material

Earth is the most popular low-cost construction material available in rural areas around Qīr and, in general, in most rural areas of Iran except in the wooded and moist area around the Caspian Sea. Earth is generally used in the construction of walls in the form of adobe bricks (Figure 3.11) and mud blocks (Figure 3.12).

FIGURE 3.11 Some Typical Adobe Houses.

Earth is also used for insulation purposes in the construction of roofs, as shown in Figure 3.11. A mixture of earth and straw (locally called kahgel) is used for plastering the walls and the roofs (Figure 3.13). Adobe bricks are a sun-dried mixture of earth and water. Sometimes straw is added to the mixture to prevent shrinkage cracks (Figure 3.14). Mud is used as mortar for adobe structures and in the construction of some walls made of irregular stones.

The sun-dried mud bricks possess compressive strength in the range of 10 to 30 kg/cm^2 [Razani-Behpour (1970)]. However, brittleness, low tensile strength, excessive shrinkage, weakness against water effect, and the heavy weight make it a poor construction material, especially for seismic regions. The popularity and wide use of earth as building material in rural areas of Iran is mostly due to its very low cost, local availability, good insulation properties, ease of handling and use, and lack of any other economically feasible alternative.

Other important construction materials used in the villages are stone, lime, gypsum, straw, and wood. Stone, where easily available, is used for the construction of walls with the mortar made of mud, as shown in Figure 3.15.

FIGURE 3.12 A Typical Mud-Block Wall, Reinforced with Wooden Branches, in the Village of Sekehravan.

FIGURE 3.13 Some Typical Adobe Houses in the Village of Lāghar.

FIGURE 3.14 Adobe Bricks.

FIGURE 3.15 A Typical Building with Flat Timbered Roofs and Stone-Masonry Walls with Mud Mortar in the Village of Kamasej.

In more important and permanent structures, such as domes and arches of the mosques, more regularly shaped stones are used with gypsum mortar. For the construction of walls which are in contact with water, such as bridge foundations and piers, stone is used with a sand-silt lime mortar.

Wood is a relatively expensive construction material in Iran. Locally grown, untreated, irregularly shaped timbers made of trunks of trees are used in most villages as beams for the support of roofs, for columns, and as lintels over windows and doors. In most villages in the earthquake zone, the trunks of date trees are cut longitudinally in two or three pieces, and each piece is used as a beam.

In the town of Qīr and in some villages there were a few structures designed and constructed according to some engineered plans and specifications. These buildings have used modern construction materials, such as cement, concrete, steel I-beams, reinforcing bars, bricks, etc. Sometimes these modern construction materials were used alone, and sometimes they were incorporated with the normal sun-dried adobe or stone and mud mortar materials.

3.2.1.2- Methods of Design and Construction

The typical rural houses observed in the area had relatively thick walls with small openings. They were usually rectangular in plan and only one story. In some instances, especially in the commercial areas of Qīr and in crowded villages with small open spaces, some two-story adobe structures were observed. The load-bearing walls were often made of adobe bricks with mud mortar having a typical width of two adobe bricks (approximately 18 in. or 45 cm). Non-bearing partition walls in the buildings were usually made of adobe with a typical width of 8 in. to 12 in. (one adobe brick). Non-bearing walls used around gardens or yards were often made of layers of mud blocks. The width of these walls was around 12 in. to 18 in. The height of each layer of mud blocks was about 18 in. The width of these walls was larger at the bottom and became narrower at the top. Sometimes small straight branches of wood were observed inside the walls as reinforcement against vertical shrinkage cracks (see Figure 3.12). Stone and mud mortar were also used for the construction of non-bearing walls. Rubble stone was used for load-bearing walls in some structures located near mountains or where this material was abundant. In general, the mortar was only mud. However, in some cases a mixture of mud-lime mortar was used, especially for the construction of the foundation and bottom layer of the adobe walls to prevent deterioration due to rain and water and for insulation of the upper parts of the walls. In most cases the walls were built directly on the ground with no provision for foundations.

Types of Roofs

A. Flat Roofs with Wooden Beams

This was the most common type of roof system in the Qīr area. It consists of trunks of trees or logs placed directly on top of the walls with spacing of 12 in. to 15 in. and covered with branches, foliage, or a type of mat made of flattened bamboo (locally called hasir) on which a thick layer of mud is placed to act as a hold-down weight and insulation material (see Figure 3.16). The mud layer also provides the proper slope for drainage of the rainwater. Sometimes a small amount of lime is mixed with the earth material to give it a better waterproofing property.

FIGURE 3.16 Inside View of a Typical Flat Timbered Roof in Qīr.

One or two final layers of plaster made of clay and straw are placed over the previous layer to provide waterproofing and prevent shrinkage cracks from forming (see Figures 3.11, 3.13, and 3.15). This type of roof is usually thick and, therefore, relatively heavy. Often some salt is mixed with the clay to prevent the growth of vegetation from seeds which may happen to be within this layer of clay-straw mixture. The clay-straw mixture has some insulation properties, is a relatively good waterproofing material, adheres to the adobe bricks, is relatively lightweight, and resists shrinkage cracks.

In the areas of more frequent rainfall, the roof insulation is repaired and renewed every year. This renewal of the plastering year after year without removing the earlier half-washed layers gradually increases the thickness of the roof and its dead load. In less rainy regions, as in Qīr, the repair and the re-plastering were done only once every two or three years. Therefore, the roofs were not as thick as in the northern or western part of Iran. Typical mud roofs in the Qīr area were approximately 16 in. thick. The heat and water insulation property of the roof is increased by increasing its thickness. As mentioned, the roof beams normally consist of 3- to 4-inch tree trunks or split trunks of date palms. They are usually spanned from wall to wall and are supported directly by the sun-dried-brick bearing walls. Typical spans are about 10 ft. However, in some of the more wealthy homes, in order to accommodate larger rooms, wooden girders and interior columns are sometimes used.

The inside plaster of houses is made either from a finer mixture of mud-straw or, in the better homes, from a kind of stucco composed of a mixture of clay and gypsum.

B. Dome-Shaped Roofs

A few houses and special buildings such as old mosques, mausoleums, and caravansaries (old stop-over places for caravans) had dome roofs. Almost all of the load-bearing shells of these roofs were made of stone with gypsum mortar. The shell was covered by a layer of mud and one or two layers of mud-straw for waterproofing and insulation against rain. Rooms covered with this type of roof usually have a small span on the order of 10 to 15 ft. The walls were made of stone and gypsum mortar and were generally thick enough to resist the horizontal thrust of the arched roofs. A typical inside view of a room with a domed roof is shown in Figure 3.78.

C. Cylindrical Vaults

Only a few of this type of roof were found in the Qīr area. They were made of better quality adobe bricks and were used in the lower stories and basements of some structures in such a manner that the weight of the upper floor or resistance of the neighboring buildings absorbed the thrust of the cylindrical vault. They were used to cover rooms with rectangular areas. The span of the cylindrical vaults was in the direction of the short dimension of the rectangle. The cylinder at the longitudinal ends was connected to the walls either directly or by means of some semispherical transition piece as shown in Figure 3.17.

FIGURE 3.17 Inside View of a Typical Adobe Cylindrical Vault Roof Showing the Curved End Sections.

D. Roof System Made of Steel I-beams and Shallow Brick Arches

This type of roof system, which has been used extensively in Iran during the past 30 years, is still very popular in the construction of most houses and even multi-story structures built in cities all over Iran. It consists of a series of parallel steel I-beams spaced approximately 30 to 40 in. apart, usually in the direction of the shortest dimension of the room. The ends of the beams are supported on the walls.

a. Engineered Version In the engineered version of this roof system, a typical reinforced concrete tie-beam, as shown in Figure 3.18, is poured on top of the walls, tying them together.

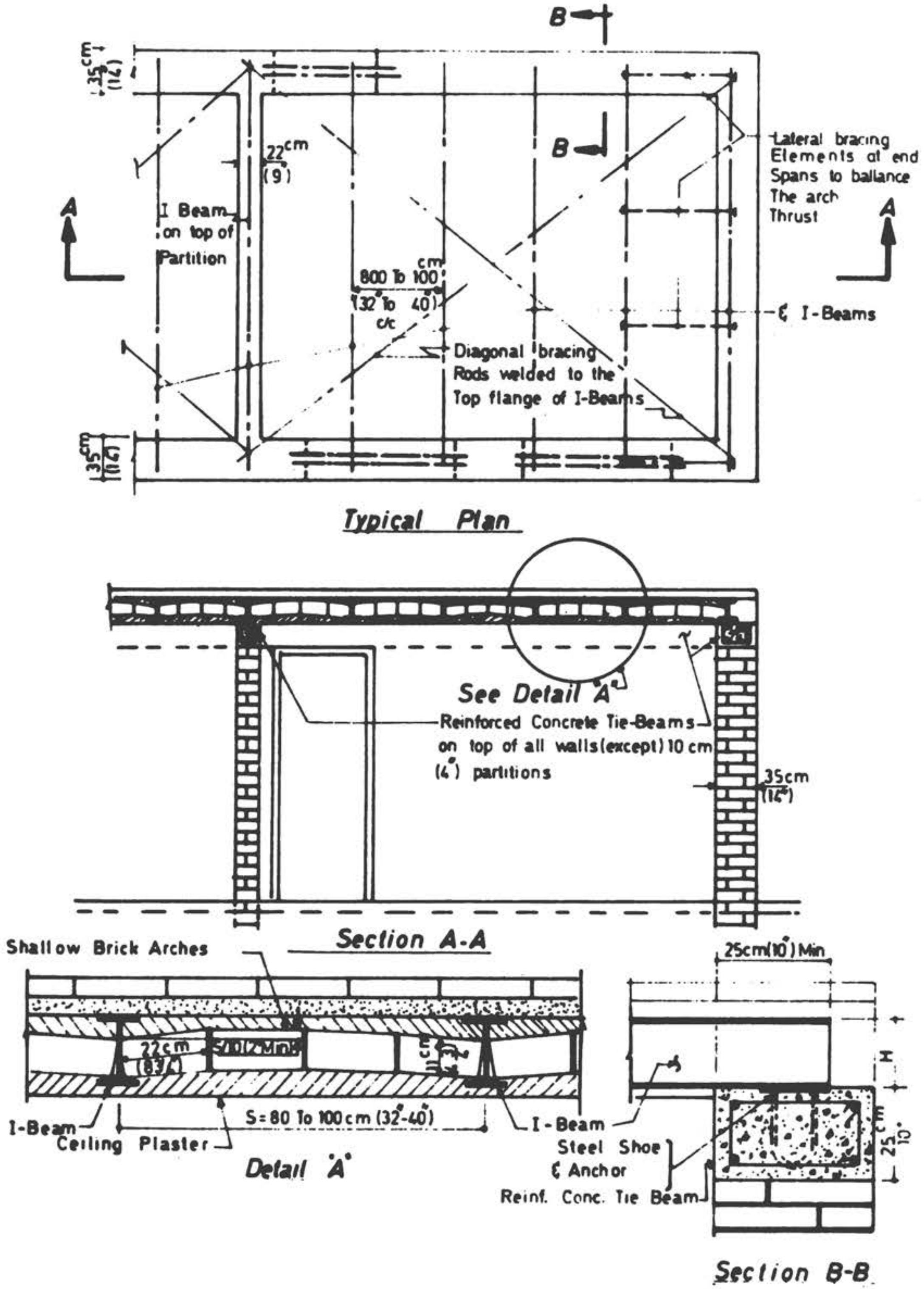


FIGURE 3.18 Typical Details of the Popular Iranian Roofing System Made of Steel I-beams and Shallow Brick Arches (SBABA Roofing System).

The ends of the steel I-beams are connected to the reinforced concrete tie-beams by means of welding them to a special steel shoe made of a piece of plate or channel with anchor rods which are embedded in the tie-beam, as shown in Figure 3.18. The main load-carrying slab consist of a shallow brick arch with a rise of about one-tenth of the span and a thickness of 11 cm (width of a common brick) with gypsum mortar (locally called gatch). The brick arch is supported on the two opposite lower flanges of the two adjacent parallel beams. These arches are constructed manually, layer by layer. No formwork is necessary as the gypsum mortar transmits the weight of the individual bricks of the new layer to the former layer by means of cohesion. The former layer is stable because it has a complete arch and also due to the fact that the gypsum mortar hardens very fast. After the arch is completed, a liquid mixture of gypsum and water is poured on top of the arch to cover the exposed area, filling all the cavities. The bottom of the arch is filled with gypsum plaster, usually without any reinforcement. The space between the extrados of the arches up to the level of the top flange of the I-beams is filled with a lightweight material. For flooring between the stories, usually a layer of sand-cement mortar and tile is placed over the top flange of the I-beam and the lightweight material. For roofing, first a layer of lean cement or lime concrete (for a drainage slope) is placed. This is then covered by insulation made of a few layers of asphalt and canvas. This insulation layer is usually protected by means of a layer of asphalt concrete, sand and tile, or mud-straw. In the engineering version of this type of roofing system, in addition to connecting the I-beams together by means of reinforced concrete tie-beams, as described earlier, long round bars extending diagonally across the roof are welded to the top flanges of the I-beams, as shown in Figure 3.18. These bars cause the roof to behave in a monolithic fashion as a slab and to prevent the appearance of longitudinal or shear cracks in the brick arches due to tension resulting from non-uniform lateral displacement of the roof. In order to resist the outward thrusts of the end spans, the two outside adjacent I-beams are laterally connected together by means of connecting rods spaced about 3 to 4 ft apart.

b. Non-engineered Version In the non-engineered version of this roofing system, any or all of the following elements are usually missing:

1. Reinforced concrete tie-beams,
2. Steel shoes in the tie-beams and welding of I-beams to these shoes,
3. Diagonal braces,
4. Lateral braces.

In addition, in most non-engineered roofs, for the sake of economy, the end beams are omitted and the arch is directly supported on top of the end walls. Also, when there are interior partitions parallel to the I-beams, the spans between the beams are so selected that the interior partition can be used as a support for the two adjacent arches, thus saving an I-beam at that location.

Each of these omissions represents an apparent short-term economy, but leads to a considerably weaker roof structure which is often incapable of surviving a mild earthquake.

3.2.1.3- Construction Skill and Management

With the exception of the engineered structures whose designs are based on plans and specifications and are constructed under engineering supervision, the rest of the structures in the cities and towns all over Iran are designed and constructed by local contractors (who are locally called "me'mar", i.e., architect). Usually the owner supplies the material, and the contractor supplies the laborers and masons. The contractor's payment is often based on unit floor area; however, in some cases cost-plus-fee contracts also are seen. In these types of contracts the owner has control over the material and workmanship. The more wealthy contractors also design and build houses for sale. In this case they supply both the material and laborers. These types of buildings, while pleasing to the eye, are very inferior in structural quality and workmanship. Due to the shortage of housing in Iran since World War II, a large portion of the buildings in many expanding cities are of this type and are very dangerous in the case of earthquake.

Most construction laborers are poor villagers who come to the cities to work during non-farm seasons. They usually have no specialized skills. In addition, most contractors have some professional construction laborers who work for them more or less continuously during the year. In a construction job these professional laborers are assigned more responsible positions as foremen and receive slightly higher wages.

In general, masons (who are locally called "banna," i.e., builder) have no technical education. They have learned their trade during years of practice and are usually skilled in one area of specialization, such as brick laying, plastering, etc. Masons generally develop from among the more intelligent, hard working, and careful professional construction laborers after a relatively long period of apprenticeship under older masons. The more imaginative and responsible masons are called master masons (or "Ostade-banna") and are selected by the contractor to lead and supervise a job. The more intelligent and aggressive masons who have a flair for management and economics eventually become contractors. Each contractor usually has a group of masons with various specialities and many laborers who work for him during the year on his numerous projects.

Due to the extensive amount of construction activities in Iran during the past few decades, many modern contracting firms have been developed. However, they usually operate in large cities or on large projects. In small, far-away towns, such as Qīr and in rural areas, even the engineered structures are constructed by local contractors. The village buildings are designed and constructed by local rural masons and contractors. Poor villagers often design and build their own adobe houses.

3.2.2- Effect of Earthquake on Engineered Structures

There were only a few structures in the area which had been built according to engineering plans and specifications. Those inspected by the authors were the Qīr clinic, the school of the village of Marand, the elevated steel water tank at Qīr, the Shāhābād bridge, and some minor culverts and smaller buildings. The behavior of these structures is as described in the following Sections.

3.2.2.1- The Buildings of the Qīr Clinic

This clinic complex consisted of three separate buildings: the residence of the doctor, the main clinic building, and the garage-janitor building. All were single-story brick structures constructed very recently using modern construction materials and lime-sand-cement mortar. The summarized plans, the location of roof beams, and a section through the buildings are shown in Figure 3.19.

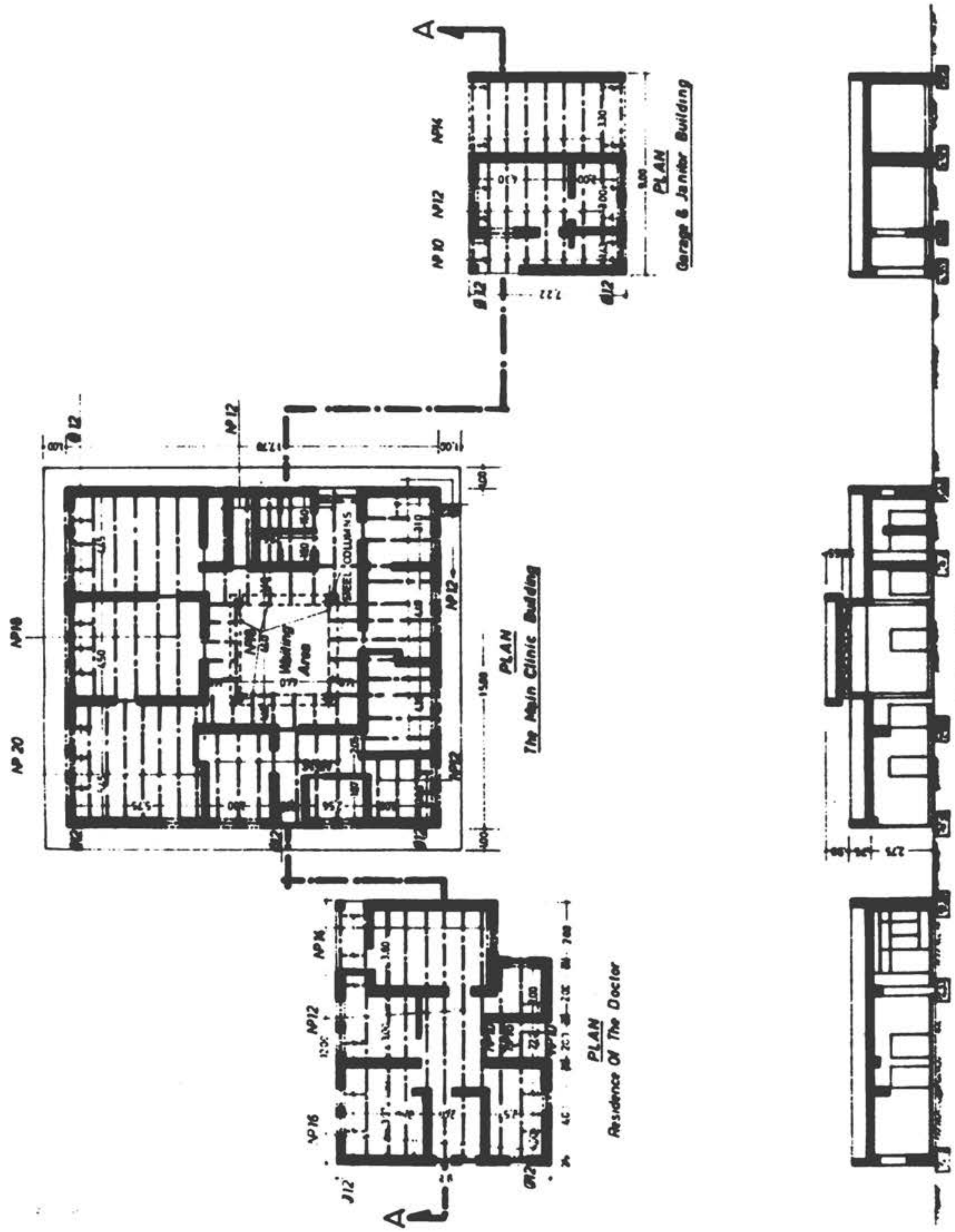


FIGURE 3.19 Clinic Buildings of the Town of Qīr.

A general view of these buildings after the earthquake is shown in Figure 3.20. The buildings were designed according to the prevailing practice on non-reinforced brick buildings by the engineering office of the Ministry of Housing and Development in Shīrāz. The roofing system of this building was an engineered version of steel I-beam and shallow brick arches with reinforced concrete tie-beams, as described in Section 3.2.1. However, the field inspection of the ruins revealed some defects in the construction of the roofing system which seem to have contributed in part to the partial collapse of these buildings. There were no vertical tie columns at the corners or locations of the intersection of walls. The behavior of each of these buildings is described separately.

FIGURE 3.20 General View of the Qīr Clinic After the Earthquake.

A. The Residence of the Doctor

The roof of this building completely collapsed, and the walls were totally destroyed during the earthquake. The doctor was saved from under the debris and, fortunately, nobody was killed in this building. The ruins are shown in the foreground in Figures 3.20, 3.21, and 3.22. Inspection of the ruins showed that reinforced concrete tie-beams were used under the I-beams on top of the walls. However, in contrast with the plans, in most places the I-beams were not anchored to the tie-beams,

FIGURE 3.21 Western End of the Main Clinic Building. The Ruins of the Residence of the Doctor is in the Foreground.

FIGURE 3.22 Western End of the Main Clinic Building.

and no embedded steel plate for this purpose was used. The main cause of the collapse and destruction of this building appeared to be due to the following factors and their interaction:

1. Destruction of load-bearing masonry walls and partitions due to shear and lack of vertical tie columns,
2. Separation of steel beams from the reinforced concrete tie-beams due to lack of proper anchorage,
3. Disintegration of the roofs due to falling, vibration, and lack of proper tension-resisting elements such as diagonal bracing bars or lateral braces,
4. Discontinuity of the tie-beams in a few places due to the passage of the chimney pipes, omission of diagonal and knee-shape reinforcements at corners in the tie-beams, etc.

B. The Main Clinic Building

The roof of the northern portion of this building collapsed, as shown in Figure 3.23. It seems that the total destruction of the east-west wall on the northern view of the building, the relatively large span of the northern rooms, the smaller ratio of the length of the walls

FIGURE 3.23 Northern End of the Main Clinic Building.

to the area of the rooms, and the lack of the rigidity and subsequent failure of the north-south walls in this part of the building caused the collapse of the roof. Further field inspection also showed that during the earthquake the roof did not remain monolithic due to the partial failure of the tie-beams, the lack of proper anchorage between steel beams and the tie-beams, and insufficient diagonal bracing. This portion of the roof collapsed due to the reasons described in Items 1 through 4 for the doctor's residence building.

The southern portion of the main clinic building was extensively damaged but did not collapse. The exterior and interior walls received minor shear cracks, as shown in Figures 3.20, 3.21, and 3.24. The roof remained monolithic and attached to the tie-beams. The roof of the waiting-hall had an elevation higher than the other roofs. It was supported on four steel columns, each made of two welded channels. This roof did not collapse but most of its parapet walls fell, as shown in Figures 3.22 and 3.23. The plan of this roof is seen in Figure 3.19. The existence of the steel columns had a large influence on preventing the collapse of the roof of the main clinic building, as the beams of the lower roofs were also welded to these columns, as shown in Figure 3.25. The effect of reinforced concrete tie-beams in preventing the collapse of the roof, even when a large portion of the bearing walls was

FIGURE 3.24 The View of the Eastern and Southern Sides of the Main Clinic Building.

FIGURE 3.25 A View of the Interior Steel Columns Supporting the Roof of the Main Waiting Hall and the Adjacent Roofs.

destroyed, can be seen in Figure 3.22. In addition, the vulnerability of the masonry building without vertical tie columns at the corners and at the joints between the walls in various directions is shown in Figures 3.20, 3.22, 3.23, and 3.24. The failure mode of the wide, short walls between the openings is of the shear type in the form of x-shaped diagonal tension cracks. However, the failure modes of the narrow, long walls between the openings is of the flexural type in the form of horizontal cracks and compression failure zones at the ends of the walls, as shown in Figures 3.21 and 3.22. The steel frames around the openings had some effect in preventing the collapse of the roof.

The parapet walls of the main building in most parts remained sound except at the locations where the roof collapsed.

C. The Garage and Janitor Building

The west view of this building is seen in the background of Figure 3.20. A close-up of the damage to the southern end of this building is shown in Figure 3.26. The roof of this building did not collapse and the parapet walls also remained undamaged; the tie-beams were effective in tying the entire roof together. The load-bearing walls at the west and south sides of this building were totally destroyed due to shear. However, as can be seen in Figure 3.26, the frames of windows made of rectangular steel profiles acted as load-bearing columns and supported the roofs in spite of the failure of almost all of the walls. This interesting behavior once again shows that if the total destruction of vertical load-resisting elements can be prevented and the roof remains monolithic, then the collapse of the roof can be avoided.

FIGURE 3.26 The Southwest Corner of the Garage-Janitor Building.

The failure modes and other aspects of the destruction of this building were similar to that of the main building. The northern view of this building is shown in Figure 3.27. It is seen that the eastern wall of the garage and the masonry column at the northwest corner of the building remained relatively undamaged. This is due to the fact that the mode of failure of the long walls or columns is of the bending type with horizontal cracks and crushing at their ends. This failure

FIGURE 3.27 The Northern End of the Garage-Janitor Building.

mode is not as rapidly deteriorating and destructive as the failure mode of short columns or short walls due to shear or shear-flexure.

3.2.2.2- School Building of the Village of Marand

The summarized plan, section, and some details of this school building of four classrooms are shown in Figure 3.28. This building was designed by the engineering office of the Ministry of Development and Housing in Shīrāz. According to design drawings, this building was a brick masonry structure constructed with sand-cement-lime mortar. The roofing system was supposed to be an engineered version of steel I-beams and shallow brick arches with reinforced concrete tie-beams. This building was completely destroyed by the earthquake. The ruins are shown in Figure 3.29. The cause of the destruction of this building was the weakness and discontinuity of the tie-beams, lack of connection between the steel beams and the tie-beams, disintegration of the roofing system due to the lack of proper diagonal bracing rods and lateral braces, and destruction of the load-bearing walls due to shear.

Figure 3.30 shows a portion of the destroyed reinforced concrete tie-beams. Inspection of this member revealed that the contractor used only three reinforcing bars in the beam, while according to the drawings,

Notes: All dimensions are in cm.
NP 16= Normal European Std. I-Beam 16 cm. height(b tob flange)

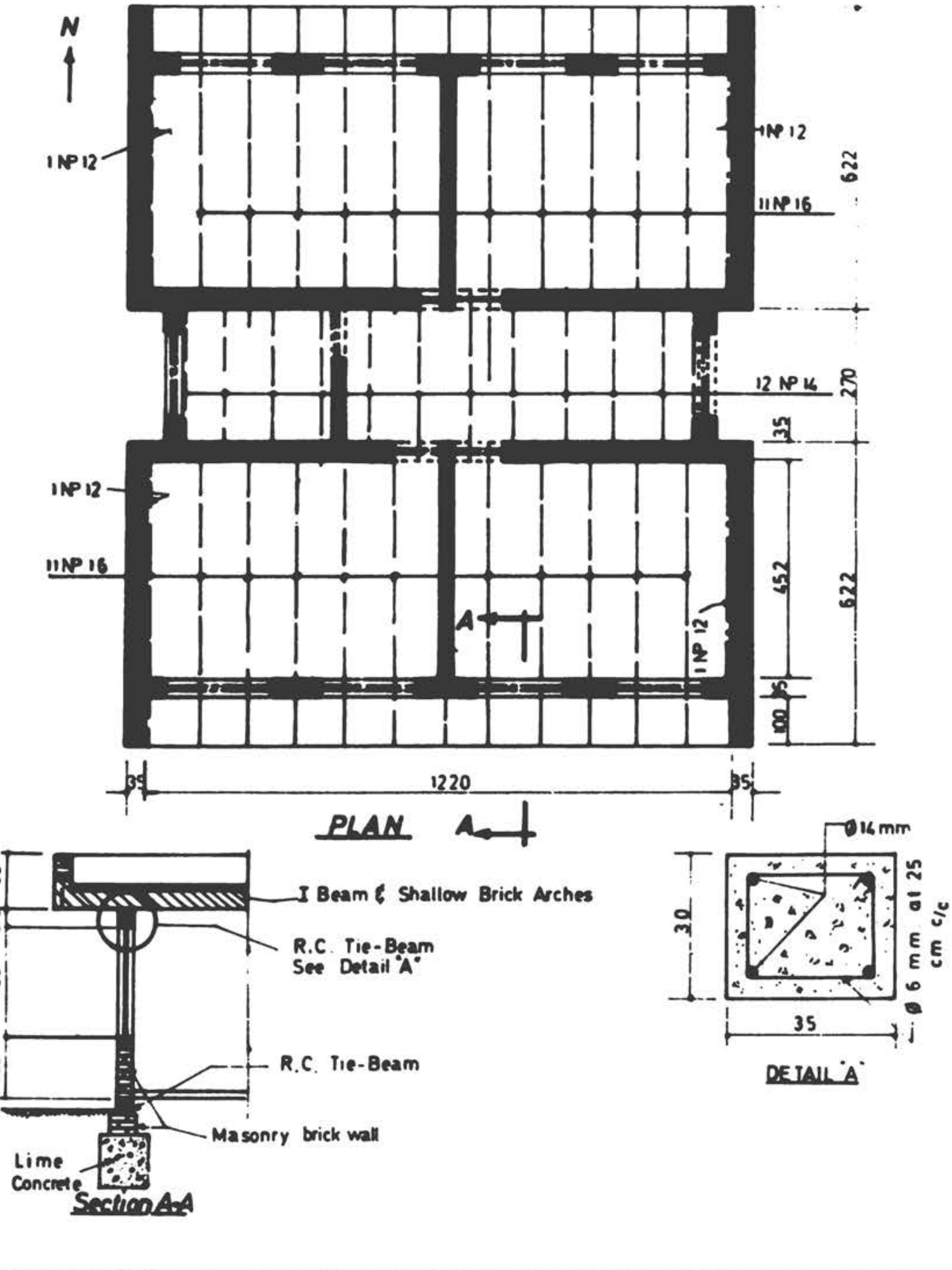


FIGURE 3.28 Summary Plan and Details of the Elementary School in the Village of Marand.

FIGURE 3.29 The Ruins of the School of Marand.

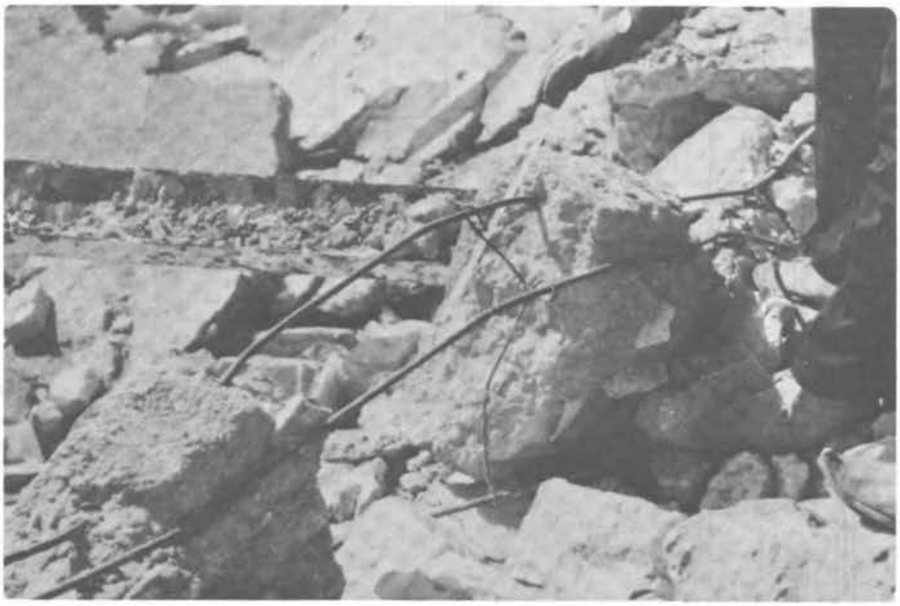


FIGURE 3.30 A Close-up View of the Destroyed Reinforced Concrete Tie-beam of the Marand School.

four bars should have been used. Also, it is seen, instead of using a tie bar of 6 mm diameter for connecting the longitudinal bars together, an open L-shaped bar 4 mm in size had been used. The quality of the concrete was very poor; in fact, in some regions it consisted only of a mixture of low cement mortar and large boulders. However, in the external view it had the appearance of concrete. The poor condition of the constructed tie-beams in this building reveals the following important point with regard to the future seismic design in this area and in similar remote locations.

In small scale construction jobs in the remote areas where skilled laborers are not available, the execution and construction of any design which uses unfamiliar modern material and technology is very difficult and costly for the contractor. He must bring and maintain skilled laborers from outside the area, which is very expensive for small jobs. At the same time a technically difficult job, no matter how small, demands constant, expert supervision, which is relatively more costly in remote areas because competent personnel must be imported. The profit margin of the contractor pressures him to economize, and he may omit essential items or proper supervision during construction. This seems to have happened in the case of the school building of Marand. The main conclusions in this case are as follows:

1. In designing small scale jobs in remote areas, simple material and methods should be used where either local skills and technology are utilized or the results are not influenced by the inferiority of the local skills and lack of continuous supervision, such as in the construction of prefabricated or assembled systems.

2. Complex construction material and technology should be used only in the following situations: a) in large jobs, where the maintenance of skilled laborers and continuous supervision are economically feasible, and b) in a set of small jobs which are all being constructed within a short period of time within a small area, where the maintenance of outside skilled laborers and supervision is economically justifiable. This latter situation can be brought about by proper planning of the construction in a given area, similar to that done in road and bridge construction. In this situation the use of a single contractor for each set of jobs in an area may be more advantageous.

3.2.2.3- The Elevated Steel Water Tank in the Town of Qīr

One of the principal engineered structures in the town of Qīr was a 4,000 gal steel water tank. The summarized plan, section, and construction details of this water tank are shown in Figure 3.31, and a view of this tank after the earthquake is shown in Figure 3.32. The

Note: All dimensions are in cm. except as noted

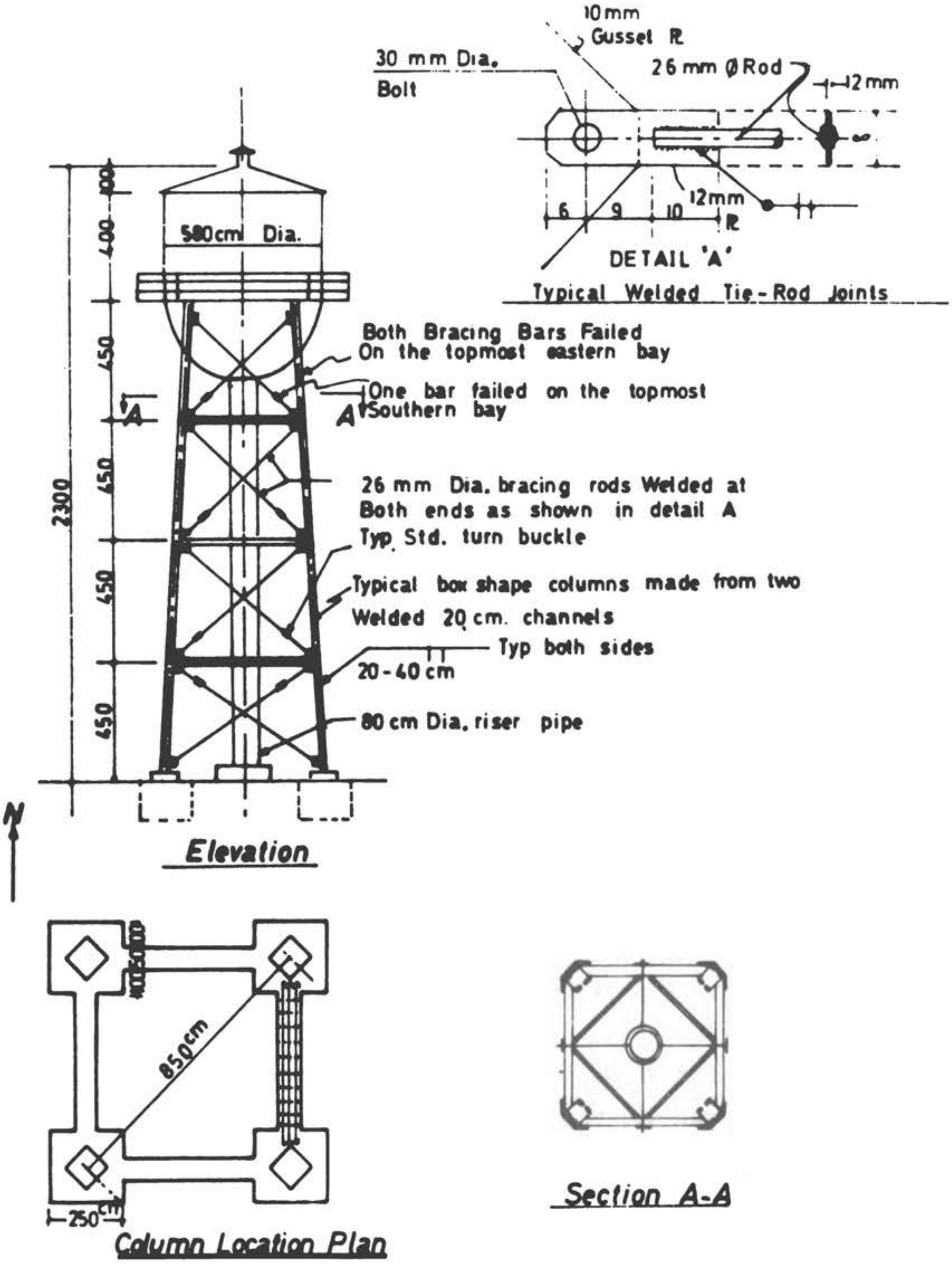


FIGURE 3.31 Summary Details of the Elevated Steel Water Tank of Qīr.

authors could not positively determine the elevation of the water in the tank at the moment of the occurrence of the earthquake. Some people who visited the area soon after the earthquake mentioned seeing a large amount of water around the tank on the ground. Others reported that the man in charge of the tank used to fill the tank early in the evening for the morning peak water consumption. It was probably between half and totally full.

FIGURE 3.32 Qīr Water Tank After the Earthquake.

The tank was of the typical design common in many small towns in Iran. Most of the parts of these tanks are fabricated in Teheran, shipped from there, and then assembled and welded in the receiving town. The only damage to the tank was the fracture of three diagonal bracing bars in the topmost bays. One was at the southern side and the two others at the western side. A sample of these bracing failures is shown in Figure 3.33. Inspection of the failure sections revealed

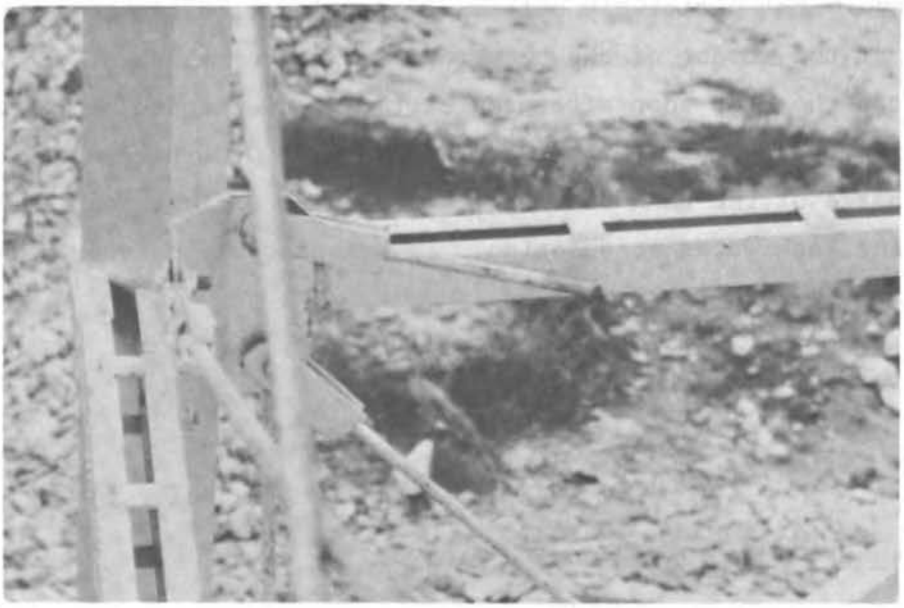


FIGURE 3.33 A Close-up View of the Failure of a Bracing Bar of Qīr Water Tank.

that the inferior quality and brittleness of steel at these cross sections may have been responsible for the destruction of the bars. The bracing bars of the remaining bays and of the horizontal wind braces were not damaged, but a few showed some evidence of elongation. No evidence of damage was apparent on the surface of the tank, nor on its columns, anchor-bolts, foundation, or other related parts. It appeared that the tank could be put into use after some minor repairs. The structural survival of this tank confirmed the observation made earlier: the construction of seismic-resistant structures made of assembled parts, where the quality of material, fabrication, and erection are not influenced by inferior local skill and technology, is feasible in these areas.

3.2.2.4- The Shāhābād Bridge

This is one of the few engineered structures in the earthquake zone, and the only bridge of any significant size in the area. A general view of this bridge is shown in Figure 3.34. This structure was located near the village of Shāhābād on the Qara-Aqaj River. It was a ten-span reinforced concrete bridge where the length of each span was about 12 m. It consisted of three T-shaped beams supporting the

FIGURE 3.34 A General View of the Shāhābād Bridge on the River Qara-Aqaj.

reinforced concrete deck, as shown in Figure 3.35. The interior supports were made of two cylindrical piers supporting the transverse support girder, as shown in Figure 3.35, and resting on the foundation. The foundations of the interior supports appeared to consist of relatively deep single reinforced concrete footings, connecting the two piers together. The authors were not able to obtain the design drawings for

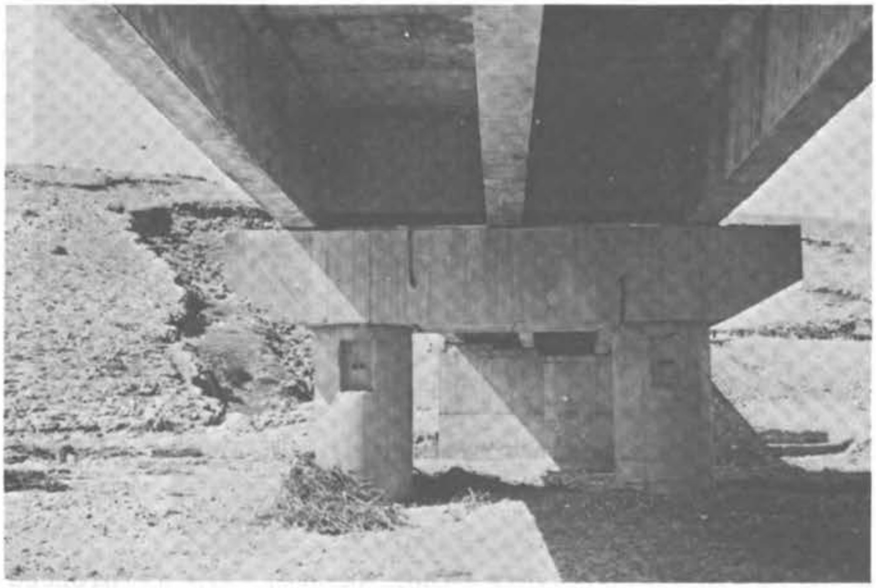


FIGURE 3.35 First Interior Support from the Eastern Abutment. The Locations of Hair Cracks are Marked.

this bridge and its foundations. The western abutment is shown in Figure 3.36 and the eastern abutment is shown in Figures 3.34 and 3.37.

FIGURE 3.36 The Western Abutment of the Bridge and the Retaining Walls.

FIGURE 3.37 The Eastern Abutment of the Bridge and the Retaining Walls.

The bridge received only very minor damage. The reinforced concrete retaining walls on both sides of the abutment on the western end moved outward at the top about six in., as shown in Figure 3.36. The abutment on the eastern end was surrounded by conical-shaped fills. The end of these fills was supported by a low, circular, masonry retaining wall, as shown in Figure 3.37. Due to the earthquake the retaining wall cracked and, in some places, moved outward. The soil behind the walls settled about two ft (Figure 3.37).

Inspection of the first western span, shown in Figure 3.36, revealed that this span moved northward about one in. on the abutment, causing a short vertical crack across a construction joint between the end of the southern beam and the abutment. This movement of the bridge can be seen better in Figure 3.38, taken from the top of the bridge deck. This figure shows the movement of the position of railings attached to the first span with respect to the portion attached to the abutment. Several cycles of both North-South and East-West differential movements seem to

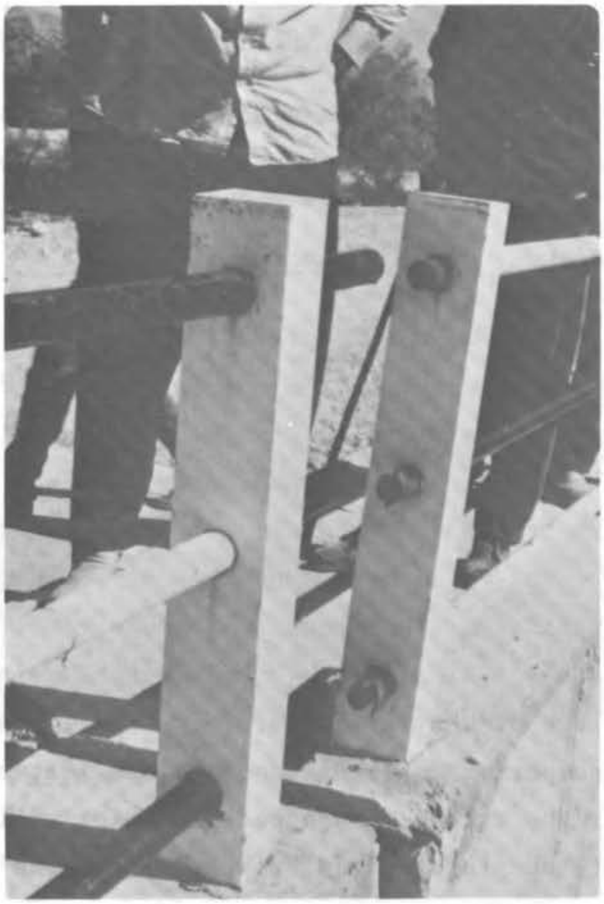


FIGURE 3.38 Movement of the Bridge Deck and its Railing with Respect to the Western Abutment.

have occurred, because the ends of the railings were not only permanently displaced, but were damaged as they collided with each other.

There were some hairline cracks on the support of the girders of the first interior piers on the east side of the bridge, as marked on Figure 3.35. These cracks indicated a relative downward movement of the right-hand side pier with respect to the other. It was not clear whether this crack had been caused by the earthquake or had existed before.

In general, the behavior of this bridge during this earthquake was satisfactory. This is in sharp contrast to the behavior of the adobe houses in the nearby village, all of which were totally destroyed. The behavior of this bridge again emphasizes that a well-engineered and well-constructed structure can safely resist the type of earthquake which causes total destruction of buildings made of adobe or non-engineered masonry.

3.2.2.5- Other Miscellaneous Engineered Structures

There were a few other minor engineered structures in the area. Those which were studied by the authors are described below.

3.2.2.5.1- Highway Culverts and Small Bridges

Recently a main highway was constructed of gravel between Qīr and Lār. On this highway between Qīr and the Shāhābād bridge there were about a dozen small bridges or culverts, many of which received some damage. These culverts were made either of reinforced concrete slabs or of stone masonry arches and sand-cement mortar. The supporting piers and the retaining walls were stone masonry. In most of these structures the retaining walls around the bridge received some damage.

Figure 3.39 shows a single-span bridge with a reinforced concrete slab near the village of Khayrābād (No. 3 in Figure 2.1). The bridge had moved on its support a small distance to the left along its length. The top portion of the triangular-shaped retaining wall, shown on the right-hand side of the picture, was broken. There was no backfill behind this portion of the wall. The failure was due to the lack of tensile reinforcement, similar to the type which occurs in the unreinforced parapets.

Figure 3.40 shows another smaller culvert with a rectangular slab near the Shāhābād bridge. The slab is supported on two masonry walls.

FIGURE 3.39 Failure of the Wing Wall of a Small Bridge near the Village of Khayrābād (No. 3).

FIGURE 3.40 Failure of a Culvert near the Shāhābād Bridge.

These supporting walls, which also support the soil pressure, moved toward each other. The top of the left-hand side wall moved about eight in. inward, and that of the right-hand side support also moved about three in. inward. This wall had also sustained some local damage. The bridge slab slid on top of the left-hand side support by as much as eight inches.

Figure 3.41 shows another culvert with a circular masonry arch. The two triangular-shaped wing-walls were pushed forward, and the highway retaining wall on top of the arch was damaged, as shown in the figure. Small cracks can also be seen inside the arch along the mortar lines between the arch stones.

FIGURE 3.41 Damage to a Circular Culvert and its Retaining Walls near the Village of Shāhābād.

Figure 3.42 shows another culvert with a circular masonry arch where the wing-walls and the outside ring of the masonry arch showed some damage.

3.2.2.5.2- Public Bathing House of the Village of Liferjān

This structure was constructed of stone masonry walls with relatively good mortar. The roofing system was made of steel I-beams and a shallow brick arch with reinforced concrete horizontal tie-beams. There was a cylindrical masonry water-storage tank on top of the roof of this building, as shown in Figure 3.43. The roof of this building did not collapse, but it did sustain some damage, especially at the corners.

FIGURE 3.42 Damage to a Masonry Circular Culvert and its Wing Walls, near the Village of Shāhābād.

FIGURE 3.43 Western View of the Public Bathing House of the Village of Upper Liferjān.

Figure 3.44 shows the cracks in one of the corners, which destroyed the tie-beam at this location. Lack of knee-shaped and diagonal reinforcing bars at the corners in the tie-beams, omission of vertical tie-beams, and the presence of the weak line (due to the existence of the chimney pipe inside the wall) contributed to the cracking at this corner.

FIGURE 3.44 Failure of the Structure at the Corner Due to the Weakness in the Tie-beam and Existence of a Weak Line Along the Chimney Inside the Wall.

Figure 3.45 shows another view of the cracks at one of the corners, which also clearly shows the lack of any corner reinforcement in the tie-beams.

3.2.3- Earthquake Effects on Non-Engineered Modern Structures

In the construction of the buildings described in this category, modern construction materials and techniques such as steel beams, cement, reinforcing bars, welding, etc., were used. However, these buildings were neither designed nor constructed according to accepted engineering standards under the supervision of competent engineers. These structures were usually constructed by local masons (banna) and contractors (me'mar). The role and qualifications of these people were discussed in Section 3.2.1.3.

The steel I-beam is one of the most popular construction materials used in this type of structure, chiefly in the form of a non-engineered version of the steel I-beam and shallow brick arch roofing or flooring system. This system was discussed in Section 3.2.1.2. Walls of this type of structure are usually made of local bricks with clay-lime, sand-lime, or in rare cases with lime-sand-cement mortar. In the earthquake zone it was observed that in some cases the walls of this

FIGURE 3.45 Failure of the Tie-beam at a Corner
Due to the Lack of Corner Reinforcement.

type of structure were constructed of better quality adobe with clay or clay-lime mortar, and in other cases, of rubble stone and gypsum, lime-clay, lime-sand, or sand-cement-lime mortar. The behavior of a few examples of this type of structure is given below.

3.2.3.1- Schools Built for the 2500th Anniversary of the Persian Empire

In 1971 the government of Iran celebrated the 2500th anniversary of the establishment of the Persian Empire. One of the landmarks of this celebration was the construction of more than 2,500 small elementary schools in various villages and rural areas all over Iran. These schools were built with the help of the local people, who supplied the labor. Modern construction materials such as steel beams, cement, gypsum, doors, windows, etc., were procured from the larger neighboring cities. The cost of each school was estimated to be about $4,000. The construction of these schools was financed by donations from the people and business firms throughout the country. Several different types of design were chosen, depending on different climatic conditions. For the north and northwest areas with cold temperatures and large snowfalls, and for the north-central areas around the Caspian Sea which have extensive rainfalls, two distinct types were designed. For the arid areas with moderate temperatures in central Iran and for the arid areas with hot temperatures in southern Iran, other suitable designs were selected.

According to the information obtained from local officials, there were four of these schools in the earthquake-stricken area, which were of the design-type used for the arid-warm climates. The walls of these schools were made of rubble-stone masonry, and the roofs were made of a non-engineered version of steel beams and shallow brick arches. All of these schools, with the exception of the one in Ābe Garm, collapsed and were completely destroyed. Following is the description of the damage to these schools caused by the earthquake.

3.2.3.1.1- The School of Ābe Garm

This school was at the foot of a mountain, relatively far from the center of intensive shaking, and it did not collapse completely as did the other schools which were closer to the area of greater damage.

The authors did not obtain the official design plans and drawings of the school. However, Figure 3.46 shows the approximate plan of the beam locations and the collapsed regions of this building. Figure 3.47 shows the west-end view of the building, where very little damage is apparent. The mortar used inside the wall seems to have been a mixture of lime-clay. The mortar lines on the exterior surface of the wall had a sand-cement finish. Figure 3.48 shows the inside view of the western wall of the west-side classroom. The roof beams collapsed and separated from the wall due to the lack of tie-beams and anchorage. Figure 3.49 shows the destroyed eastern wall of this room, which supported the eastern side of the roof beams. This wall had been used as the end support for the roof arch of the interior classroom. Destruction of this load-bearing interior partition-wall due to shear-compression was the main

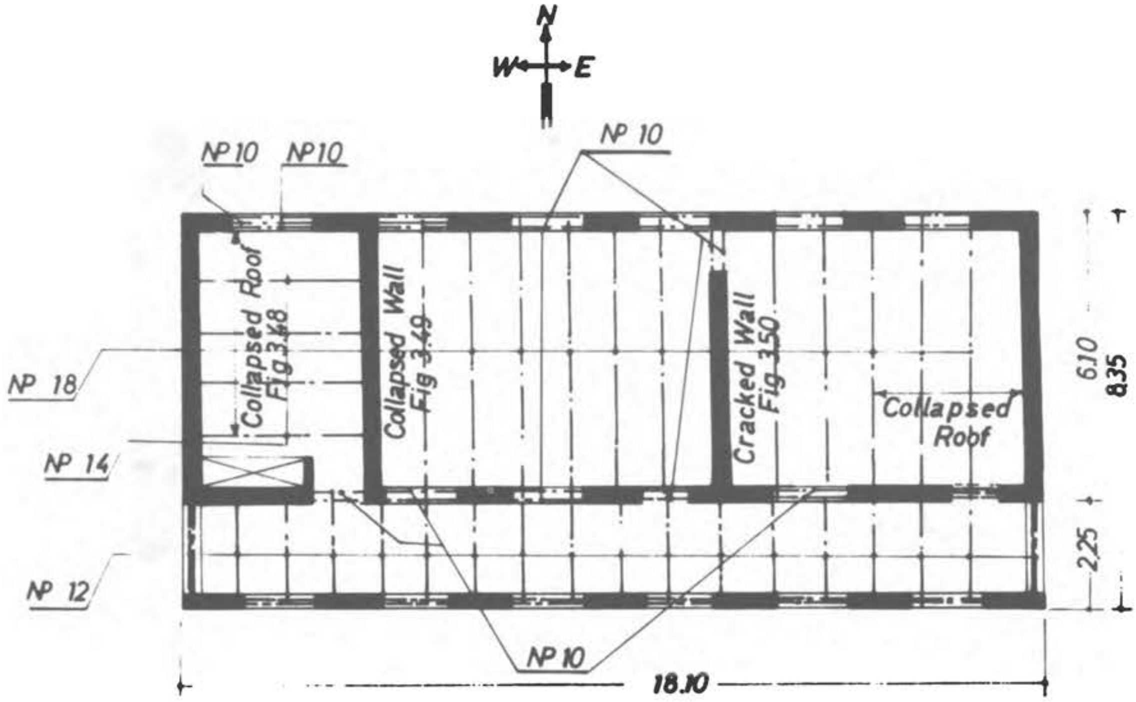


FIGURE 3.46 A Sketch of the Plan of the 2500 Years Anniversary School of the Village of Ābe Garm.

FIGURE 3.47 West-end View of the Ābe Garm School.

cause of damage to this part of the building. The roof collapsed because the ends of the beams were supported directly on top of the partition with no provision for a supporting girder at this location.

FIGURE 3.48 Interior View of the West-end Class of the Ābe Garm School.

FIGURE 3.49 Interior View of the Central Classroom. Note the Mode of Failure of the Interior Load-bearing Stone Masonry Wall.

Disintegration of the roof was caused by lack of diagonal bracing and low transverse rigidity and strength of the brittle arches. Figure 3.50 shows a view of the standing east-end interior partition-wall where diagonal shear cracks can be seen.

FIGURE 3.50 A View of the Cracked East-end Interior Partition Wall of the Ābe Garm School.

3.2.3.1.2- Other 2500th Anniversary Schools

According to the information obtained from the local officials, there were three other schools of this type in the earthquake-stricken area in the villages of Biān (Karzin), Tange-Rudeh, and Berikhun. All these schools collapsed and were totally destroyed. The authors were able to visit the school in Biān; the general view of its ruin is seen in Figure 3.51. According to local villagers, three teachers who were members of the educational corps died under the debris of this building. The main cause of the collapse of this building was the total destruction of the load-bearing walls, combined with the falling and disintegration of the heavy and non-monolithic roof. Figure 3.52 shows a view of the ruins of the school in Tange-Rudeh which shows the total disintegration of the rubble-stone walls. It also shows the extreme weakness of walls made of rubble stone and weak mortar.

3.2.3.2- Qīr Post-Telegraph & Telephone (PTT) Building

This structure was a brick building with steel I-beams and a shallow brick arch roofing system. The quality of mortar and bricks was relatively good. However, it completely collapsed due to the

FIGURE 3.51 The Ruins of the Modern One-year-old 2500 Year Anniversary School in the Village of Biān (Karzin).

FIGURE 3.52 The Ruins of the Modern One-year-old 2500 Year Anniversary School in the Village of Tange-Rudeh (Courtesy of Mr. Arthur Grantz).

destruction of the vertical load-bearing walls and lack of horizontal and vertical tie-beams; the collapsed roof totally disintegrated due to the lack of proper bracing bars. A view of the destruction is shown in Figure 3.53.

3.2.3.3- Public Bathing House in Qīr

The remains of this building following the earthquake are shown in Figure 3.54. All that is left are the twisted steel beams which once supported a brick arch roof. In front of these twisted arches are the remains of the water tank for this bathing house. This tank was a kind

FIGURE 3.53 The Ruins of the Qīr Post, Telegraph, and Telephone Building.

FIGURE 3.54 The Ruins of the Public Bathing House in Qīr.

of 'reinforced concrete' structure with a small amount of reinforcing bars. The roof of the tank was constructed of steel beams and shallow brick arches. Although the foundation of the tank settled enough in the middle to split the wall into two parts, neither the walls nor the roof of this tank collapsed. Figure 3.55 shows a close-up view of the position of the splitting. There was only one reinforcing bar at the bottom of the wall. The foundation consisted only of rubble bricks, and it was unable to carry the load during the earthquake shaking. The behavior of the wall was similar to that of a highly under-reinforced deep beam. The reinforcing bar failed in tension after an extensive amount of stretching.

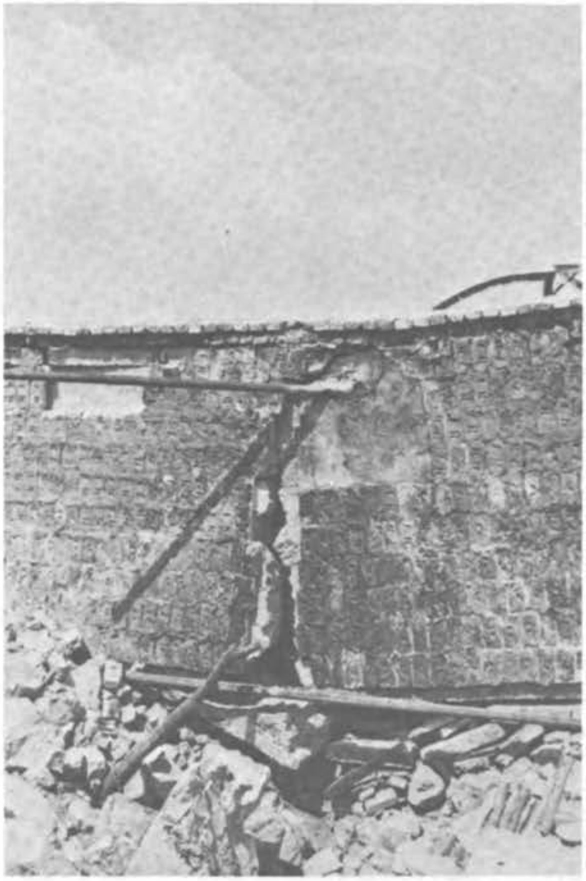


FIGURE 3.55 A Close-up View of the Central Crack in the Water Tank of the Qīr Bathing House.

Figure 3.56 shows the steel skeleton of the main dome of the bathing hall. The bathing rooms were located partially underground so that water pressure from the tank would be sufficient. The walls were constructed of stone masonry with sand-lime or in some locations with

FIGURE 3.56 A Close-up View of the Destroyed Dome of the Qīr Bathing House.

sand-cement-lime mortar. The roofs of all parts except the main dome were made of steel I-beams and shallow brick arches. Cement plastering had been used for partial insulation of the wet rooms. All of the flat roofs and the main dome collapsed. About 36 people were reported to have been killed under the debris of this building.

The main brick dome was stiffened by nine longitudinal steel I-beam ribs, as seen in Figure 3.54. These ribs were welded at the top of the dome to the vertices of an eight-sided polygon made of steel beams. The ventilation and natural lighting of the hall took place through a special window which was installed on top of the eight-sided polygon. The dome was destroyed and disintegrated so severely that it was not possible for the authors to distinguish its original form. The dome had a thickness equivalent to two brick layers (about 30 cm) at the supports. From the shape of the remaining debris, it seemed that the dome was constructed of a series of orange-peel-shaped shallow brick arches spanning the two adjacent steel ribs and supported by these ribs in a fashion similar to the shallow brick arches used in typical flat roofs. However, the possibility of the roof being a simple large-span masonry spherical dome with auxiliary steel ribs cannot be ruled out. Unfortunately, this point was not resolved during the field observation. No tension-carrying transverse bracing to connect the ribs laterally together had been used.

The dome was completely destroyed and disintegrated, and the steel ribs were twisted, as shown in Figures 3.54 and 3.56. The main cause of the destruction of this dome was its very heavy weight, the partial destruction of its support, and the lack of tension-carrying transverse bracings or stiffeners. A comparison of the very poor and catastrophic behavior of this supposedly 'steel reinforced' dome with the remarkably good behavior of the traditional masonry domes in the Friday Mosque of the village of Biān (Karzin), which is discussed in Section 3.2.4.2.1, shows that if strong, modern construction material is used unwisely by technically unqualified masons, the resulting strength of the structure may be much lower than that of similar structures made with traditional construction materials by time-proven traditional methods.

3.2.3.4- Other Miscellaneous Buildings

A. Buildings with a Non-engineered Steel Beam and Brick Arch (SBABA) Roofing System and Masonry Walls

There were numerous buildings of this type in the area which were constructed as homes by well-to-do people or used as offices and schools by various governmental agencies. The fate of all these buildings was the same as similar ones described earlier. In general, due to the earthquake their load-bearing walls were crushed, their roofs collapsed and disintegrated, and their steel I-beams were exposed. Two typical views of the ruins and the failure mode of this type of structure are seen in Figures 3.57 and 3.58. The main cause of collapse of these buildings was the same as those described earlier for other buildings with non-engineered SBABA roofing systems.

B. Buildings with Non-engineered SBABA Roofing Systems and Combined Masonry and Steel Vertical Load-carrying Members

A few cases of this type of construction were observed in Qīr. The following is a discussion of some typical samples.

Figure 3.59 shows the ruins of the house of a wealthy businessman in Qīr. The roof over the balcony on the southern end of the house was supported on a row of steel columns which were made of hollow profiles with a square cross-section. A continuous girder was supported on top

FIGURE 3.57 The Ruins of a Typical Building with Steel Beams and Shallow Brick Arches (SBABA) Roofing System.

FIGURE 3.58 The Ruins of Another Building with SBABA Roofing System.

of these columns, and the floor beams were welded to this girder. The northern end of the floor beams were supported on masonry walls. The ends of the continuous girder were also supported on top of the side walls. Due to the earthquake the load-bearing walls were destroyed, and the roof fell and disintegrated, as shown in Figure 3.59. That portion of the roof which was supported on steel columns did not collapse.

FIGURE 3.59 The Ruins of a Building in Qīr Where Part of its Roof was Supported by Steel Columns.

The brick arches in a portion of the roof where the beams were tied together at both ends by means of welded transverse girders cracked, but they did not disintegrate even after falling. The brick arches in the other areas of the roof, where the northern end of the floor beams were not completely tied together, disintegrated after falling.

Figure 3.60 shows the ruins of another similar building where floor beams at one end were supported on masonry walls and at the other end were welded to a girder which was supported on steel vertical load-carrying members made of hollow square-shaped cross-sections. The masonry walls of this building were completely destroyed, but the steel columns and the floor beams supported by these columns did not collapse. If both ends of the beams had been tied rigidly together or if the uneven vertical movement of the beams with respect to each other had been prevented by the use of proper steel bracings, then the brick arches probably would not have disintegrated when one end of the roof fell. Also, if instead of shallow brick arches, a stronger slab of reinforced concrete had been used between the beams, probably no disintegration due to falling would have occurred.

C. Buildings with Masonry Walls and Reinforced Concrete Roofs

No building of this type was found in the earthquake zone. The closest example to this type of construction was a reinforced concrete slab supported on adobe walls. The ruin is shown in Figure 3.61. This

FIGURE 3.60 The Ruins of Another Building in Qīr Where a Portion of the Roof was Supported by Steel Columns.

FIGURE 3.61 The Ruins of a Reinforced Concrete Slab Supported by Adobe Walls.

slab had supported a small rectangular-shaped steel water tank of a house near the Shāhābād bridge. The adobe house collapsed and was destroyed completely. The slab fell to the ground but was not damaged or even cracked.

Observation of these structures once again stresses that, from the point of view of providing some protection to people even when buildings are severely damaged, it is important to use: 1) vertical load-carrying elements in the structure, such as steel columns or members which will not be destroyed by an earthquake, and 2) a monolithic roofing system that will not disintegrate or fall apart because of partial destruction of vertical load-bearing elements.

3.2.4- Earthquake Effects on Non-Engineered Traditional Masonry and Adobe Buildings

Most of the buildings in the earthquake zone were of traditional adobe construction. Only a few structures were of masonry and brick. The great destruction of life and property in the town of Qīr and in all the affected villages was due to the poor seismic resistance and collapse of these types of structures. The local masonry and adobe type structure is generally very rigid with a high natural frequency and low coefficient of damping. Local masonry and adobe materials are heavy, brittle, and weak in tension; therefore, the damage during a moderate earthquake is usually very high.

From the damage survey it was concluded that the type and extent of earthquake damage in this type of structure is not uniform. It depends on many factors: the most important are the type of material used, the form and dimensional arrangement of the structures, the type of roofs, the connections of buildings to adjacent structures, the type of foundation soil, the location of the building and its age, the state of erosion of the buildings by rain and water, the size and arrangement of openings in the walls, the number of stories, etc. The seismic resistance of the earth houses built on rigid foundations, such as rock and hard soil, is found to be more than those built on soft soils. Most buildings located at the foot of mountains received less damage than those located in the middle of alluvial valleys. This conclusion has also been arrived at by investigations of previous earthquakes in Iran [Ambraseys (1962), Omote (1962)]. In most villages, crowded areas and houses joined together on two or three sides, forming a wide, rigid block, seem to have received relatively more damage, and they produced a higher fatality rate than isolated buildings. Two-story structures received much more damage than those of one story. Rubble stone walls with mud mortar had the poorest seismic resistance. Walls constructed from adobe or layers of earth blocks were stronger than the previous types. The resistance of the adobe walls in some cases was more than that of walls made of kiln bricks and mud mortar. These observations have also been reported in previous earthquakes in Iran [Ambraseys (1962)].

For the present type of material and method of construction, a seismic intensity of VI (MM) seems to be an upper limit of safety for the traditional rural masonry and adobe buildings in this region. Tassio (1969) also reached this conclusion for similar types of structures in his study of the 1968 Dasht-e-Bayaz earthquake in northeast Iran.

A very large percentage of traditional buildings had flat timbered roofs. There were a few structures with dome-shaped roofs and cylindrical vaults. In the following sections, the behavior and failure mode of each type of roofing system is described.

3.2.4.1- Structures with Flat Timbered Roofs

The load-bearing walls of this type of structure in most cases were constructed of adobe and mud mortar. In some cases the walls were of stone masonry with mud or mud-lime mortar. In a few rare cases the walls were made of kiln brick masonry with mud or mud-lime mortar.

Destruction of buildings with flat timbered roofs caused the large number of deaths in this earthquake. The failure mode of these structures due to earthquake can be described better if first the failure mode of the walls and roof elements is described.

3.2.4.1.1- Failure Modes of the Wall Elements

Walls were either load-bearing or non-load-bearing. They were either solid or had openings. In the latter case, some part of the wall on top of the opening acts as a lintel or spandrel wall. The vertical part of the wall between the two adjacent doors or windows acts as a column.

A. Behavior Under In-plane Lateral Loads

a. Shear or Shear-compression Failure Modes This mode of failure occurred in the relatively wide load-bearing walls or partition elements. Destruction of these walls was generally due to shear and often in the form of slanted or diagonal tension x-shaped cracks. This failure mode often happened in the walls or partitions where the height-to-width ratio was less than two. Some typical views of this failure mode are seen in the wide walls of Figures 3.62, 3.63, and 3.64. The effect of compression was found to be beneficial to the shear resistance; as an example, in Figure 3.64 the lower story walls do not show any obvious shear cracks.

A similar mode of failure was observed for the spandrels or lintels on top of openings in walls, as shown in the deep lintels of Figures 3.63, 3.64, and 3.65. Figure 3.66 shows the failure mode of the lintels in a mosque. These lintels have the form of pointed arches; they were destroyed due to shear at the center portion, where they were the weakest.

FIGURE 3.62 Typical X-shaped Shear Cracks on a Wide Adobe Wall.

In many other cases the existence of wooden beams suppressed the appearance of the diagonal cracks and forced the failure zone to the extreme ends of the lintel, as shown in some of the deep lintels of Figures 3.62, 3.63, and 3.67.

The existence of timber elements within the short walls and columns resulted in a similar situation and forced the failure zone to the extreme upper or lower ends.

FIGURE 3.63 Typical X-shaped Shear Cracks and Flexural Cracks on the Walls of a Symmetrical Adobe Building.

FIGURE 3.64 A Brick-masonry Building in the Village of Deh-beh.

FIGURE 3.65 Flexural and Shear Cracks at the End of Lintels and Columns (Village of Deh-beh).

FIGURE 3.66 Typical Shear Failure of the Arched Lintels of a Mosque in Qīr.

b. Flexural Failure Modes This mode of failure occurred in narrow load-bearing walls, masonry columns, and non-load-bearing partition elements. Destruction of these elements was primarily due to flexure or flexure-compression at upper and lower end-zones of wall elements. Flexural mode of failure usually produced horizontal cracks at upper and lower ends of load-bearing walls with compression failure zones at these ends. Sometimes the failure zone extended into the joints between

FIGURE 3.67 A Brick-masonry House in the Village of Deh-beh.

load-bearing walls and lintels. This failure mode often happened in members with height-to-width ratio greater than five. Some typical views of this mode of failure are shown in ends of tall, narrow column walls of Figures 3.63, 3.65, and 3.68, and at the lower ends of columns shown in Figures 3.66 and 3.69. Members under high compression loads had a larger compression failure zone.

FIGURE 3.68 Shear and Flexural Cracks in the Load-bearing Wall Elements and Lintels of an Adobe Building.

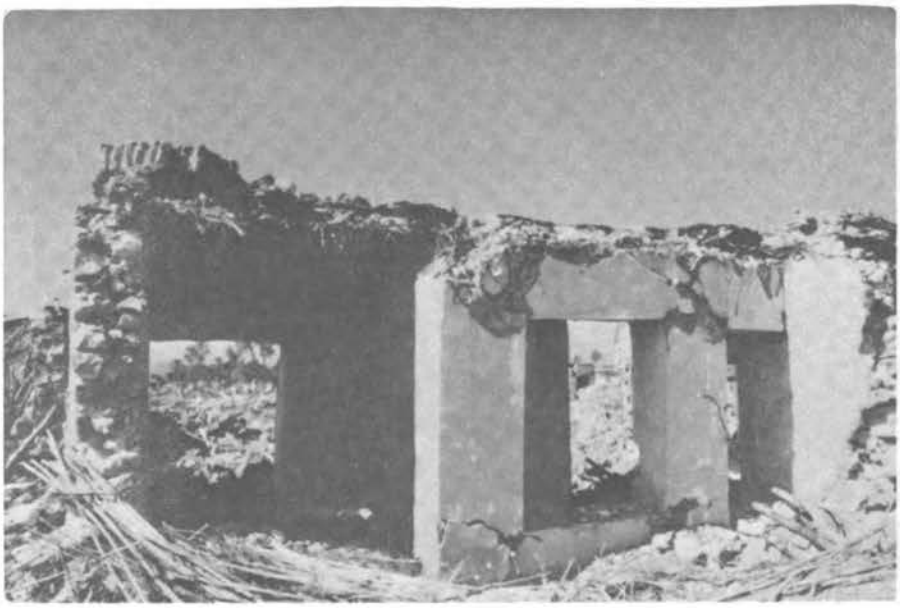


FIGURE 3.69 Typical Failure Mode and Crack Shapes of Lintels and Wall Elements.

Non-reinforced masonry elements cannot resist any significant amount of tensile stress. Therefore, resisting moments which act at ends of wall elements result from eccentricity between the line of action of gravity forces in the wall and the center line of wall elements. This eccentricity increases as story-drift (relative displacement between the top and bottom of the wall) is increased. This increase in eccentricity leads to concentration of gravity forces in a small region at the diagonally opposite upper and lower corners of wall elements, causing their compression failure.

Similar flexural failure mode has occurred in relatively long lintels. Typical examples of this failure mode are seen in the long, narrow lintels of Figures 3.65, 3.68, 3.69, and 3.70.

c. Shear-flexure Failure Mode This mode of failure often occurred in relatively wide wall elements having a height-to-width ratio between two and five. Destruction of these elements was primarily due to shear-flexure-compression effects. The failure modes were in the form of horizontal cracks and compression failure zones connecting into a series of diagonal lines at upper- and lower-end regions of wall elements. Some evidence of this mode of failure is seen in Figures 3.64 and 3.68. The mechanism of moment resistance and of formation of compression

FIGURE 3.70 Typical Failure Mode and Crack Shapes of Lintels and Wall Elements.

failure zones at the end of wall elements is similar to that discussed for flexural failure modes. However, existence of shearing stress at highly compressed corners of walls causes formation of diagonal cracks and triangular-shaped failure zones at corner regions of wall elements.

Similar shear-flexure failure modes have occurred in lintels with moderate length-to-depth ratios, as shown in Figures 3.65 and 3.69. However, the effect of wooden beams at the bottom of the lintel has suppressed formation of shear-flexure diagonal cracks and resulted in flexural-type vertical cracks at end zones. In some cases when wooden timbers of lintels were continuous, failure zone was restricted to vertical cracks, as shown in Figure 3.70.

B. Behavior Under Lateral Loads Perpendicular to the Plane of Walls

<u>a. Non-load-bearing Walls</u> These walls, in general, behaved like a standing wall or a cantilever free at the top and supported at the bottom. Typical walls of this type are free-standing walls around gardens and courtyards, partition walls in buildings, and non-timber bearing walls around rooms. Equilibrium of this type of wall is maintained by its weight, as in the case of any free-standing object, and by the small cohesiveness of mud mortar. Effect of the cohesive force is

usually destroyed due to propagation of cracks in mortar resulting from a few cycles of intensive shaking. Depending upon the ratio of height of the wall to its thickness, these walls may or may not collapse during small intensity earthquakes. Under high intensity shaking, these walls collapse due to shear or overturning. The natural period of a free-standing wall is relatively long; therefore, in many cases it was observed that only upper portions of tall walls had been thrown down by the earthquake. This failure mode was caused by high shearing force resulting from so-called "whip effect." A typical example of this mode of failure is shown in Figure 3.12. A case of complete overturning caused by separation of collpased non-load-bearing walls from other walls and subsequent shear failure of its base is seen in Figure 3.71.

b. Load-bearing Walls These walls support weight of the roof by means of reaction with the end of timbers. In the direction longitudinal to roof timbers, wall-roof systems behave as a portal. Depending upon relative flexibility of walls, various modes of failure may occur.

Shear failure of the wall is represented by movement of timbers on top of the walls, or by movement of upper portions of walls with respect to their lower portion along the longitudinal direction of roof timbers.

FIGURE 3.71 Collapse of One of the Upper-story Non-load-bearing Walls of the Gendarmeri (Rural Police) Station at the Village of Lāghar.

This mode of failure was observed frequently in relatively thick and rigid walls with small height-to-thickness ratio.

Flexural failure of load-bearing walls is represented by horizontal cracks and compression failure zones at upper and lower ends of walls. This mode of failure was also seen frequently in walls with a large height-to-thickness ratio. In some cases this failure mode resulted in tilted walls. In many extreme cases, it caused the complete overturning of walls and collapse of the roof. When there were many parallel walls in a row, the overturning of one of them pushed out other walls by means of the roof, and caused successive collapse of all walls and the roof in that row.

c. Lintels or Spandrels Typical behavior of lintels is shown in Figures 3.70 and 3.72. When the wooden lintel beams were not continuous or the amount of gravity vertical loads on lintels was small, all or a part of the lintel was thrown down by the earthquake. Lintels behaved satisfactorily when their wooden beams were continuous or when they had sufficient bearing length on top of supporting walls.

FIGURE 3.72 Typical Failure of the Arched or Timbered Lintels with Insufficient Bearing Length on the Supporting Walls.

C. Miscellaneous Other Failure Modes

Some rubble-stone masonry walls shown in Figures 3.49 and 3.73 failed along the vertical mid-plane with half the wall standing and the other half thrown down. This failure mode was the result of vertical compressive force and use of a poor mortar with insufficient cohesive strength. This mode of failure occurred in stone-masonry walls where either the size of stones was smaller than thickness of walls, or layers were arranged such that both sides of walls could be easily separated along the mortar joint.

3.2.4.1.2- Failure Modes of Roof Elements

The most important mode of failure of flat-timbered-roof elements can be classified as follows:

a. Separation of Wooden Beams from Supporting Walls Due to Insufficient Length of Bearing Typical view of this mode of failure is seen in Figure 3.74. In this case walls remained standing. Due to lateral movement of the structure as a portal, the bond between roof timbers and the top of the walls breaks. Then, adobe walls under the timber fail locally due to concentration of compressive stresses, which results from insufficient length of bearing and large relative displacement between ends of timbers and tops of walls. After a few cycles of alternating motion, the bearing area under the timbers fails and the roof collapses when one end of the wooden timbers falls.

b. Collapse of Roof Due to Total or Partial Collapse of Supporting Walls Typical view of this mode of failure is shown in Figures 3.62, 3.65, 3.66, and 3.72. In these cases load-bearing walls or supporting lintels have failed in one of the modes described in Section 3.2.4.1., causing the supported roof to fall. The mud-timber roof system is not monolithic and rigid because timbers are connected only by brittle and weak earth materials. For this reason, if the supporting wall under any timber fails, that timber usually falls. Also when a large portion of roof falls, the earth material on roof timbers cracks, becomes loose, and causes total disintegration of the roof. From the point of view of rescuing people trapped under the roof, total disintegration of the roof

FIGURE 3.73 Typical In-Plane Failure of the Exterior Walls of a Stone-Masonry Building in the Village of Kamasej.

FIGURE 3.74 Typical Failure of a Roof Due to Insufficient Length of Bearing of the Timbers (Village of Deh-beh).

may be helpful. However, it usually causes suffocation of entrapped people by closing all cavities and spaces used for refuge or air passage. Collapse of this type of roof causes a larger percentage of fatalities than the collapse of rigid monolithic type roofs.

Sometimes, collapse of non-load-bearing walls at ends of the room and failure of upper corners of load-bearing walls at these ends cause collapse of end spans of the roof, as shown in Figure 3.71. In some cases it was observed that a central portion of the roof had collapsed while portions at both ends remained standing. This mode of failure is caused by relative flexibility of the timbered roof, which is incapable of transmitting lateral inertial forces to end walls. These lateral forces are transmitted by means of timber ends to load-bearing walls. Load-bearing walls are usually more flexible at the central regions, and often, due to existence of openings, are weaker in these regions. Under high intensity shaking, roofs in central regions fail either in the mode described in Part a, or collapse after destruction of the central portion of load-bearing walls. End portions of the roof usually receive less damage due to restraining effects of non-load-bearing walls at these ends. A typical view of this mode of failure is seen in Figure 3.74.

3.2.4.1.3- Failure Mode of Composite Wall-Roof Structural System

The pattern of destruction of structures with flat-timbered roofs can be explained as follows. Under low intensity shaking the structure behaves as rigid box. When intensity of shaking increases at various locations of stress concentration, tensile and shearing cracks will form. These cracks are usually formed under roof timbers, between intersecting walls, and at locations and levels where rigidity of wall elements changes appreciably, such as around openings where vertical wall elements intersect spandrels or lintels. Appearance of these cracks causes the structure to become more flexible. This, in turn, increases the magnitude of lateral displacement of the structure and relative deformation of one part with respect to the other. As earthquake shaking continues, this increase in amount of deformation, in turn, increases length and depth of cracks and makes the structure more flexible. Study of response spectra of various earthquakes in the past has shown that for a rigid, small structure with a very small period of vibration, an increase in flexibility increases the natural period of the structure and, in most cases, causes an increase in the earthquake base-shear acting on that structure, which, in turn, will cause more cracking.

After cracking has progressed sufficiently, the structure no longer behaves as a box system. Individual elements of the structure become independent and fail in their particular failure modes, as described in Sections 3.2.4.1.1 and 3.2.4.1.2.

If shaking becomes more intense or continuous, depending upon which failure mode of structural elements prevails first, the structure begins to collapse progressively. As an example, in a typical structure, first the load-bearing walls may collapse, causing collapse of the roof; non-load-bearing walls may collapse afterward. Other sequences of failure may occur. The important conclusion is that the structure must first crack, and then elements must become disconnected from each other before any critical element can fail. If the structure remains rigid as a box, it will not collapse.

3.2.4.1.4- Lessons Learned from Failure Study of Structures with Flat-Timbered Roofs

From this failure study, the following lessons for strengthening this type of structure can be obtained:

1. Points of high concentration of seismic stresses should be eliminated in this type of structure. When this goal is not possible, general stress level should be reduced well below cracking level in all parts of the structure by reducing weight of roofs and increasing size and number of resisting walls.

2. Lateral shearing stresses in wall elements should be reduced below cracking level. This can be achieved by using smaller openings and by designing walls in such a manner that shear stress becomes uniform within all resisting elements. Increasing size and rigidity of lateral-load resisting wall elements may disproportionately increase its share of lateral-shearing loads and cause its premature cracking.

Cracking and failure of one wall element in a row may lead to a successive failure of all resisting elements, one after the other.

3. The brittle shear failure of wall elements should be replaced by a more "ductile" flexural failure mode. This can be achieved by increasing height-to-width or height-to-thickness ratios of wall elements. Proper insertion of ductile load-resisting components, such as wooden or steel columns or timbers, within wall elements can suppress brittle shear failure mode and preserve the vertical-load carrying capacity of wall elements even after a substantial amount of drift and lateral deformation. Timbers used for support of lintels and spandrels over openings should have sufficient bearing length and preferably should be continuous.

4. Use of stronger and more ductile material, such as wooden or steel columns, for carrying vertical loads is highly recommended. These columns can act as the last line of defense against collapse of the roof when load-bearing walls are destroyed by shear. These parts should be located in corners of rooms at the location of intersection of walls, or around openings. Doors or window frames can be designed such that vertical members are continued and connected to tie-beams on the roof.

5. Development of a monolithic roofing system suitable for mass use in the earthquake area is urgently necessary. This system cannot be achieved by using present available material and technology in the area. Rigidity and monolithicity of existing flat-timbered-roofing system can be increased by:

1) Using tie-beams on top of walls under the ends of roof timbers and nailing all roof timbers to these tie-beams.

2) Using transverse or diagonal boards or wooden elements for connecting all timbers together.

3) Increasing cohesion of soil used for roof-covering by additives such as lime, gypsum, and cement.

Tie-beams should connect wooden roof timbers to the vertical wooden or steel columns proposed in Items 3 and 4. In summary the use of a wooden skeleton for adobe buildings, designed in a manner to resist roof collapse, is highly recommended.

6. Dead weight of the roof should be reduced either by using a thinner layer of mud, or when economically feasible, by using other modern types of roofing and insulation systems, such as corrugated asbestos-cement products or lightweight-truss or joist-type roofing systems.

7. Wooden timbers should have sufficient bearing length on top of walls for protection of the upper portion of walls against water erosion. The roof should extend some small distance beyond external faces of walls.

3.2.4.2- Buildings with Dome-Shaped Roofs

In contrast with the north-central and northeast regions of Iran, because of relative abundance of locally grown timber and popularity and low cost of flat-timbered roofs, cylindrical- and dome-type roof construction has not found much application in the earthquake zone. The authors did not see any private house with a dome-shaped adobe roof in villages which they visited. Only a few structures with dome-shaped roofs were found in the area and were investigated by the authors. These structures were the Friday Mosque of the village of Biān (Karzin) and some mausoleums around a few scattered villages. Description of seismic behavior of these structures is given in the next section. Because of relative local importance, these structures have been constructed of stone masonry and gypsum mortar, which is superior to adobe and earth type materials. Due to superiority in material and design form, dome-shaped roofs of these buildings had a good seismic resistance.

3.2.4.2.1- The Friday Mosque of the Village of Biān (Karzin)

This mosque was the only building which did not collapse during the earthquake in the village of Biān. The southern view of this mosque is seen in Figure 3.75. The view of its roof is seen in Figure 3.76. The structure of this mosque consisted of two parallel rows of seven domes each. The third dome from the eastern side had a bigger span and higher elevation and rise, as seen in Figures 3.75 and 3.76. The last bay of the southeastern corner of this building was partially damaged, and the front portion of the dome and its spandrel wall were destroyed, as shown in Figure 3.77. All other domes remained virtually undamaged and even

FIGURE 3.75 South-end View of the Friday Mosque of the Village of Biān (Karzin).

FIGURE 3.76 A View of the Domed Roof of the Friday Mosque of the Village of Biān.

uncracked. The construction of the dome and its support can be seen in Figure 3.77. The dome is of stone masonry with gypsum mortar and seems to be insulated against moisture and rain by means of a layer of mud-straw plaster. The dome is relatively thin and of good workmanship. Each dome is supported on four onion-shaped four-centered arches, one at each side. Arches are supported by walls or piers at each corner of the dome. A transition shell has been used to support the dome around each corner and to transfer thrust of the dome to arches and corner piers. Arches, piers, and the transition shells are all made of stone masonry and gypsum mortar. Figure 3.78 is a photo taken of ruins of a caravansary

FIGURE 3.77 Damage to the Southeast Corner of the Friday Mosque of Biān.

FIGURE 3.78 Ruins of a Caravansary on the Qīr-Jahrom Road, Showing the Method of Construction of the Dome-Shaped Roofs.

on the road between Qīr and Jahrom; it shows a better view of the relationship among domes, arches, and supporting piers. (The caravansary, which is an old travel inn at caravan stops, was far from the epicenter of the earthquake. It received minor damage but was not destroyed. The ruins shown in Figure 3.78 were not caused by the earthquake.) Superior strength and resilience of this old mosque compared with poor behavior and total destruction of adobe buildings and the modern 2500th anniversary school in the area, while heartening to surviving Moslem faithful, was also evidence of better seismic strength of buildings with dome roofs in comparison with flat roofs.

Figure 3.79 also shows a view of some mausoleums in a cemetery near the village of Ābe Garm. It is seen that all old mausoleums with domed roofs are standing while some old flat-timbered-roof mausoleums have collapsed. The new flat-roof mausoleums are also standing.

Observations made on earlier earthquakes in Iran have indicated that seismic behavior of adobe houses with dome-shaped adobe roofs is much better than flat-timbered or cylindrical-vault roofs. Omote (1962) has described failure mode and collapse of dome-shaped roofs in the following manner. During the earthquake, tops of supporting vertical walls first became displaced by formation of cracks. Due to this

FIGURE 3.79 A Few Mausoleums in the Ābe Garm Cemetery. Note that Those with Dome-Shaped Roofs are Standing While Some of Those with Flat Timbered Roofs have Collapsed.

dislocation, even though it may only be a small amount, cracks are easily formed in the edge of the dome which then run upward to the top of the dome. After cracking, these roofs are not capable of holding together the top of walls and of maintaining a box-type structure. The cracked roofs produce a thrust, push the top of walls out, and cause gradual destruction of the wall. This thrust increases as extension of cracks in the dome is increased. Flexibility and existence of large openings in supporting walls of these structures facilitate their destruction.

Damage to dome-shaped roofs resting on rigid walls is less, because the domes fail only when their supporting wall fails. However, sometimes part or all of heavy roofs have fallen without damaging or collapsing supporting walls. In some cases portions of supporting walls have collapsed, and the rest have remained undamaged. In these cases, it has been observed that part of the dome on undamaged walls has remained intact while the rest of the dome has collapsed, as shown in Figures 3.77 and 3.78. For this reason, it seems dome-shaped roofs offer a greater degree of safety in the event of failure of one or more walls. Domes are built with various orientations of the brick layer; therefore, they are more rigid, which gives better protection and lateral stability to walls. Heavy domed roofs with large spans are more susceptible to damage than light ones with short spans.

3.2.4.3- Buildings with Cylindrical Vault-Shaped Roofs

Only in the town of Qīr did the authors observe a few destroyed buildings with adobe cylindrical-vault roofs. Figures 3.80 and 3.81 show ruins of two structures with cylindrical vault-type roofs. The type of construction and workmanship of this structure was better than that of neighboring adobe flat-roof structures. It is not possible to make any definite conclusion about mode of failure and comparative strength of this type of roof and structural system as almost all structures in Qīr were completely destroyed. However, from observations made in the earlier earthquakes in Iran [Ambraseys (1962), Omote (1962), Tassio (1969), Moinfar (1969)], it seems that strength of adobe cylindrical roofs is less than that of dome-shaped and even flat-timbered roofs. Some important observations on behavior and failure mode of this type of roof made in earlier earthquakes in Iran are as follows.

FIGURE 3.80 The Ruins of a Structure with Cylindrical Vault in Qīr.

FIGURE 3.81 The Ruins of Another Structure with Cylindrical Vault in Qīr.

Adobe houses with cylindrical vaults did not have good seismic performances, especially when rise of arch was small. When direction of the main shock was perpendicular to generatrix of the cylindrical roof, the vault was ruptured at its base line. This happened especially when the tie between cross-walls and bearing walls was insufficient, leading to excessive lateral displacement of bearing walls. When the ratio of vault-thickness to thickness of bearing walls was large, collapse of the roof caused collapse of walls. When vault-thickness was small compared to thickness of bearing walls, the roof collapsed without causing collapse of walls. Vaults with gypsum mortar had a better resistence and less damage. Use of horizontal wooden or steel rods for tying two supporting walls of cylindrical vaults at intermediate points increased their stability against collapse. Large openings in walls resulted in more damage. When direction of main shock was parallel to generatrix of vaults, end walls and end portions of vaults collapsed and cracks formed along openings of longitudinal walls. The mid-portion of some cylindrical vaults with dome-shaped ends collapsed while end domes remained undamaged (Figure 3.80).

3.3- Earthquake Effects on Slopes, Soils, Foundations, and Pavements

3.3.1- Slope Stability Problems

By far the most common earthquake effect on natural soils and rocks in the area were numerous rock falls and rockslides that occurred extensively on steep slopes throughout the area. Most of these occurred high in the mountains at crests of ridges and involved instability of vertical or overhanging cliffs formed by steeply dripping beds of limestone. Most of these were of no engineering consequence since these high mountain crests were not inhabited nor crossed by highways.

The authors climbed one of the smaller mountains to inspect the nature of these small rockfalls at close hand. This particular mountain showed a negligible amount of rockfalls as seen from the valley floor. However, at the crest an extensive amount of cracking and fracturing of rock was observed. These observations are illustrated in Figure 3.82. These rock fractures were only observed at the very crest, and no such cracks were observed along the slope, although rocks appeared similar. It, therefore, appeared that shaking was much more violent at the crest than anywhere along the slope or at the valley floor.

In some areas where roads cut through mountain passes had artificially steepened rock slopes, even small rockfalls were sufficient to close the road. This occurred at several places on access roads into

FIGURE 3.82 Typical Cracks at the Crest of the Mountains Near the Village of Ābe Garm.

the area and caused delays in bringing relief supplies to survivors. Except for one major slide, these roads had all been opened by the time of the authors' visit fourteen days after the earthquake.

The largest rockslide which was observed, and which was still blocking the road at the time of the authors' visit, was located in a high mountain pass called Jalalie Pass. A large area at the top of Jalalie Mountain of some 1,300 meters elevation slid down and completely covered several switchbacks of a jeep trail which provided the only access over steep Jalalie Pass into a few towns in an adjoining valley. This rockslide is located on the west of the village of Kamesej (between villages Nos. 56 and 73 in Figure 2.1), and a photograph of it is shown in Figure 3.83. At the time of the authors' visit, supplies were being ferried over the slide and mountain pass by pack donkeys.

In addition to rockslides, there were a few examples of soil instability. At several locations there were cases of a small amount of slumping of creek banks. About one km to the east of Shāhābād bridge, the river makes a sharp turn which leads to bank erosion and results in an almost vertical bank about 15 ft high. Soil exposed in this bank was silty sand, and thus it is not surprising that comparatively extensive slumping occurred all along this stretch of river bank. Behind the bank there were numerous echelon cracks up to about 3 in. wide, running parallel to the bank. These extended back a distance of about 60 ft from the crest. These cracks and the slumped bank are illustrated in Figure 3.84.

In the same area, on the dry, rocky talus slope well above the river, some small vertical cracks were observed near the crest of fairly

FIGURE 3.83 Rock Slide at Jalalie Pass Near the Village of Kamasej.

FIGURE 3.84 Typical Cracking and Slumping of the Banks of the River Qara-Aqaj Near the Shāhābād Bridge.

steep slopes. This is additional evidence that at the crest of hills on mountains shaking was more violent than elsewhere. In all of these cases cracks were small, and the area uninhabited, so that they are of no significance to structures or to people.

An example of excellent bank behavior was observed on the north bank of the Qara-Aqaj River, immediately to the east of Shāhābād bridge. Here, a near-vertical bank of silty sand some 20 ft high had been stabilized from river erosion by a network of boulders encased in wire mesh (gabions), as shown in Figure 3.85. There was no evidence of any disturbance either of gabions or of soil behind the slope.

In another uninhabited area near the village of Khoshābjān (no. 46 in Figure 2.1), Mr. Arthur Grantz of USGS reported to the authors that he had seen extensive slumping and lurching cracks running parallel to a small creek and extending back from the creek for a distance of about 500 ft. These cracks were as much as one-foot-wide with 6-in. vertical offset.

From the point of view of local farmers, serious slope stability problems developed along many of their irrigation canals and qanats. In one instance, an irrigation canal leading into the Qīr valley from the Qara-Aqaj River was blocked in several places. This is one of many

FIGURE 3.85 A Retaining Wall Made of Boulders Encased in a Wire Mesh (French Gabion System) Near Shāhābād Bridge at the West Bank of the River Qara-Aqaj.

ancient irrigation facilities in the area, which consist of a series of tunnels and steep, open excavations. Of interest to western visitors is the tremendous amount of hand labor that has gone into constructing and maintaining this canal. Figure 3.86 is a photograph showing a team of laborers at work at the point where the canal begins to divert water from the river. Soil here was a silty sandy gravel, and hand-excavated steep banks had all slumped in. This canal led water away from the river and out into the agricultural valley, but in doing so had to cross several major obstacles. The first of these was a large ridge of limestone bedrock which had been uplifted and twisted until bedding planes were almost vertical. At some unknown time in the distant past, a tunnel had been carved through solid limestone rock to give passage for the water.

FIGURE 3.86 A Team of Laborers Cleaning the Intake of the Irrigation Canal Near the River Qara-Aqaj.

Beyond this tunnel the canal traversed hilly terrain of silty sandy, gravelly soil to the level farmland in the valley. Following the ancient system of qanats, the canal consisted of a series of very steep, hand-excavated holes or wells and connecting tunnels. Figure 3.87 shows a team of laborers at work, cleaning out one of the open excavations which had slumped in sufficiently to block the canal. The upper part of the excavation sloped at about 1 horizontal to 1 vertical.

FIGURE 3.87 A Team of Laborers Cleaning Out One of the Slumped-in Open Excavations.

At the lower 6 ft there was a 2½-ft-wide cut with vertical walls. Stability of walls of this excavation depended on the small amount of natural cementation and cohesion developed by capillary tension in this silty sandy material. It must be metastable only under static conditions, and it is not surprising that banks caved in during the earthquake. To us it was remarkable that the amount of slumping was not more extensive than was observed.

In conversation with these laborers, they reported that on the previous day a small aftershock had occurred and caused banks to slough in again, completely burying three of their fellow workers. Fortunately, they were rescued alive. During the occurrence of this aftershock, the authors felt the shock in the area nearby, and saw it cause a small amount of additional landslides of a creek bank by which they were standing. It seemed to have an intensity of about V on the MM scale.

3.3.2- Performance of Level Ground and Foundations

Soil in all of the level agricultural plains was a brown clayey sandy silt. Texture varied slightly from place to place, being a little more clayey in Q̄ir than in other areas. Looking down open wells indicated that the same soil conditions existed down to at least the water table, which ranged from 20 to 50 ft below the surface. In some areas there were a few gravel strata about 2-ft-thick in the walls of some wells.

Except for the few cases of cracking and slumping near stream banks, which were described before, there was no indication of any other soil cracks, settlement, or foundation soil malfunction.

3.3.3- Behavior of Pavements

No asphalt or concrete pavement was observed in the area as all roads were of unimproved-dirt type except for the engineered gravel road between Qīr and Lār, which was a newly constructed grade with compacted base and embankment. Behavior of bridges and culverts of this road was discussed in Section 3.2.2. Road embankment was not damaged; however, some cracks and slumping were observed on shoulders of the embankment, especially near small bridges and culverts, as seen in Figures 3.88 and 3.89.

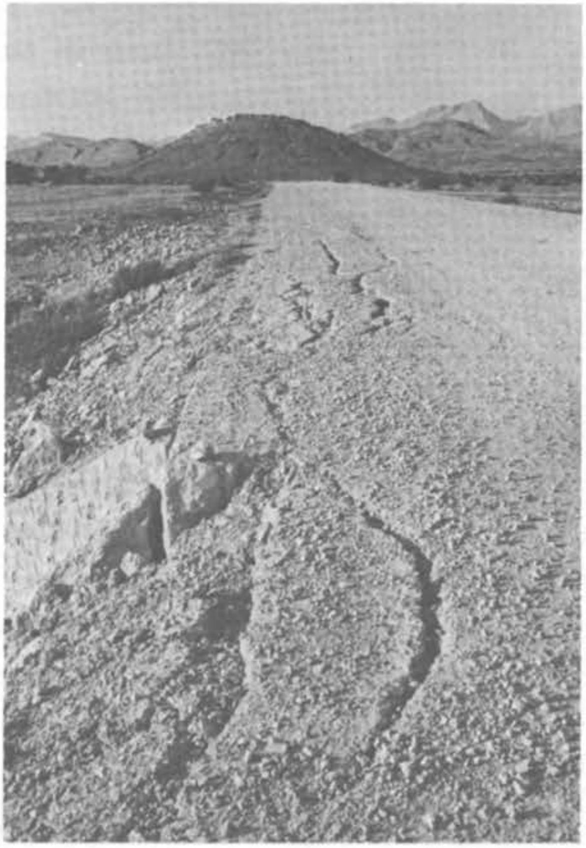


FIGURE 3.88 Damage to the Road Embankments Near a Small Culvert.

FIGURE 3.89 Damage to the Road Embankment Near the Eastern End of the Shāhābād Bridge.

4. HUMAN ASPECTS OF THE EARTHQUAKE DISASTER

From an overall point of view, the most important results of this earthquake were human aspects--death of some 5,300 people and suffering of survivors due to loss of friends and relatives, homes and belongings.

4.1- Rescue and Relief Operations

Considering the isolation of the area, it is somewhat miraculous that word of the disaster reached the outside as soon as it did. According to some reports, a French helicopter pilot and two of his companions were in the town of Qīr during the earthquake. One of his companions was killed and the other seriously injured. The pilot was not hurt, and he immediately flew his injured companion out to the city of Shīrāz and informed the outside world of the earthquake disaster. At Shīrāz the Governor General of Fārs Province had come early to the airport for arrival of a visiting royal dignitary. On learning of the disaster in Qīr, he immediately flew by helicopter to the earthquake area, surveyed damage, and returned to report the magnitude of the disaster to Teheran and to order an immediate large-scale relief mission. The Iranian Army was ordered to move into the area to clear roads, establish communication, and carry on the rescue operation. An airlift operation was set up, and an emergency landing field was established near Qīr. Emergency supplies were flown into the disaster area by army helicopters, and injured were flown out to hospitals in Shīrāz.

According to reports, first relief supplies in the form of food and rescue laborers were totally organized and financed by the people themselves under recommendation of religious leaders and arrived in the afternoon of the day of the earthquake from nearby towns of Lār, Jahrom, and Fīrūzābād. It was two or three days before roads could be cleared and major relief supplies arrived from the outside by army trucks.

The first relief operation was the rescue of survivors trapped below wreckage, and hundreds were rescued alive in the first several hours following the quake. Dead bodies were also recovered as quickly as possible, it being an Islamic custom to give the dead a formal burial within 24 hours of death. Graves were hurriedly dug for this purpose, mostly beside the wreckage of village mosques. White cloths for burial shrouds were air-dropped and also brought in by rescue workers from Jahrom and Lār. Many women from Jahrom came to Qīr to help in burial of the dead women, including their final washing, which according to Islamic laws must be done by a woman or a very close male relative.

Medical teams were immediately flown into the area, and all survivors were inoculated against cholera. This was needed to avoid a possible epidemic resulting from disruption of normal drinking water supplies and other unsanitary conditions which naturally resulted from people being suddenly forced to camp out in large groups away from normal sanitary facilities.

Virtually all relief and aid was provided by Iran itself, with little or no help from foreign countries. Newspapers reported some immediate confusion and problems due to conflicts among various organizations participating in rescue and relief operations, but, after a few days, these problems had been taken care of and various organizations functioned smoothly together.

The main agency in charge of relief in Iran is the Red Lion and Sun (RLS) organization, a rough equivalent to the Red Cross and Civil Defense in the U.S. The mission of the RLS was to provide immediate emergency relief. Hundreds of tents were brought into the area immediately, along with food, clothing, and cooking utensils. Tent villages sprang up spontaneously beside every town and village as virtually every surviving resident was forced out of his home. At the time of our visit, 14 days after the earthquake, at the town of Qīr the refugee camp consisted of 750 tents housing 3,100 people. A view of this camp is seen in Figure 4.1.

Laboratories had been set up. A large, elevated water tank had been erected and was supplied by a fire pump truck which obtained water from a nearby spring. From this tank water was piped to several central outlets in the refugee tent camp. A portable electric generator had been installed, and "street lighting" was provided at several places throughout the camp. In addition, a bank, post office, and radio telephone station had been installed, as well as several hospital tents, where rather intensive first aid was being administered to many patients. A crew of men were continually spraying disinfectant around the camp.

FIGURE 4.1 Tent Camp at Qīr.

School had been reestablished in tents. We were told that several teachers and 200 of the original 350 students had been killed by the earthquake.

Meanwhile, scrapers and bulldozers were at work, leveling and smoothing off an adjacent area for a more permanent refugee camp. It was planned to move the tents onto this area within a few days and to establish them in an orderly fashion with better water and sanitary facilities.

All the while, survivors were busy digging through remains of their homes in search of belongings or caring for each other. As it happened, the earthquake occurred shortly after daylight when many men had already gone to the fields. Thus, the high portion of survivors consisted of men, many of whom had lost wives and children. Thus, there were some problems with men left to both work the fields and care for young children. However, in most cases friends and relatives were cooperating to help in these unfortunate situations. Only a few surviving children may be sent to orphanages.

Out in the villages there was a similar scene, only on a smaller scale with some of the factors missing. For example, there was no electricity nor piped water. Villagers used the traditional method of collecting water from rivers, streams, or springs in ceramic jars or goatskin bags and bringing it into their tent campground. A view of village tents is seen in Figure 3.8. A view of a temporary tent school is seen in Figure 4.2.

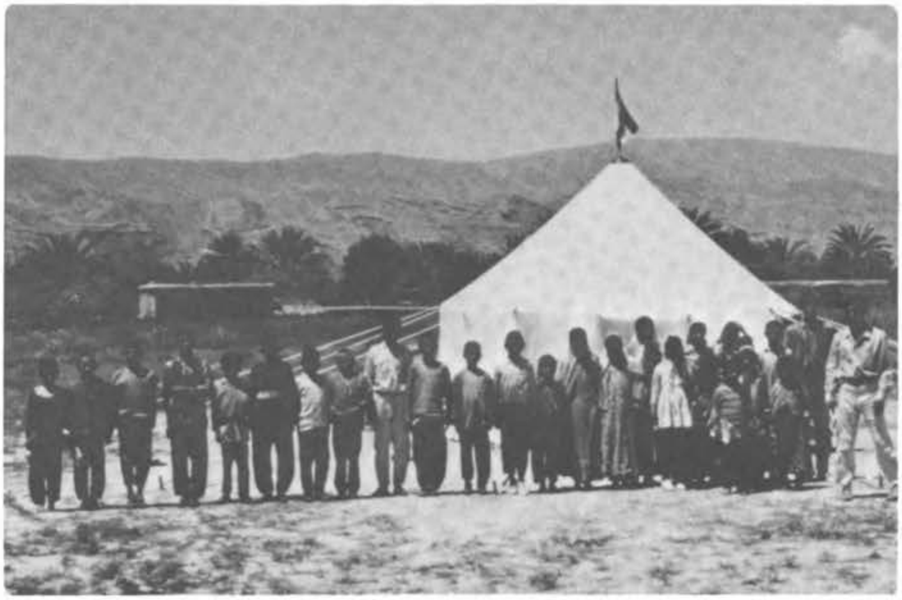


FIGURE 4.2 A School under the Tent in the Village of Seif-abad.

Nourishing food was somewhat scarce. Rice and other usual foodstuffs had been lost in the rubble of houses. The RLS was supplying sugar and tea, traditionally the most important necessity of life all over Iran, as well as other foods. Newspapers reported that, prior to the earthquake, people in the area were relatively well off and that there were no beggars. The authors' observations under these trying conditions were certainly in agreement. Everyone looked well-nourished and dressed comfortably. It was concluded, therefore, that emergency relief was adequate for immediate needs of the people.

4.2- Rehabilitation and Future Plans for the Region

In conversation with survivors, it was learned that their chief concern was for their future. They had heard many rumors about what the government was going to do to rehabilitate them, and they were concerned and anxious about what lay ahead.

About nine years ago Iran went through an effective land reform. Large parcels of private land were expropriated from the owners (largely absentee owners) and redistributed to local people who were living and working on the land for landlords without hope of ever acquiring property of their own. Long-term credit was offered so that village farmers could buy and eventually own a parcel of land. Everything seemed to be going well around the Qīr area, and land payments were being met on time.

One of the problems, however, was that the rural people chose to live in very small semi-isolated villages surrounded by their farms. It was, therefore, very expensive for the government to provide these villages with modern conveniences such as electricity, water, sewers, hospitals, banks, etc. A further complication was that each individual farm was small and would not support an investment in farm machinery. As a result, farming was almost completely done by hand.

4.2.1- Government Plans for Rehabilitation

Recognizing these situations, the Ministry of Rural Affairs and Cooperatives of Iran had developed a plan for improvement. They wanted to move people from small villages and consolidate them into larger rural centers which could be given adequate services. They also wanted to establish cooperatives which would jointly buy mechanized farm equipment and otherwise provide a large base to support a modern productive farming community. This type of plan was intended for many of the rural areas in Iran. The major problem with it was that it was financially, socially, and psychologically difficult to execute. People in general resist change, and the thought of abandoning their newly acquired lands and former homes in tiny villages to move into unknown situations in larger towns was not popular among local people and farmers.

It is not surprising then that land-reform people naturally look upon this earthquake disaster as an opportunity to launch the new plan in the Qīr area. By the time of the authors' arrival, three large, self-propelled John Deere combine-threshers had been brought into the area for use in harvesting vast areas of wheat and other grains due to ripen two to three weeks later. Meanwhile, plans are being laid for four large new towns into which most of the people will be moved as soon as possible. Other cooperatives are also being planned to market and distribute produce. In addition, meetings are being arranged to inform villagers of this new plan for their future. Land-reform people told us that, while they expect some reluctance and resistance on the part of villagers, they anticipate that they will soon be all in favor. At present, the government of Iran has a very strong hold on the population; therefore, no serious problems are anticipated in executing this new land reform plan, irrespective of how villagers may feel.

4.2.2- Attitude of the People

While there was not enough time to discuss these matters in detail with a large sample of population, discussion with some local people, local government officials, research workers, and sociologists indicated that the government plan of creating four rural centers and abandoning all villages in the area, while being progressive and well-intentioned, is based on insufficient research and studies, which may fail to gain acceptance by farmers. It is the authors' opinion that such a large-scale operation, which probably will involve an expenditure of millions of dollars and relocation of thousands of people, should be carried out after an exhaustive socio-economic, technical, historical, and cultural investigation. Otherwise, it may become a futile investment which may never be accepted or utilized by farmers. Many unfortunate cases of insufficiently-studied and hastily-created rehabilitation projects exist, both in Iran and in other countries, to make this warning serious.

Presently villagers are mourning for their past and worrying for their future. There was already a tendency among many people to become too dependent on outside relief. Although more than two weeks had passed since the earthquake, many able-bodied men still had not moved from their tents out to work in their fields. Although they were concerned about their future, a combination of shock from the past and fear of the unknown which lay ahead was making them more and more dependent upon regular, free (though meager) relief supplies. It will be very important to deter this feeling of helplessness and dependency because in a few more weeks the large volunteer army of RLS and other emergency relief workers will be gone, and the future of survivors will be largely in their own hands.

Unfortunately, in spite of well-intended desires of people in charge of rehabilitation, it is expected that quality of housing will not be much improved from the point of view of earthquake safety. Before the authors left the area, construction had already started on an office building. As shown in Figure 4.3, this new structure is being made of rubble stone by the same techniques used to construct hundreds of houses which collapsed and inflicted so much death and injury during the earthquake only two weeks past. Destitute of apparently any other suitable construction material in the area and lacking financial means to import better material from outside, new towns are bound to be reconstructed much as they have been for centuries past, and those who inhabit them must live in constant fear of another similar disaster in the future.

FIGURE 4.3 The Foundation of a New Structure Being Built Again with Rubble Stone.

5. SUMMARY OF RESULTS AND OBSERVATIONS

5.1- Some Observations on Earthquake Hazards in Iran

Although during the past decade alone more than 30,000 people have died in Iran under debris of collapsed buildings due to earthquakes, it seems that so far no significant steps are being taken by either government, legislators, engineering societies, or the public to minimize the looming earthquake hazard in this country. It is fortunate that all destructive earthquakes of the past decade have occurred in rural areas having a small concentration of population. Without any doubt, if any of these earthquakes had occurred in large cities, a much higher human catastrophe would have resulted, and many more thousands of people would have perished.

Seismic resistance of Iranian buildings, especially that of residential dwellings, is generally very poor and only in rare cases is better than that of the Qīr clinic. Most of the buildings are built by contractors with no technical knowledge. They are not engineered, often of poor structural material and workmanship, with a SBABA (steel beam and shallow brick arch) roofing system, without any provision of tie-beams. The most dangerous one are those buildings constructed by contractors (me'mars) for sale purposes. In construction of structural elements of these buildings, which will hide under plaster covering, the poorest quality material and workmanship is used. A few samples of typical buildings are discussed below:

Figure 5.1 shows a typical building under construction in the city of Shīrāz with concrete-block walls and SBABA roofing system. As can be seen, concrete blocks, mortars, and workmanship used in this building are of poor quality on the basis of any accepted standard. No steel reinforcement is used any place within the wall and no vertical tie-columns or horizontal tie-beams are used in either. Bearing length of steel beams on top of the concrete-block wall is very small. No lateral or diagonal bracing of beams is going to be used. It is apparent that seismic resistance of this building will not be more than many buildings destroyed in Qīr.

FIGURE 5.1 A Typical Building with the Concrete Block Walls and SBABA Roofing System in Shīrāz.

Figure 5.2 shows a view of a typical brick masonry wall of a residential building in Shīrāz. Here again, inferiority of material and workmanship is evident. In order to save the cost of using timbers or steel beams as lintels over doorways, the contractor instead has used a very shallow (almost flat) brick arch with gypsum mortar. Without doubt, under an earthquake of moderate intensity, these walls will soon come apart.

Figure 5.3 shows a view of a typical two-story brick-masonry house with Shiravani roof (a type of low-cost roof made of wooden trusses and thin roof covering of tin plates. This type of roofing system is very popular in most cities in Iran.). These types of buildings are being built by contractors (me'mars) in an increasing number for sale in most cities of Iran. Existence of large openings in walls, the small percentage of resisting shear walls in any direction, and poor condition of the wooden trusses and masonry materials used is evident in the figure. This type of construction has a poor seismic resistance and probably will collapse in an earthquake of moderate intensity.

FIGURE 5.2 A Typical Brick-Masonry Wall of a Residential Building in Shīrāz.

FIGURE 5.3 A Typical Two-Story Brick-Masonry House with Shiravani Roof.

Figure 5.4 shows a typical modern four-story building in a corner of a street block in a newly-built zone of Shīrāz. In this structure reinforced concrete columns and SBABA roofing system are used. A close-up view of one of the first-story columns taken after installation of the screen frame is shown in Figure 5.5. Column is deeply gouged on the sides to expose reinforcing bars and to weld screen frames to these bars. At the joint between columns and roof, all main steel girders pass through the reinforced concrete column. Attachment between lower- and upper-story

FIGURE 5.4 A Typical Modern Four-Story Building in a Corner Street Block in a Newly Built Zone of Shirāz.

FIGURE 5.5 A Close-up View of One of the First-Story Columns of the Structure Shown in Figure 5.4.

columns are only by means of four small size (12 mm) reinforcing bars, with no concrete around them, as shown in Figure 5.5. The steel girder is supported on reinforced concrete columns with no bearing plates. The joint is practically a hinge. The lower story of this building, at present a branch office of a bank, has no lateral-load-resisting shear walls or partitions in street directions. The apartments in the upper stories do have sufficient interior partitions. The building is an approximate representation of a structure designed on the basis of the flexible first-story concept. It is doubtful if this building will resist a moderate earthquake such as the one which occurred in Qīr.

Up to the present time, no building code has been officially adopted in Iran. After each earthquake, some brief codes have been proposed by various engineering and technical organizations; however, no legislative action for adopting and enforcing any of these codes so far has been taken. At present using any code in the design is voluntary except in major governmental buildings designed by consulting engineers, where often codes of foreign countries, in particular, American (SEOAC or UBC) and German (DIN) codes, are used. So far, any privately-owned structure can be designed and built by any non-qualified mason. No regulations or city ordinances with regard to minimum technical qualification and licensing of building designers and contractors exist. In recent years, some cities have required that design drawings of major buildings used by the public be signed by a graduate civil engineer or architect. This is an improvement over the past, but in actuality, it has become only a formality in most cases.

In order to assess magnitude of earthquake risk in Iran, an estimate of extent and percentage of destruction due to probably future earthquakes of various intensities for four large Iranian cities are shown in Table 4. In this table types and number of existing constructions are from statistical information published by the Planning Organization of the Iranian Government for the year 1966. Assumed percentages of destruction of each type of structure by earthquakes of intensity VII, VIII, and IX are shown in the upper three lines of the table. These assumed percentages are lower-bound, optimistic values based on study of previous earthquakes in Iran and in similar countries. From this table, it is seen that an earthquake of intensity VIII, similar to the one which destroyed Qīr, may destroy almost 90,000 building units (about 25% of all structures) in the city of Teheran. A similar earthquake may destroy 45% of buildings in Tabrīz, 44% of buildings in Isfahan, and 33% of buildings in Shīrāz. Study of historical earthquakes [see Wilson (1930), Ambraseys (1968)] has indicated that with the exception of Isfahan, all the above cities or their surrounding areas have been recurrently destroyed by earthquakes within the past 1,000 years.

Probability of occurrence of earthquakes and high magnitude of resulting damage and destruction is real and should be taken very seriously by the Government and by responsible people and organizations in charge of planning and construction in Iran. Minimization of earthquake hazards in Iran should gain a high priority in national planning and development. Determination of effective, feasible, and economical methods for earthquake-hazard minimization in Iran needs much in-depth research and study. However, some obvious steps can temporarily be taken which will give immediate results.

Some inexpensive improvements in seismic resistance of buildings can be achieved by establishing proper educational programs for common contractors (me'mars), masons, and the general public. Higher degrees of improvement demand better design, better materials, and superior workmanship. Cost of improving seismic resistance of a residential building in Iran as a percentage of total cost of finished structure, is not very large. Some earlier estimates by Professor Razani have shown that an increase in cost from 7% to 15% may be involved. This improvement will bring expected resistance of structures up to level of intensity VIII in MM scale.

One important step which urgently must be taken is adoption and enforcement of a National Seismic Building Code, so that at least all new buildings are built according to the code. After World War II many Iranian cities grew rapidly, and many new buildings have been constructed. Because of rapid industrialization presently underway, the size of many cities will double in less than 20 years.

Figure 5.6 shows the importance and urgency of adopting a seismic building code. As an example, this figure shows growth of the number of buildings in the city of Shīrāz during the past few decades. At present there are about 40,000 buildings in Shīrāz. Probable pattern

CONDITION OF SHIRAZ BUILDINGS IN YEAR 1984 (1363) AND THE CODE EFFECT.

Year of Adopting Seismic Code		1951 (1330)	1961 (1340)	1971 (1350)	1981 (1360)
Built According To Seismic Code	No. Buildings % Total	82400 %94	73600 %84	59000 %67	20000 %23
Built Before Code Adoption	No. Buildings % Total	5600 %6	14400 %16	29000 %33	68000 %77

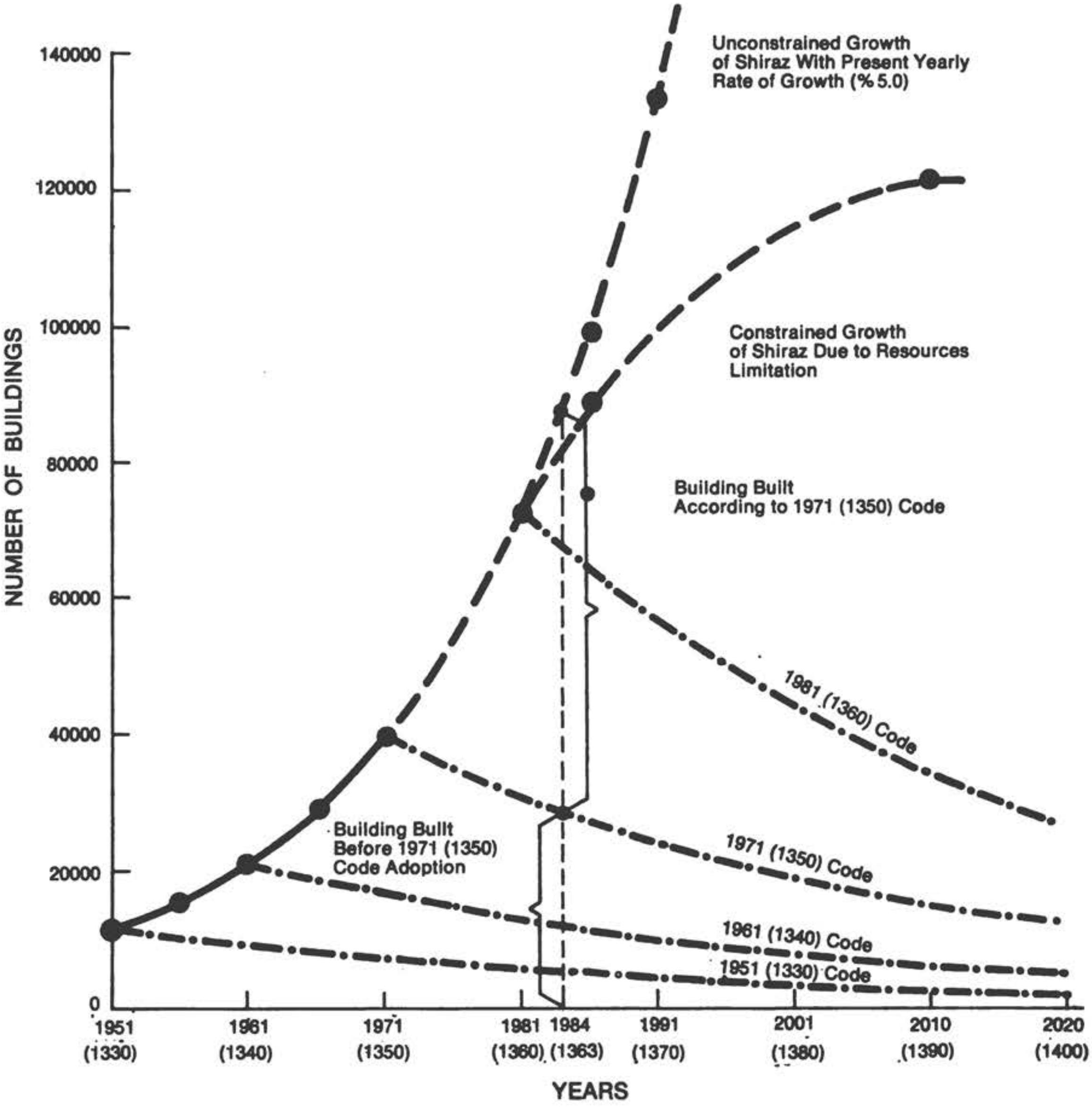


Fig. 5.6: Growth of the Number of Buildings In the City of Shiraz, Iran and the Effect of Delay In Adopting a Seismic Code In the Condition of Buildings.

of growth of the number of buildings in the future in Shīrāz is also shown in this figure. Curve A shows exponential growth of the number of buildings in the city if rate of growth of the last decade (about 5% annually) is maintained. However, due to limitation of resources and space, it is reasonable to assume that after some time this rapid rate of growth will diminish, and a more reasonable and constant growth rate will follow, as shown by Curve B. Both curves show that the size of the city and number of buildings will almost double in about 12 more years.

If after the occurrence of the Buin-Zahra earthquake of 1961, a suitable seismic building code had been adopted nationally, then all buildings constructed after that time in Shīrāz would have been built according to the code, and presumably would have been earthquake resistant. Older buildings which were not built according to the code would have gradually vanished by urban renewal processes and projects. Curve E shows the condition of buildings in future years, if in 1961, a seismic code had been adopted. The ordinate of Curve E at any future year shows the number of existing old buildings not built according to the code. The vertical distance between Curves E and B represents number of existing new buildings built according to code. Similar discussion can be made for Curves F and D, representing the effect of adoption of a seismic code in the years 1951 and 1971, respectively.

The table on top of Figure 5.6 shows effect of early adoption of seismic building codes for a hypothetical future earthquake, say at year 1984, in Shīrāz. If the code is adopted in the year 1981, then about 77% of buildings will not be according to code in 1984 and will presumably be dangerous. If the code had been adopted last year (1971), then only 33% of buildings in 1984 would not be according to code. If the code had been adopted in 1961, then only 16% of buildings in 1984 would not be according to code and the remaining 84% of structures would have been designed and built according to code. Small variations in rate of growth of new buildings and rate of mortality of old buildings used in obtaining these curves will not substantially change the above conclusions. These conclusions show importance and urgency of adopting a seismic building code. Much valuable time so far seems to have been wasted by rivalry among various responsible organizations for development of a code and for determination of so-called Optimum Code. Modification and improvement of codes are a continuing process and can be achieved later on, as it is done in advanced countries. In light of the urgency of the problem, it is proper to say, "Any code is better than no code."

Adoption of the code will not, by itself, be sufficient. Enforcement of the code is the final objective. This requires the organizing of building inspectors and educating construction people and the public for acceptance of the code. These steps must be taken before the code is adopted and enforced.

Finally, much needed improvement in present technology of construction in Iran must be given priority in national planning and in future investment of resources. Increasing seismic consciousness is also needed. The entire problem of earthquake risk and earthquake hazard minimization must be given proper attention, priority, and resources if future earthquake catastrophes are to be prevented.

5.2- Conclusions

A. With Regard to the Qīr Earthquake

1. There were numerous rockfalls from steep mountains and relatively minor ground cracking and slumping along stream banks and on sides of highway embankments. However, these events did very little damage except to block some roads, irrigation canals, and wells; thus, effect of the earthquake on soils, lands, foundations, and pavements was not significant.

2. From the point of view of human suffering, this earthquake was a major disaster. It inflicted numerous injuries and caused great loss of life and property. Collapse of heavy roofs of inferior quality adobe and masonry structures in the area was the main cause of death and injuries.

3. This earthquake once again showed extreme seismic vulnerability of adobe and unreinforced masonry type structures. Since this type of construction is very common, not only in Iran, but also in many other parts of the world, this Qīr earthquake stresses once again need to develop a better type of acceptable low-cost housing for earthquake-prone areas.

4. There was very little significant damage to a few well-engineered and well-built structures, such as the Shāhābād Bridge and the elevated steel water tank in Qīr. Thus, from a modern engineering point of view, this was not a significant earthquake. This also shows that if buildings in the area were well-engineered and well-constructed, they could have withstood the earthquake with only an insignificant amount of damage and destruction.

5. A few brick-masonry buildings with steel I-beam and shallow brick arch roofing system, which were designed according to engineering standards and specifications, behaved very poorly in this earthquake because:

a. Standards and specifications used for construction were insufficient and unsatisfactory from earthquake-engineering viewpoints.

b. Due to absence of continuous and competent supervision and the low level of construction skills and technology in this remote area, these structures were not constructed according to plans and specifications. These shortcomings illustrate that in these areas use of simple construction techniques with minimal dependence on local skill and supervision is needed. This condition can be materialized by using factory-made, field-assembled, prefabricated structural systems.

6. Primary causes of failure of masonry and adobe structures were:

a. Very poor strength and seismic properties of local building material, especially mortars used in construction of these buildings.

b. Structures did not behave as a rigid box system because: 1) tying and interconnection between various elements, such as walls and roof, were not sufficiently strong, and 2) rigidity and strength of some individual elements were not sufficient, thus causing their premature failure.

c. Destruction of vertical-load-bearing wall elements due to shear, shear-compression, and shear-flexure.

d. Disintegration of brittle, non-monolithic, and non-rigid timbered or steel-beam roofs.

e. Separation of roofs from walls due to insufficient length of bearing of beams on supporting walls and subsequent failure of bearing areas.

7. When roof beams were tied together by means of reinforced concrete or steel tie-beams with sufficient in-plane bracings, they did not disintegrate due to falling or due to partial collapse of load-bearing walls. Existence of steel or wooden vertical-load carrying elements in some cases prevented collapse of these roofs, even when load-bearing walls were totally destroyed. Use of horizontal tie-beams on top of all bearing walls connecting roof beams together, plus use of steel, reinforced concrete, or wooden tie columns with sufficient strength to carry vertical loads in case of failure of load-bearing walls may be very helpful in preventing collapse of roofs of these buildings. In general, use of a ductile earthquake-resistant structural skeleton in masonry or adobe type building will be very effective in preventing roof collapse; however, it may not prevent earthquake damage. Added cost of these improvements is only a small precentage of total construction costs.

8. A few structures with dome-shaped roofs made of stone masonry and gypsum mortar behaved relatively better than those structures with flat-timbered roofs or cylindrical-vault-type roofs.

9. Unwise use of modern construction materials, such as steel and reinforced concrete, with traditional masonry and adobe material did not improve seismic resistance of resulting hybrid structures.

10. Rescue and relief operation carried out by the government and people of neighboring towns was very swift and effective. Announced future plans of the government for the rehabilitation and renewal of the area involve high investments and will cause relocation of people and important social and economical changes in the region. These plans need an in-depth technical, economical, and social investigation if the resulting operation is to be successful.

B. With Regard to Earthquake-Related Problems in Iran

1. Iran is located in a relatively active seismic zone and most regions of Iran may experience destructive earthquakes in the future.

Therefore, the problem of earthquake-risk and earthquake-hazards minimization should be given the proper attention it deserves.

2. Seismic zoning of the country is necessary for use in building codes and for further scientific and engineering studies. This zoning should be done on the basis of seismological studies of this century plus information regarding old historical earthquakes. Increasing the number of seismological stations in southern and eastern regions of Iran, and installation of strong-motion accelerographs, at least one in each town or in each large-scale construction project, would be very useful for scientific and engineering purposes.

3. Adoption and enforcement of a national seismic building code which reflects realities of Iranian conditions is urgently needed, as construction of new buildings in most cities is expanding at a very sharp rate.

4. Most existing buildings in rural and urban areas of Iran have very poor seismic resistance. If a moderate earthquake occurs in a large city, it may cause a large-scale human catastrophe. Proper steps should be taken immediately to discourage further construction of these types of buildings, and to renew and strengthen existing ones. The government can set an example in this direction by upgrading quality of public buildings, such as schools, hospitals, government offices, etc.

5. Another high priority need is research development on materials, methods, and technologies for feasible, low-cost rural and urban housing which is seismic-resistant and the behavior of various types of construction presently used in Iran in earthquake-prone regions. So far, no organized research and development effort in the area of earthquake-risk analysis and earthquake-hazard minimization has been carried out in Iran. Establishment of a permanent national committee in charge of problems related to earthquakes and other natural hazards in Iran is needed. This committee should be responsible for encouraging, promoting, and guiding research efforts in problems related to earthquakes. However, it should not be so rigid or restrictive as to discourage independent work.

6. After three major earthquakes within the past decade, causing the death of more than 30,000 people, it seems as though the public,

government officials, engineers, architects, and construction people are still not thinking seriously about earthquake risks. There is an urgent need for elevating the level of seismic consciousness of the people by a process of continuous education and information distribution.

7. Earthquake engineering is a relatively new discipline; therefore, many Iranian engineers and designers are not familiar with this field and with its recent progress. Exposing designers and engineers to earthquake-engineering techniques and its developments is urgently needed. Universities in Iran should play a major role in this continuing educational process.

8. A national program for educating and licensing the local contractors (me'mars) and masons is needed so that the level of their technical competency will be upgraded, and so that unqualified people will be prohibited from constructing buildings. This program should be integrated with other national programs which are designed for training construction technicians and building inspectors.

5.3- Recommendations

A. Concerning the Qīr Earthquake

1. Development of some type of low-cost earthquake-resistant housing as a substitute for presently used adobe and unreinforced masonry buildings with non-rigid flat roofs is urgently necessary.

2. Existing engineering standards and specifications of various agencies in charge of rural development in Iran should be revised and improved so that a higher seismic capability is obtained.

3. In the earthquake area and in other relatively remote regions, use of complicated designs and unfamiliar materials and construction technologies, where quality of the product is too dependent upon insufficient local construction skill and supervision, should be avoided. Development and use of prefabricated and locally assembled structural systems in these areas is recommended.

4. When it becomes necessary to build and use traditional type of adobe and masonry structures, the following steps should be

taken to minimize possible loss of life in case of an earthquake:

a. Only single-story adobe or unreinforced masonry structures should be constructed.

b. The adobe structures should be reinforced by means of a wooden skeleton to support the roof. This skeleton should have wooden tie-beams on top of all load-bearing walls and should connect all roof timbers together with sufficient strength. Wooden tie-columns should be used at intersections of walls and around openings. Wooden boards should be used to laterally brace together roof timbers and columns.

c. In unreinforced masonry construction with steel I-beam and shallow brick arch roofing system, a steel or reinforced concrete skeleton should be used to support the roof. This skeleton should have horizontal steel or reinforced concrete tie-beams on top of all load-bearing walls and should connect all steel beams together with sufficient strength. Steel or reinforced concrete tie-columns should be used at intersections of walls and around openings (if necessary). Steel plates or reinforcing bars should be used to laterally brace together roof-beams and tie-columns.

B. Concerning Earthquake Problems in Iran

1. Efforts in seismic regionalization and zoning of Iran should be expanded. Geological, tectonic, and seismological research should be increased. Determination of earthquake history of various regions of Iran is needed.

2. New seismological stations should be installed in suitable locations in southern and eastern regions of Iran so that a better coverage of seismic activities in Iran is obtained.

3. In each town and each major construction project, such as dams, important factories, and major buildings, at least one strong-motion accelerograph should be installed.

4. A national seismic building code should be prepared, adopted, and enforced as soon as possible.

5. Construction of buildings with poor seismic strength of adobe or unreinforced masonry type in rural and urban areas of Iran

should be discouraged. When it is feasible, existing buildings, in particular public buildings, should be strengthened and, if needed, renewed.

6. More research on seismic resistance of present types of construction in Iran and on earthquake risks and earthquake-hazard minimization should be carried out by universities and other research organizations. Materials and technologies for feasible, low-cost rural and urban building systems should be developed as soon as possible for Iranian conditions.

7. Formation of a national committee or council responsible for research and activities in problems related to earthquakes and other natural hazards in Iran is recommended.

8. Level of seismic consciousness of the public and of people in charge of construction in Iran should be elevated by a continuous process of education, using mass media.

9. Iranian universities should offer courses in earthquake engineering and should provide programs of continuing education for the older generation of engineers and designers who may not be familiar with recent advances in the field of earthquake engineering.

10. Iranian universities should expand their present educational and research programs in the field of earthquake engineering. They should organize joint research and exchange programs in the area of earthquake engineering with leading universities and institutions abroad.

11. When feasible, a program of registration and professional examination of engineers and architects should be nationally adopted, so that designers will be required to have the necessary knowledge and competency in design of structures against earthquake.

12. National programs for training construction technicians, building inspectors, and for educating and licensing the local contractors and masons should be developed.

C. A General Recommendation Concerning Earthquake Investigations

In addition to the above technical recommendations, the authors wish to mention difficulties which they and many other research teams have encountered in investigating this and other earthquakes. On arrival at the earthquake zone it is often difficult to obtain reliable briefings, adequate maps and air photographs, and other general information. As a result, there is much duplication of effort and wasted time with an "every-man-for-himself" attitude in seeking out information and points of interest. Also, considerable time must be spent in the capitol of the country and in other administrative centers in formalities of obtaining proper credentials and letters of introduction. Every investigating team would greatly benefit from the services of even a small-but-recognized group responsible for providing or streamlining the necessary credentials, general information, maps, air photos, etc.

There is an international interest in scientific and engineering investigation of earthquakes which may occur in any part of the world. Therefore, it is recommended that representatives of the ministry of science or of the national committee responsible for earthquake research in the host country organize and carry out duties of the credential and information exchange group outlined in the previous paragraph. In Iran most ministries send their representative to the earthquake zone to assist the Red Lion and Sun in their rescue and relief operations. So far, the Ministry of Science has not been required to take part in this operation. The task of providing information and guidance to national and foreign investigating teams so far has been on the shoulders of over-worked Red Lion and Sun representatives, who are deeply involved with relief operation. It would be desirable if representatives of the Ministry of Science or of the national committee on earthquake and natural hazards (if such a committee were formed) sent representatives to the field to relieve relief people from the demanding task of dealing with scholars and to provide more scientifically-oriented information and guidance.

In the absence of such a national group, an equivalent group may be organized by some international organization, such as the "International Association for Earthquake Engineering." This group should consist of a few volunteers from supporting nations, each of whom would be ready at a moment's notice to go into the earthquake zone and to set up a type of headquarters in the field within a short period after any major earthquake. Cooperation of the host country in this matter is very important.

Principal duties of this field group would not be to investigate the earthquake directly, but rather to get all information and supporting documents from the government, local officials, and other investigators. They should then compile this information in some orderly fashion and transmit it to other investigators on an information-exchange basis. Services of this team would be of great benefit to scientific investigating teams coming into the area.

APPENDIX

Table 1
Preliminary Casualty and Damage Statistics
Qīr, Iran Earthquake, April 10, 1972 - Richter Magnitude 7.0

Data from Police List as of April 28, 1972

				Fatalities		No. of Buildings		
No.	Town or Village	Population	Injured	No.	Percent of Population	Before Quake	Undamaged	No. of Families
1	Qīr	5,068	889	3,399	67	809	0	750
2	Deh-beh	1,117	10	45	4	293	0	238
3	Khayrābād	332	10	36	11	42	0	62
4	Sekehravan	627	40	150	24	143	0	124
5	Kordshoul	90	9	11	12	14	0	16
6	Najafābād	253	7	16	6	39	0	46
7	Fadam	17	0	0	0	9	0	5
8	Vajishk	189	4	2	1	47	0	43
9	Qāssimābād	178	6	14	8	56	0	36
10	Liferjān	581	4	5	1	169	0	126
11	Jourkān	105	3	1	1	23	0	22
12	Azizābād	183	10	31	17	33	0	41
13	Fakhrābād	203	6	13	6	34	0	34
14	Gāvakei	872	100	400	46	181	0	181
15	Biān (Karzin)	941	45	300	32	168	0	172
16	Mansourābād	68	0	1	1	19	0	12
17	Manāl	254	6	25	10	55	0	54
18	Rizjān	10	1	2	20	5	0	2
19	Mehrābad	20	1	1	5	2	0	4
20	Ābsakoun	10	0	0	0	5	0	2
21	Tangeroudah	238	40	56	23	61	0	49
22	Mobarakābād	1,417	20	2	0	286	0	266
23	Shahrepir	108	5	2	2	23	0	16
24	Dotoulaqaz	94	3	4	4	14	0	17
25	Berijān (Berikhoun)	160	7	40	25	32	0	29
26	Heidarābād	20	1	2	10	4	0	4
27	Hassanābad	68	2	0	0	12	0	13
28	Aliābād	852	0	9	1	172	0	183
29	Ab-ābād	59	0	8	14	14	0	11
30	Qalāt	362	3	29	8	71	0	70
31	Khomar	115	1	5	4	31	0	24
32	Fathābād	17	1	3	18	3	0	3
33	Nahviyah	154	10	13	9	36	0	34
34	Nassirābād	86	5	5	3	12	0	16
35	Aliābād-bahman	160	3	16	10	27	0	35
36	Sarcheshmeh	699	50	70	10	142	0	154
37	Kordshaykh	155	0	0	0	14	0	25
38	Abe-bidak	31	0	0	0	14	0	6
39	Abe-mordi	12	0	0	0	2	0	2
40	Shahābad	195	18	80	40	39	0	37

Table 1, Cont.

				Fatalities		No. of Buildings		
No.	Town or Village	Population	Injured	No.	Percent of Population	Before Quake	Undamaged	No. of Families
41	Ābe Garm	255	5	20	8	48	0	44
42	Otrouieh	81	15	12	15	17	0	15
43	Abedeh	242	15	60	25	44	0	46
44	Bagenow	467	60	70	15	86	0	79
45	Tangegalleh	188	5	4	2	42	25	33
46	Khoshābjān	29	4	5	17	5	0	5
47	Dashteshour	144	15	16	11	21	0	24
48	Mazraʿeh	94	2	5	5	16	0	16
49	Shahmoumen	157	0	6	4	12	0	31
50	Sharafkhalil	182	50	64	34	36	0	37
51	Shourkuieh	17	0	0	0	3	0	3
52	Tashouieh	121	12	9	8	22	0	24
53	Kardil	233	3	2	1	51	24	47
54	Karkuieh	268	23	31	12	52	6	51
55	Krimbeigi	128	3	5	4	22	0	26
56	Kamasej	150	1	4	3	28	18	28
57	Mobārakeh	57	2	1	2	3	0	12
58	Marand	182	10	4	2	35	0	32
59	Mozaffari	456	25	80	17	83	0	81
60	Manganouieh	154	5	40	26	31	0	28
61	Nohtan	146	1	0	0	31	4	30
62	Nimdeh	115	5	7	6	25	0	23
63	Haftāsiāb	365	90	80	22	62	0	65
64	Abuaskar	65	4	1	2	12	0	11
65	Nowābād	75	0	4	5	16	0	14
66	Hengām	569	16	2	0	102	52	114
67	Tengebādi	26	4	4	16	6	0	6
68	Pāgozāreh	173	10	5	3	33	0	35
69	Houraz	311	0	0	0	52	0	60
70	Hajiābād	43	0	0	0	9	0	8
71	Bāgenow (Hangām)	170	0	0	0	40	20	38
72	Zeinābād	60	0	0	0	10	0	12
73	Sākhtemānmahdi	49	0	0	0	7	0	11
74	Sākhtemānakram	28	0	0	0	5	0	7
75	Jegardān	253	0	0	0	54	54	53
76	Tangekeish	362	0	0	0	63	63	72
77	Berkehābi	50	0	0	0	11	11	11
78	Chār-chār	17	0	0	0	2	2	3
79	Sourmeh	24	0	0	0	2	2	2
80	Bābānajm	75	0	0	0	14	7	14
81	Bāleq-lou	30	0	0	0	2	0	4
82	Khabis	218	2	2	1	38	3	36
83	Konardān	94	0	0	0	23	9	18
84	Abechenārou	18	0	0	0	4	0	3
85	Khanyāb	65	0	0	0	13	5	11
Total:		23,126	1,710	5,374	23%	3,465	305	4,284

Note: Of the injured, 404 sent to hospitals out of the area - all others treated in the earthquake zone.

Table 2
Some Historical Earthquakes in the Province of Fārs in Southern Iran

Date	Location	Description	Reference
3-31 Dec 856 (Sha'ban 242 A.H.)*	Province of Fārs (exact location is not given)	The earthquake was accompanied by horrible noises. In this year there were also earthquakes in the region of Qumes, especially in the city of Dameghan, killing 48,690 people, also in Khurassan, Syria, and Yemen.	Tabari** V. 12, p. 1433
17 Jun 978 (7 Dhu-al-Qa'dah 367 A.H.)	The port of Siraf near the present port of Tahiri in the Persian Gulf.	The land shook for seven days. Most of the houses were destroyed and more than 100 people were killed. A portion of the buildings fell into the sea. Siraf prior to the earthquake was the most important harbor on the Persian Gulf with excellent buildings.	LeStrange p. 258 Ibn-al-Jauzi V. 7, p. 87
11 Apr-9 May 1008 (Sha'ban 398 A.H.)	Siraf and the Coastal Areas	The earthquake caused an inundation at Siraf, wrecking many ships at sea and killing many people. In this year an earthquake also damaged the region of Dinawar killing more than 16,000 people and cracking the ground in many places.	Ibn-al-Jauzi V. 7, p. 238

---

*A.H. refers to Islamic Lunar calendar starting from the Hegira (Immigration) of prophet Mohammed from Mecca to Medinah in the year 622 A.D.

**The list of references are given at the end of this table.

Table 2, Cont.

Date	Location	Description	Reference
3 May 1052-22 Apr 1053 (444 A.H.)	City of *Arrjan* or Arghan (31°, 40'N, 50°, 20'E) (about 14 km East of the present city of Behbahan on the river Marun. Encycl. of Islam V. 1, p. 659)	The occurrence of earthquakes in *Khuzestan*, *Eyzaj*, and *Fārs*. It was strongest in *Arrjan* which cracked and opened up a large mountain near that city. In this year there were also earthquakes in *Khurassan* destroying the town of *Beyhagh*.	Abulfeda, V.2, p. 172 Ibn-al-Jauzi, V. 8, p. 154
29 Apr-27 May 1085 (Muharram 478 A.H.)	*Fārs* in *Arrjan*	Strong earthquakes occurred in *Khuzestan* and *Fārs*. It was most severe in *Arrjan* which destroyed many buildings and killed many people under them. In this year there were also destructive earthquakes in *Rum* (present *Turkey*).	Ibn-Athir V. 10, p. 95 Ibn-al-Jauzi V. 19, p. 14
4 Jan-23 Dec 1291 (690 A.H.)	*Shīrāz*	A strong earthquake caused the destruction of Masjid-i-Naw (new Mosque).	Sami, p. 325
20 Nov 1588-9 Nov 1589 (997 A.H.)	*Shīrāz*	A strong and destructive earthquake destroyed half of the dome and the structure of the shrine of Shahe-Cheragh.	Sami, p. 337 Fasa'i, p. 154
7 May 1769-26 Apr 1770 (1183 A.H.)	*Shīrāz*	A strong earthquake again caused the destruction of Masjid-i-Naw.	Sami, p. 325
1813	*Shīrāz*	A destructive earthquake occurred.	Encyclopaedia of Islam. V. 4:1, p. 377

Table 2, Cont.

Date	Location	Description	Reference
2 Jun 1824	Shīrāz	Some slight motion in Shīrāz, premonitory of the great earthquake of 25 June.	Wilson
25 Jun 1824 (27 Shawwal 1239 A.H.)	Shīrāz and Kazerun	A violent shock followed by many slighter ones for six days and nights. The principal damage was done by the first and three others that followed it before 10 a.m. A part of Shīrāz was almost completely destroyed and swallowed up. Kazerun also suffered severely and some mountains in the neighborhood of Kazerun were leveled. In Shīrāz most of the mosques, shrines, important buildings and the adobe city wall destroyed, notably the shrine of Shahe-Cheragh, Ali-ibn-Hamzah, Seid-mir-Ahmad, and the College of Khan. Some strong masonry buildings constructed during the reign of Karim Khane Zand such as Bazar & Mosque of Vakil were damaged but survived the earthquake. Earthquake intensity seems to have been between VII to IX (MM). Condition of the city and people is described in poetry by Vassal Shirazi.	Wilson Sami, p. 92, 340, 352, 493 Vassal, p. 29 Fasa'i, p. 162, 154
30 Dec 1824	Shīrāz	Several shocks occurred.	Wilson
1825	Shīrāz	A shock almost as severe as that of the year before; a number of buildings were reduced to ruins.	Wilson

Table 2, Cont.

Date	Location	Description	Reference
19 Apr 1851	Gwadur in Persian Gulf	Three shocks occurred; several houses were destroyed.	Wilson
22 Apr 1853 (1269 A.H.)	Shīrāz	A large portion of Shīrāz was destroyed killing about 13,000 people. The main shock occurred early in the morning and was accompanied by a loud noise. It caused extensive ground settlements and cracking on the surface of the ground and on the mountains around the city. There were land and rock slides filling the sky over the city with dust for a few days. Aftershocks occurred for many days. The Dome and some parts of the Shrine of Shahe-Cheragh, Masjid-i-Naw and College of Khan were destroyed. The Bazar and Mosque of Vakil and most other strong masonry buildings, which were built by Karim Khane Zand survived this earthquake also. The intensity of this earthquake in Shīraz seems to have been between VII to IX (MM). Conditions of the city and people is described in poems by Davari and Veghar and by Wills.	Wilson Sami, p. 92, 325, 326, 340 Davari, p. 161, 382 Vassal, p. 146 Fasa'i, p. 163, 154, 155, 160
21 Dec 1862	Shīrāz		Wilson
1-2 Jan 1863	Shīrāz		Wilson
4 Jan 1863	Shīrāz	Two slight shocks.	Wilson
21 Jan 1863	Shīrāz	A very strong shock.	Wilson

Table 2, Cont.

Date	Location	Description	Reference
1865	Shīrāz	Five shocks occurred of which three were violent.	Wilson
1865	Around Bushire Persian Gulf	The village of Darveh Asuh near Mugam was leveled to the ground; and its remarkable effects were witnessed by Dr. Colnill of the Bushire residency.	Wilson
19 Apr 1868	Bushire	Several shocks of which two were violent.	Wilson
1 Mar 1869	Bushire	A violent shock.	Wilson
6 Sep 1871	Bushire	Several violent shocks.	Wilson
Aug 1880	Bastak Persian Gulf	One hundred twenty deaths. According to Movahid in the year 1297 A.H. (1880) a strong earthquake occurred in Bastak and the villages of Faramarzan. In the village of Jonah about 35 km SW Bastak, there was extensive loss of life and property where many buildings and mosques were destroyed. This earthquake occurred during Friday noon prayer. In Jonah alone it killed about 80 people while some were praying.	Wilson Movahid, p. 19
16-24 Oct 1883	Kangun Asalu (very near to the location of old Port of Siraf) Tahiri	Much damage was done.	Wilson
	Bushire	Earthquake was felt.	

Table 2, Cont.

Date	Location	Description	Reference
Mar 1884	Persian Gulf		Wilson
19-20 May 1884	Qishm Is.	One hundred thirty-two persons killed; many villages destroyed. Shah gave 1400 Tomans ($200.00) for relief. Annual Revenue remitted. Many inhabitants left the island. The earthquake was felt in the port of Lingeh with no damage. According to Kababi, during May 1885 (corresponding to 1303 A.H.)* a major earthquake occurred in the Qishm Island which continued for some period of time. It killed 71 people in Laft, two in Soheili, seven in Tonban, 30 in Deyrestan, one in Suza, eight in Bande Haji Ali, 16 in Ramkoun, 10 in Koushah, 20 from Gorbah-dan and Sourghan, seven from Karavan, 11 from Zeinali, 18 from Peiposht, four from Majian, and 13 from Geyahdan. Total people killed were 218. Almost all houses which were not from wood were destroyed. This earthquake had not much effect on the city of Qishm.	Wilson Kababi, p. 129
Jun 1884	Ras-al Khaimah (Persian Gulf)		Wilson
14-24 Nov 1887	Bushire		Wilson

---

*There seems to be some error in the conversion of dates from the Moslem to Christian calendar. The year 1303 A.H. is from 10 October 1885 to 29 September 1886.

Table 2, Cont.

Date	Location	Description	Reference
1890	Jahrum Kamarij Khisht	Thirty people killed.	Wilson
	Fasa	Earthquake felt, not much damage.	
End of Feb 1894	Shīrāz	Some injury to life and property.	Wilson
11 Jan 1897 (at night)	Qishm Is.	The town was leveled to the ground; 1,600 people were killed. Only two mosques and three or four other buildings were left standing. According to Kababi, on Monday night, 14th of the month of Sha'ban 1316 A.H., corresponding to the year 1898 A.D. (According to computation it corresponds to 26 December 1898, which seems to fall on Wednesday.) Another major earthquake occurred in the city of Qishm which killed about 750 people there. The people changed all their adobe and masonry houses to the wooden buildings. One year after this, the city caught fire and most of the wooden buildings were burned.	Wilson Kababi, p. 129
11 Jan 1897 (all night)	Larak Island	Loss of life.	Wilson
	Port of Lingeh	No loss of life, earthquake was felt.	Wilson
9 Jun 1902	Qishm Is.	Considerable damage. Shocks also felt at Bandar Abbas, where 10 lives were lost and many houses destroyed. Shocks continued for several days.	Wilson

Table 2, Cont.

Date	Location	Description	Reference
25-27 Apr 1905	Bandar Abbas	The shock was also felt on islands of Qishm and Hangam. Landslides and destruction of buildings in Kuh-i-Giano, and in Isin village.	Wilson
31 Oct 1956	Lār-Bastak	A destructive earthquake of Magnitude 6.4 occurred in Lār near Bastak, killing some 225 people and injuring more than 3,000 people. According to Movahid, this earthquake cracked only a few houses in Bastak; however, it was so strong in Gawdah area that the three villages, Dehtal, Chahdozdan, Barke-lari, which were close to each other, plus the village of Fatviah which was far from the others, were totally destroyed. It also damaged other villages such as Tadruyah and Dahnak. In this earthquake about 253 people of Gawdah area were killed. It caused about 20 million rials (2.5 million dollars) damage.	Banisadr, p. 16 Movahid, p. 19
24 Apr 1960	Lār	A destructive earthquake of magnitude 5.9 demolished the city of Lār. All the buildings were completely ruined and some 1,500 persons killed.	Banisadr, p. 17 Afshar
11 Jun 1961	Lār	An earthquake with magnitude 6.9 occurred in Lār, causing some damage to the old city and killing about 60 people.	Banisadr, p. 17

Table 2, Cont.

Other Miscellaneous Historical Earthquakes

1. Clarke (p. 13) based on report No. 3, 15 April 1962, of the seismological station of Shīrāz entitled "sur la seismicite de l'Iran," states that "as well as the two major earthquakes of the nineteenth century there is evidence to support the fact that many others occurred in Shīrāz during the previous thousand years, notably, in 856, 1505, 1586, 1588, 1621, 1681, 1789, and 1814 A.D." However, except for those underlined and discussed previously, no verification for the occurrence of the others has yet been found by the authors.

2. In a private communication, Professor Sami, the well-known recent Historian of Shīrāz, has indicated that the Island Qishm was destroyed in the year of 762 A.H. (11 November 1360 - 30 October 1361). He also indicated that the Islands of Kish and Hangam were destroyed in the years 1115 A.H. (17 May 1703 - 5 May 1704) and 1301 A.H. (2 November 1883 - 20 October 1884). Correct references for these earthquakes at present is unavailable.

3. The following information was obtained from interviewing some educated people in the earthquake zone. No verification has yet been obtained.
    a. The city of Khonge had been very large and wealthy up to the year 1300 A.D. (700 A.H.) but afterward it was destroyed by an earthquake.
    b. The city of Lār had been destroyed 300 years ago (1670). It also had been destroyed a few times earlier than this date. There is evidence of the occurrence of an old earthquake in the region of Evaz, a dependency of the County of Lār; the ruins of the villages of Barzejan, Khoshab and Marbout which are in the Evaz region can still be seen.
    c. The Township of Gawdah, a dependency of Bastak, was damaged by an earthquake about 200 years ago (1770 A.D.) and the villages of Bask and Bodlofan were destroyed.
    d. In Jam and Riz above Siraf there is evidence of early destruction by earthquakes. Around Hermi, which is now a small village, there are the remains of a large old ruin indicating that in old times it had been a large city.

Table 3, *Cont.*

Date	Time	Epicentre		Magnitude	Focal	Source
	H,M,S	N°	E°	Richter	Depth km	
10 Aug 1963	04:27:27	27.90	53.20		46	BCI,SHR
10 Aug 1963	04:27:27	28.10	53.30	4.8	46	USA
12 Aug 1963	07:19:53	27.00	53.10	5.0	33	BCI,USA
		27.70	52.30	5.0		SHR
9 May 1964	07:47:01	29.50	52.40		36	ISC,USA
9 Jul 1964	03:38:08	28.80	52.80		50	MOS,ISC
9 Jul 1964	03:38:08	29.30	52.70		55	USA
16 Aug 1964	15:52:45	28.10	52.48		52	ISC
		27.60	52.50		31	MOS,USA
19 Aug 1964	09:33:10	28.20	52.60	5.6	37	ISC,USA,MOS
19 Aug 1964	15:20:14	28.20	52.70	5.6	47	ISC,USA,MOS
19 Aug 1964	22:40:16	28.20	52.52	4.9	46	ISC,USA,MOS
20 Aug 1964	05:08:49	28.15	52.64	5.1	35	ISC,USA,MOS
20 Aug 1964	05:39:48	28.20	52.60	5.5	33	ISC,USA,MOS
20 Aug 1964	22:54:50	28.80	52.76		92	ISC,USA
21 Aug 1964	07:59:15	28.19	52.59	4.9	44	ISC,USA,MOS
11 Dec 1964	05:25:56	28.05	52.87	4.9	45	ISC,USA,MOS
11 Dec 1964	12:48:05	28.50	52.98		59	ISC
11 Dec 1964	12:48:05	29.00	53.20		74	USA
11 Dec 1964	12:48:05	29.10	52.80		96	MOS
18 Dec 1964	00:35:22	28.20	52.80		46	ISC
18 Dec 1964	00:35:22	27.80	52.80		33	USA
24 Jun 1965	10:54:00	28.90	52.90	4.2		USA
9 Jun 1966	22:24:39	27.60	52.50	5.0	8	USA
2 Sep 1966	11:13:06	27.70	52.40	5.0	33	USA
2 Dec 1966	03:07:54	28.20	53.20	5.2	40	USA
10 Jul 1967	10:57:54	28.20	53.60	4.4	33	USA
2 Jan 1968	11:59:32	29.40	52.60	5.0	26	USA
30 May 1968		27.80	54.00	5.2	27	USA
14 Sep 1968	13:48:31	28.40	53.10	5.7	33	USA
14 Sep 1968	19:20:23	28.40	53.20	4.5	31	USA
15 Sep 1968	06:14:50	28.30	53.20	4.5	31	USA
19 Sep 1968	22:12:38	28.40	53.20	5.1	334	USA
19 Sep 1968	23:35:56	28.30	53.10	4.8	33	USA
12 Mar 1969	17:43:34	28.30	53.10	4.5	16	USA
11 May 1970	03:12:20	28.50	52.30	5.1	22	USA
18 May 1970	06:55:26	27.60	52.90	4.7	40	USA
21 Jul 1970	10:39:14	29.30	52.20	4.5	20	USA

Note: BCI = Bureau Central International de Seismologie
FS = Fisher
GR = Gutenberg and Richter
ISS = International Seismology Summary
MOS = Moskva
PRS = Press
REC = Revue Pour l'etude des Calamites
SHI = Shillong
SHR = Shīrāz
STH = Stahl
USA = United States, Coast and Geodetic Survey

Table 4
The Type of Construction in Four Large Iranian Cities and an Estimate of the Extent and Percent of Destruction Due to Probable Future Earthquakes of Various Intensities

			Reinf. Concrete	Masonry & Steel	Masonry & Wood	Adobe & Wood	Total	% Ruined
Assumed Percent of Destruction in Earthquakes w/Intensity of		VII	0	10	20	30	---	---
		VIII	10	20	40	50	---	---
		IX	20	40	60	70	---	---
TEHERAN	No. Buildings		2,835	262,446	73,855	15,210	354,346	---
	Percentage		0.8	74	20.9	4.3	100	---
	Destruction in Earthquake Intensity:	VII	---	26,240	14,780	4,700	45,720	13
		VIII	280	52,480	29,560	7,600	89,920	25
		IX	560	104,960	44,340	11,300	161,160	45
TABRIZ	No. Buildings		45	3,448	21,710	36,576	61,779	---
	Percentage		0.1	5.6	35.2	59.1	100	---
	Destruction in Earthquake Intensity:	VII	---	340	4,340	11,000	15,680	25
		VIII	5	680	8,680	18,300	27,665	45
		IX	10	1,360	13,020	25,600	39,990	65
ISFAHAN	No. Buildings		290	6,623	9,212	38,790	54,915	---
	Percentage		0.6	12.1	16.8	70.5	100	---
	Destruction in Earthquake Intensity:	VII	---	660	1,840	11,650	14,150	26
		VIII	30	1,320	3,680	19,400	24,430	44
		IX	60	2,640	5,520	27,100	35,320	64
SHĪRĀZ	No. Buildings		424	11,486	13,976	3,194	29,080	---
	Percentage		1.5	39.5	48	11	100	---
	Destruction in Earthquake Intensity	VII	---	1,150	2,800	960	4,900	17
		VIII	40	2,300	5,600	1,600	9,540	33
		IX	80	4,600	8,400	2,230	15,310	52

REFERENCES

1. Ambraseys, N. N. (1962), "On the Regional Conditions and Damage During the Buin-Zahra (Iran) Earthquake," UNESCO Mission Report, NS/1585/62, 2 Vols., December 1962.

2. Ambraseys, N. N. (1968), "Early Earthquakes in North-Central Iran," Bull. Seism. Soc. Amer., 58, No. 2, pp. 485-496.

3. Ambraseys, N. N., et al., (1969), "Dasht-e-Bayaz Earthquake of 31 August 1968, Part I, General Field Report," UNESCO Mission Report, NS/1214/BMS.RD/SCE, Paris, May 1969.

4. Banisadr, M. (1971), "The Seismicity of Iran (1900-1969)," D.I.C. Thesis submitted to the Imperial College of Science and Technology of the University of London, printed as Publication No. 1, Bureau of Standards and Technical Research, Plan Organization of the Government of Iran, Teheran, March 1971.

5. Moazami-Goudarzi, K. (1971), "A Statistical Study of the Seismicity of the Iranian Plateau," presented to the 15th General Assembly of the International Union of Geodesy and Geophysics, July 31 - August 15, 1971, Moscow.

6. Moinfar, A. A. (1969), "Dasht-e-Bayaz and Ferdows Earthquakes of August 31 and September 1, 1968," Publication No. 21, Technical Bureau, Plan Organization of the Government of Iran, in Persian with English summary, 1969.

7. Nowroozi, A. A. (1971), "Seismo-Tectonics of the Persian Plateau, Eastern Turkey, Causasus, and Hindu-Kush Regions," Bull. Seism. Soc. Amer., 61, pp. 317-341.

8. Nowroozi, A. A. (1972), "Focal Mechanism of Earthquakes in Persia, Turkey, West Pakistan, and Afghanistan and Plate Tectonics of the Middle East," Bull. Seism. Soc. Amer., 62, pp. 823-850.

9. Omote, S., et al., (1965), "A Report on the Buin Earthquake (Iran) of September 1, 1962," Proc. 3WCEE, Vol. III, pp. V-27 to V-44, 1965.

10. Razani, R. and Behpour, L. (1970), "Some Studies on Improving the Properties of Earth Materials Used for Construction of Rural Earth Houses in Seismic Regions of Iran," Proceedings of 4th Symposium on Earthquake Engineering, held at University of Roorkee, India, 1970, pp. 81-89.

11. Takin, M. (1972), "Iranian Geology and Continental Drift in the Middle East," Nature, 235, pp. 147-150.

12. Tassios, T. P. (1969), "Dasht-e-Bayaz Earthquake of 31 August 1968, Part II, Engineering Report," UNESCO Mission Report, NS/1214/BMS.RD/SCE, Paris, May 1969.

13. Wellman, H. W. (1965), "Active Wrench Faults of Iran, Afghanistan, and Pakistan," Sonderdruck Aus der Geologischen Rundschaus, Bd. 55, seite 716-735, 1965, Ferdinand Enke Verlag, Stuttgart.

14. Wilson, A. T. (1930), "Earthquakes in Persia," Bull. School of Oriental Stud., 6, Part I, London.