

## An Immediate and Preliminary Report on THE MANJIL, IRAN EARTHQUAKE OF 20 JUNE 1990

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**Editorial Note:** This article is based on a brief English version of a fuller report by the authors originally published as Publication No. 119, July 1990 of the Building and Housing Research Centre.

### INTRODUCTION

On 20 June 1990 at 21h 13s (UT) a destructive earthquake occurred in the north of Iran. This earthquake was strongly felt over an area of about 600,000 km<sup>2</sup> including Tehran, Tabriz and several other major cities in Iran. The towns of Manjil and Rudbar, districts like Abbar, Gilvan and Kelisham, hundreds of populated villages were destroyed and more than one thousand villages suffered damage.

According to official figures, more than 35,000 lives were lost in this event. Nearly 100,00 buildings and residential houses were destroyed or remain unusable. Farms and irrigation facilities suffered some damage and several thousand animals were buried under debris.

Based on the preliminary reports, the magnitude of this earthquake was  $M = 7.3-7.7$  with an average seismic moment of about  $1.5 \times 10^{27}$  dyne.cm (EMSC). The first report on the approximate location of the epicentre stated "200 km northwest of Tehran and 400 km southeast of Tabriz". Then it was reported that the epicentre was located in the town of the Deylaman area, about 40 km far from where the highest intensity was estimated. Also, according to some foreign reports (e.g. USGS, EMSC), the epicentre was reported to be in the Caspian sea which was far from reality but corresponds to the distances reported earlier (200 km from Tehran and 400 km from Tabriz). The earthquake is now understood to have been multiple events.

This preliminary report is the result of a 6 day observation of the affected area which took place one week after the event.

Contrary to the experience of other earthquakes that have occurred in Iran in the past, this earthquake hit a reasonably populated area. Several cities and towns with modern structures are located in the affected area.

The long period effect was experienced a relatively long distance away in the city of Rasht. There are several important structures in the earthquake affected area. Some of these include: Sefidrud dam, power plants, bridges, a 120,000 ton silo, large capacity tall water towers, a cement factory, hospitals, etc.

Large scale liquefaction occurred in the city of Astane-Ashrafiye, about 60 km from the epicentre. There were big changes in underground water levels with increases or decreases in the amount of water in some springs.

### BACKGROUND SEISMICITY OF THE MANJIL REGION

The Manjil area is located in the Alborz mountain range which is part of the Alpine-Himalayan seismic belt. This area has been recognized for a long time as a very active zone seismically and has been considered as a high seismic zone in the Iranian Code for Seismic Resistant Design of Buildings (1988).

The historical seismicity of the region shows that once in while an intensive earthquake has hit the region and caused heavy casualties. The Manjil area has not experienced any destructive earthquake in the 20th century. The only moderate earthquake to have occurred in the area this century is the 17 June 1948 earthquake with  $M = 5.0$  which caused slight damage to Manjil. Table 1 shows some of the historical earthquakes of the region ( $M > 5.5$ ) within a radius of 200 km from the epicentral area. Since the installation of the world wide seismological instruments this century, numerous earthquakes have been recorded in the region to show the active seismicity of this part of the country. Table 2 shows some of the earthquakes ( $M > 5$ ) that have occurred within a radius of 200 km from the epicentral area during the 20th century.

### EPICENTRE

The 20 June 1990 earthquake occurred as a multiple shock. Two earthquakes were felt in Tehran within 5 minutes. Although the exact instrumental epicentre has not been determined yet, according to the damage in

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various parts of the affected area, the macro-seismic epicentre of the earthquake has been estimated to be in the vicinity of town of Manjil and around Sefidrud dam (36.75°N, 49.40°E).

#### HYPOCENTRE

The Manjil earthquake was felt strongly over a vast area. In addition, the distribution of severe damage over a wide area is evidence that the focal depths for the 20 June 1990 earthquakes were not shallow. Despite of the lack of instrumental data, consideration of the past destructive earthquakes of the Alborz region suggests the hypocentre of the recent earthquake to be at a depth of 20 to 30 km.

#### INTENSITY

The 20 June 1990 earthquake was felt over an area of 600,000 km<sup>2</sup> with an intensity III (MSK). In Tehran, the earthquake (200 km from the epicentre) caused panic and cracks developed in several tall buildings. The intensity in Tehran was about V (MSK) and in Tabriz ( a major city 300 km from the macroseismic epicentre) it was about IV. The intensity in other major cities like Qazvin, Zanzan and Rasht which are located 75, 80 and 60 km from the epicentre respectively, was VI. The highest intensity was in Manjil

and Harzevil which are in the vicinity of the fault break associated with the earthquake. The maximum intensity in Manjil is estimated to have been X (MSK). The intensity in Rudbar (8 km north of Manjil) was about IX. In general, an area of about 15,000 km<sup>2</sup> was shaken with an intensity greater than IX (MSK). Figure 1 shows the preliminary isoseismal map for the 20 June 1990 earthquake.

#### PEAK GROUND ACCELERATIONS

Based on local observations and evaluations of the overturned objects at the epicentral area, it is estimated that the horizontal peak ground acceleration was rather high and over 60% of g. The preliminary evaluation of the accelerograms obtained in Abbar (about 10 km from the end of fault) confirms this estimate. The Abbar accelerogram shows 0.65 g and 0.52 g for both peak horizontal and vertical components, respectively. Several other accelerographs including those in Tehran recorded the 20 June 1990 earthquake and these are now under analysis and evaluation. The peak ground acceleration recorded in Tehran was 2%g. Table 3 summarizes the peak ground accelerations obtained by strong motion accelerographs installed at several different locations.

In total, there were 50 accelerographs within a radius of 250 km of the epicentre.

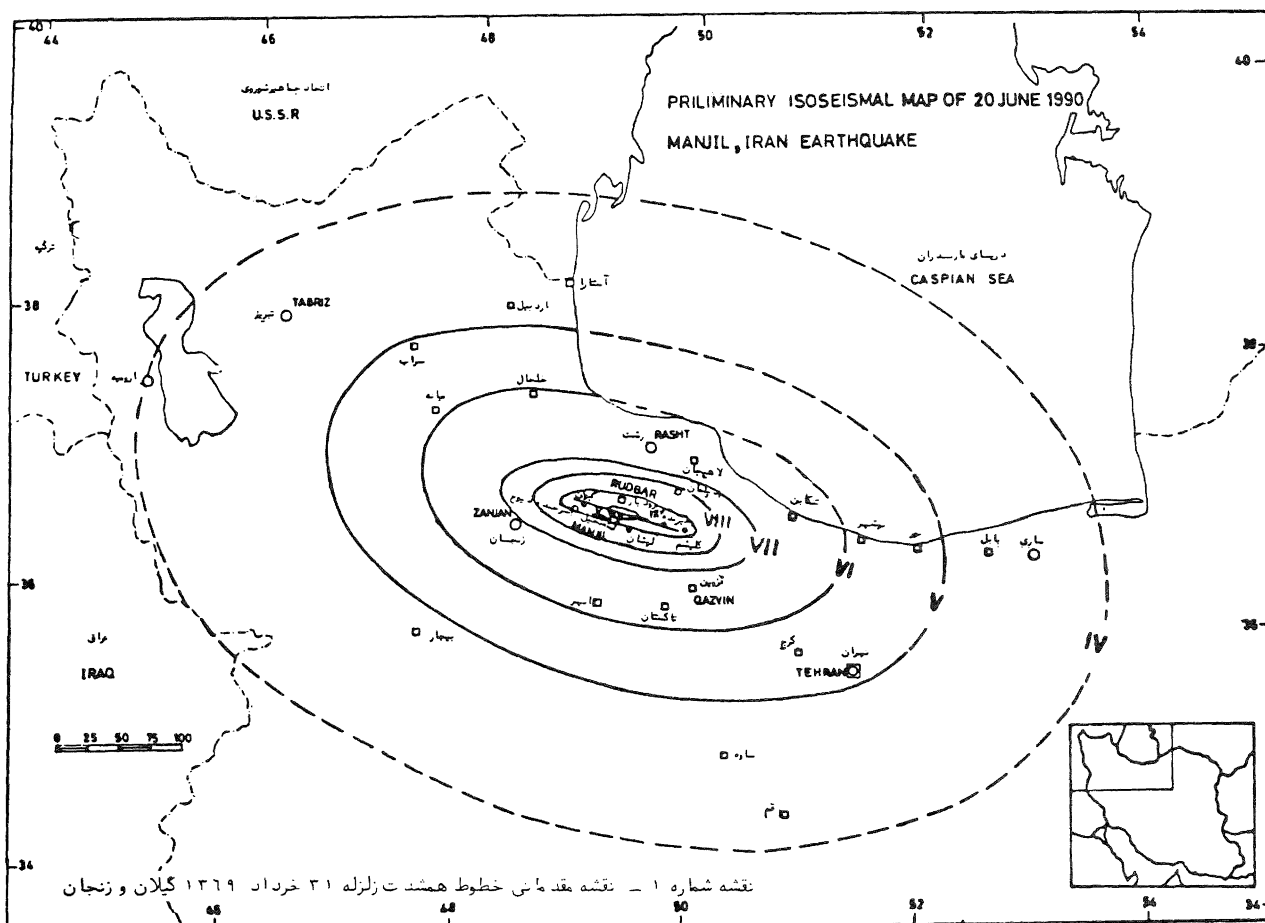


FIGURE 1: PRELIMINARY ISOSEISMAL MAP OF THE 20 JUNE 1990 MANJIL, IRAN EARTHQUAKE.

TABLE 1: List of Historical Earthquakes of  $M > 5.5$  that have Occurred in a Radius of 200 km from the Epicentral Region<sup>2</sup>

| Date |       |     | Time | Epicentre |       | Magnitude |
|------|-------|-----|------|-----------|-------|-----------|
| Year | Month | Day |      | North     | East  |           |
| 855  |       |     |      | 35.6°     | 51.5° | 7.1       |
| 958  | 2     | 23  |      | 36.0°     | 51.1° | 7.7       |
| 1119 | 12    | 10  | 18   | 37.7°     | 49.9° | 6.5       |
| 1177 | 5     |     |      | 35.7°     | 50.7° | 7.2       |
| 1485 | 7     | 15  | 18   | 36.7°     | 50.5° | 7.2       |
| 1608 | 4     | 20  | 12   | 36.4°     | 50.5° | 7.6       |
| 1678 | 2     | 3   | 6    | 37.2°     | 50.0° | 6.5       |
| 1808 | 12    | 16  | 18   | 36.4°     | 50.3° | 5.9       |
| 1844 | 5     | 13  | 19   | 37.4°     | 48.0° | 6.9       |
| 1876 | 10    | 20  | 15   | 35.8°     | 49.8° | 5.7       |
| 1879 | 3     | 22  | 4    | 37.8°     | 47.9° | 6.7       |
| 1880 | 7     | 4   |      | 36.5°     | 47.5° | 5.6       |
| 1896 | 1     | 4   | 16   | 37.8°     | 48.4° | 6.7       |

<sup>2</sup> Reference: A History of Persian Earthquakes by N N Ambraseys

TABLE 3: Peak Ground Accelerations Recorded by Some Strong Motion Accelerographs.

| No. | Instrument Location | Comp. T (%g) | Comp. V (%g) | Comp. L (%g) |
|-----|---------------------|--------------|--------------|--------------|
| 1   | Qazvin <sup>3</sup> | 8            | 9            | 19           |
| 2   | Ardebil             | 9            | 2            | 2            |
| 3   | Zanjan              | 6            | 6            | 10           |
| 4   | Abhar <sup>4</sup>  | 19           | 6            | 13           |
| 5   | Mianeh              | 2            |              | 2            |
| 6   | Gachsar             | 10           | 3            | 6            |
| 7   | Lahijan             | 10           | 6            | 9            |
| 8   | Tonekabon           | 6            | 3            | 11           |
| 9   | Abbar               | 62           | 52           | 65           |
| 10  | Kahrizak            | 2            | 2            | 3            |
| 11  | Rudsar              | 5            | 6            | 7            |
| 12  | Karaj               | 2            | 3            | 4            |
| 13  | Estehard            | 7            | 5            | 6            |
| 14  | Rudshur             | 3            | 1            | 3            |
| 15  | Robat Karim         | 5            | 2            | 4            |

<sup>3</sup> See Figures 43-45 on pp278-280 for details of the ground motion and response spectra

<sup>4</sup> See Figures 46-48 on pp281-283 for details of the ground motion and response spectra

TABLE 2: List of Earthquakes of  $M > 5$  that Occurred from 1900-1989 in a Radius of 200 km from the Epicentral Area

| Date |       |     | Time   | Epicentre |        | Magnitude |
|------|-------|-----|--------|-----------|--------|-----------|
| Year | Month | Day |        | North     | East   |           |
| 1901 | 4     | 20  | 122900 | 36.39°    | 50.58° | 5.4       |
| 1903 | 2     | 9   | 051800 | 36.58°    | 47.65° | 5.6       |
| 1903 | 3     | 24  | 165600 | 37.48°    | 48.96° | 5.9       |
| 1905 | 1     | 9   | 061700 | 37.00°    | 48.68° | 6.2       |
| 1917 | 6     | 2   | 002812 | 38.00°    | 48.50° | 5.0       |
| 1924 | 11    | 8   | 090500 | 35.50°    | 48.00° | 5.5       |
| 1924 | 11    | 8   | 174520 | 35.50°    | 48.00° | 5.0       |
| 1924 | 11    | 10  | 210856 | 35.50°    | 48.00° | 5.0       |
| 1924 | 11    | 10  | 215456 | 35.50°    | 48.00° | 5.5       |
| 1924 | 11    | 11  | 155340 | 35.50°    | 48.00° | 5.0       |
| 1928 | 3     | 24  | 105329 | 38.14°    | 48.17° | 5.0       |
| 1948 | 6     | 17  | 140831 | 36.59°    | 49.44° | 5.5       |
| 1948 | 6     | 30  | 193150 | 36.66°    | 49.48° | 5.0       |
| 1951 | 6     | 5   | 033450 | 36.50°    | 48.50° | 5.0       |
| 1956 | 4     | 12  | 223448 | 37.25°    | 50.25° | 5.5       |
| 1958 | 9     | 21  | 161830 | 36.00°    | 49.00° | 5.5       |
| 1959 | 5     | 1   | 082404 | 37.00°    | 51.50° | 5.5       |
| 1960 | 6     | 23  | 033742 | 37.00°    | 49.50° | 6.5       |
| 1962 | 9     | 1   | 192000 | 35.71°    | 49.81° | 7.2       |
| 1962 | 9     | 2   | 171204 | 35.59°    | 49.33° | 5.0       |
| 1962 | 9     | 4   | 133012 | 35.60°    | 49.90° | 5.3       |
| 1962 | 10    | 13  | 102338 | 35.74°    | 50.09° | 5.5       |
| 1962 | 12    | 2   | 222131 | 35.53°    | 50.06° | 5.0       |
| 1963 | 1     | 2   | 173800 | 35.70°    | 49.90° | 5.5       |
| 1964 | 11    | 3   | 173606 | 35.86°    | 50.39° | 5.3       |
| 1964 | 11    | 3   |        | 36.00°    | 50.60° | 5.3       |
| 1966 | 11    | 8   | 031414 | 36.16°    | 50.71° | 5.0       |
| 1968 | 4     | 26  | 025824 | 35.09°    | 50.15° | 5.1       |
| 1970 | 7     | 11  | 224114 | 37.57°    | 49.07° | 5.2       |
| 1972 | 1     | 18  | 211204 | 38.00°    | 48.90° | 5.0       |
| 1973 | 8     | 31  | 045615 | 38.00°    | 50.00° | 5.4       |
| 1975 | 10    | 20  | 031923 | 38.00°    | 50.00° | 5.0       |
| 1975 | 12    | 16  | 074234 | 38.00°    | 49.00° | 5.2       |
| 1978 | 5     | 26  | 134241 | 37.00°    | 50.00° | 6.3       |
| 1978 | 11    | 3   | 185259 | 37.00°    | 51.00° | 5.0       |
| 1978 | 11    | 4   | 152220 | 37.71°    | 48.95° | 6.1       |
| 1980 | 5     | 4   | 183517 | 37.81°    | 49.11° | 6.4       |

Of these, 8 were out of order but the remainder were operational and 22 of them were triggered by the earthquake. All were SMA-1 strong motion recorders and were located in the free field except for two instruments in Tehran which were located on the 10th and 20th floors of a 24 storey building. The instrument on the 20th floor gave a horizontal acceleration of 0.05 g while the ground acceleration was 0.02 g.

**GROUND DISPLACEMENTS AND DEFORMATIONS**

Ground deformations and displacements were developed at several places due to the earthquake. For instance, there was: east-west faulting for a distance of about 80 km, huge landslides, large rock falls, changes in water table, discontinuation of some springs and creation of several new springs, liquefaction in many areas, etc.

**EARTHQUAKE FAULTS**

Several minor faults in the epicentral area are shown on the existing geological and seismotectonic maps of Iran. Masuleh fault with a north-south direction; Rudbar fault which has an east-west direction at an angle of about 15° towards the southeast and Lahijan fault which has a southwest-northeast direction. The intersection of these faults gives rise to a complex geological feature in the area. At first glance, one may consider there was a probable rupture of the gap between the faults. Therefore, by considering the heavy

damage in the region, it was felt that the cause of the 20 June 1990 earthquake might be the Rudbar fault and the abovementioned gap. Local preliminary observation showed that there is evidence of faulting about 300 m north of the Sefidrud dam (Figures 3 and 4). Detailed study of the site showed that this fault is parallel to the mapped Rudbar fault. The fault intersects the downstream face of the dam and runs towards the west passing to the north of Gilvan and continues on to the west (Figures 5-6). The evidence of movement in Hendi Kandi village is clearly visible. In the Abbar area to the north of Hendi Kandi, cracks and ruptures are visible running north-south with an inclination to the west. The final judgement about these ground displacements will require more detailed study.

There is evidence of faulting to the east of Sefidrud dam. In the mountains to the north of Harzevil village, vertical displacements are clearly visible on farms on the mountain edges. In all cases, the extension of the fault is east-west toward the southeast and parallel to the same extension of the Rudbar fault shown on the geological maps.

The active fault continues to the east of Harzevil as far as the north of Pakdeh village, about 25 km from Harzevil close to Jirandeh, and extends on to the heights of Kelisham (Figures 7-11).

The traced fault is right lateral and its length is about 80 km. Maximum observed horizontal and vertical displacements were 20 and 50 cm, respectively. The

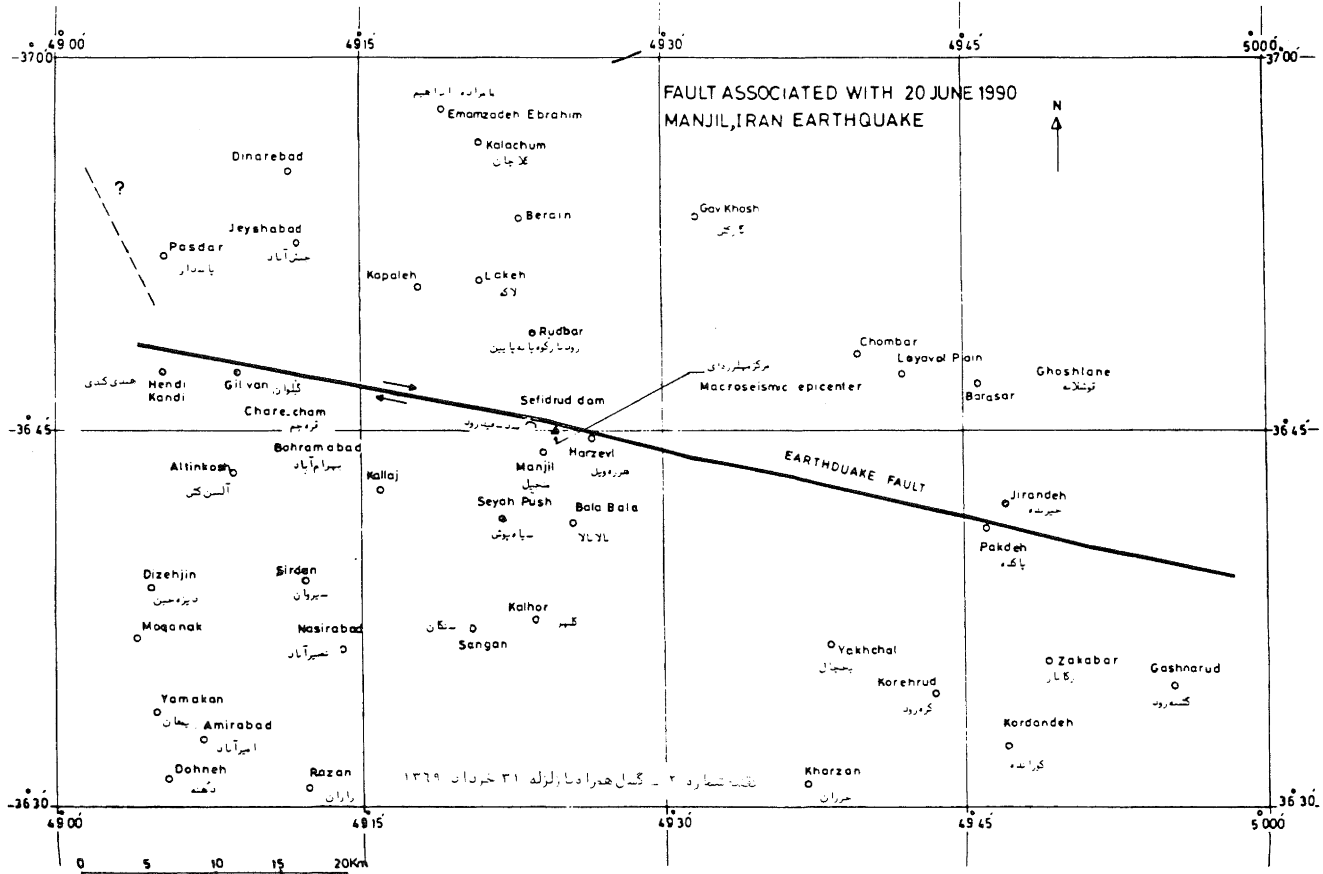


FIGURE 2: FAULT ASSOCIATED WITH THE 20 JUNE 1990 MANJIL, IRAN EARTHQUAKE.

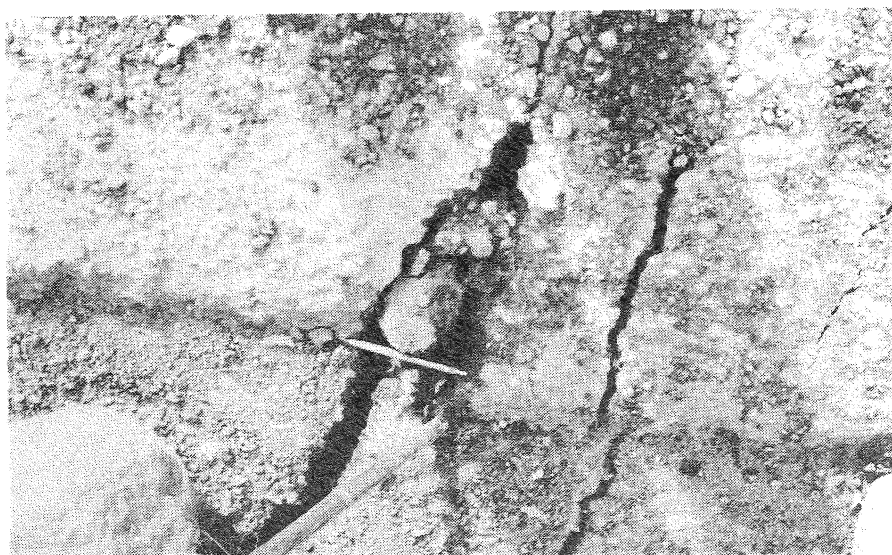


FIGURE 3: FAULT ON THE ROAD TO THE NORTH OF SEFRIDRUD DAM (TOP) WITH A CLOSE VIEW OF THE FAULT BREAK (BOTTOM).

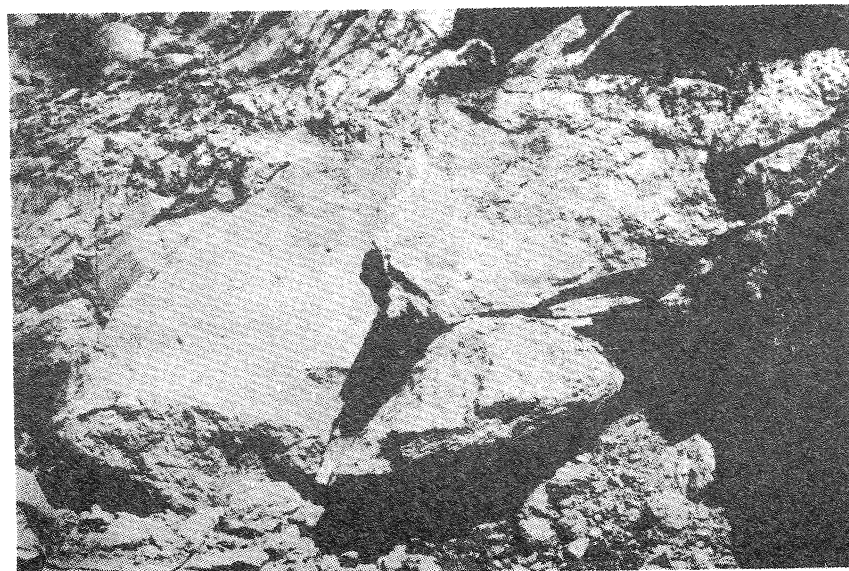


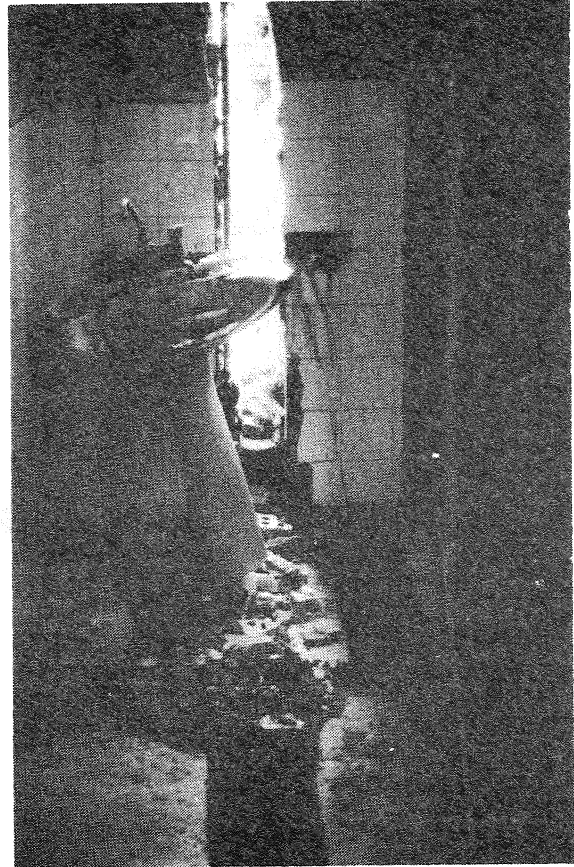
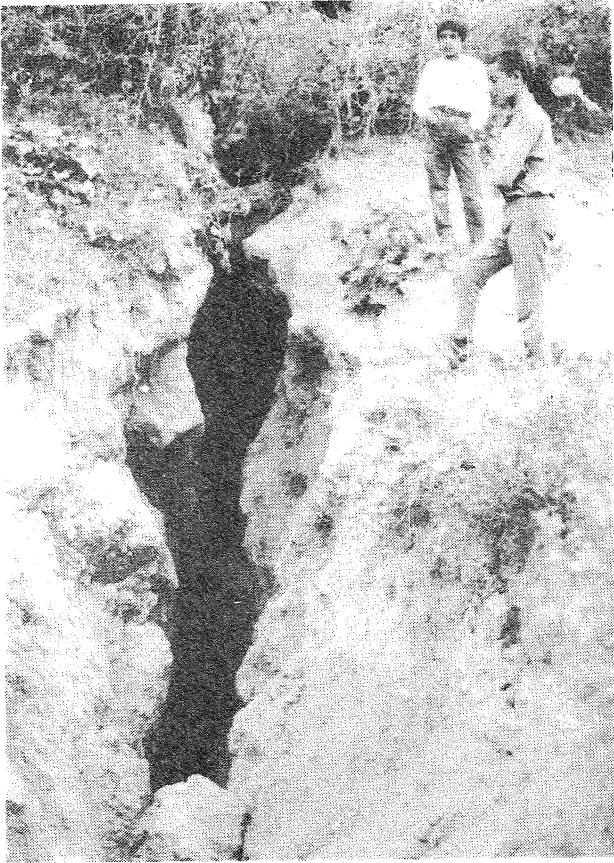
FIGURE 4: ROCK FALL NEXT TO THE SEFRIDRUD DAM.



FIGURE 5: VERTICAL GROUND DISPLACEMENT (ABOUT 30 CM) TO THE NORTH OF GILVAN.



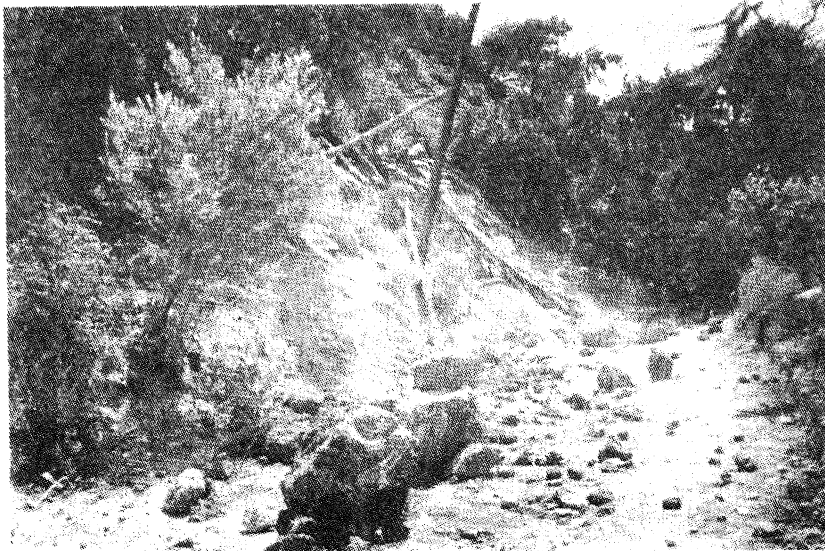
FIGURE 6: GROUND DISPLACEMENT TO THE NORTH OF GILVAN (TOP) AND IN HENDI KANDI VILLAGE (BOTTOM).



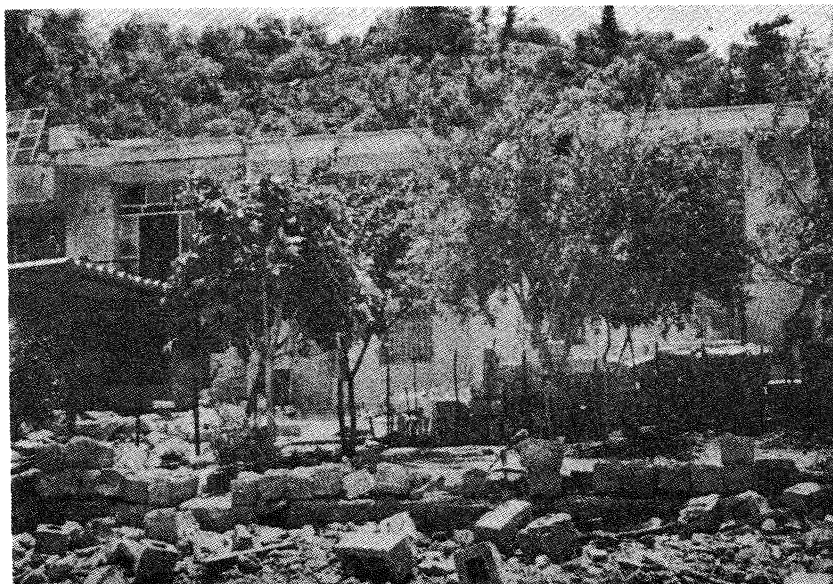
**FIGURE 7: GROUND RUPTURE IN PAKDEH VILLAGE (LEFT) WITH THE FAULT PASSING THROUGH A HOUSE (RIGHT). IN SPITE OF THE GROUND RUPTURE, THE BUILDING AND ITS ROOF REMAINED INTACT.**



**FIGURE 8: VERTICAL DISPLACEMENT CAUSED BY A LANDSLIDE ON THE ROAD TO JIRANDEH IN THE VICINITY OF THE FAULT BREAK.**



**FIGURE 9: A HUGE LANDSLIDE IN RUDBAR WHICH BLOKED THE ROAD (THIS LANDSLIDE IS STILL CONTINUING).**



**FIGURE 10: LANDSLIDE DANGER TO BUILDINGS THAT SURVIVED THE EARTHQUAKE.**

displacements are probably greater but further studies are needed to determine more accurate figures.

Figure 2 shows the observed fault associated with the 20 June 1990 earthquake. A vertical displacement as large as 2.5 m was also seen in Pakdeh village which has divided the road into two parts. This movement seems to be due to a landslide rather than a vertical displacement of the fault.

The epicentres of about 250 aftershocks which took place in the first three days after the earthquake have been calculated by the Institute for Geophysics, Tehran University, and most of them have been found to be located near Pakdeh and Harzevil which are in the east and west parts of the fault, respectively.

#### EFFECT ON BUILDINGS AND IMPORTANT STRUCTURES

As mentioned before, one of the main features of the 20 June 1990 earthquake in Iran is that it occurred in a region where different buildings and structures exist. There are many traditional buildings mainly in rural areas, and numerous masonry, steel and reinforced concrete structures in urban areas. Structures other than buildings such as a dam, power plants, water tanks, a silo, bridges, etc. were also in the earthquake affected area and these are briefly described in the following notes.

##### Traditional buildings

Traditional buildings which mainly consist of stone or sun dried mud brick walls with wooden pole roofs, suffered heavy damage and caused the death of many people in the villages (Figures 12-15).

##### Masonry buildings

Masonry buildings which are generally constructed with brick walls, cement block or stone walls and various roofing systems like steel beam jack arches, reinforced concrete slabs, joist and block and light weight roofs also suffered heavy damage in the epicentral area where the maximum intensity was IX and X.

Generally, as has been experienced in similar earthquakes in the past in Iran, if reinforced concrete tie beams under roofs were constructed properly, they remained erect and in spite of collapse of masonry walls, the roofs did not collapse and remained as a unit and thus saved lives (Figures 16-22).

##### Steel and Reinforced Concrete Buildings

There were several steel and reinforced concrete buildings in the earthquake affected area (Figures 23-31). Some suffered damage on account of weak joints, low quality concrete and poor workmanship. The most damage has been to tall buildings (7 storeys and over) in the city of Rasht, 60 km from the epicentral area. The intensity in this city was about VI. The main reason for the extension of damage to such a relatively long distance from the epicentre, other than the problems stated above, is the

long period effect which increased the structural response.

The effects of pounding were also observed and resulted in damage to a few buildings in Rasht. Several buildings were also tilted as much as 30 cm.

Generally, the bracing in steel frame buildings performed well and prevented the buildings from collapse or even severe damage.

#### Important structures

There are several important structures (e.g. dam, power plant, water towers, ...) in the earthquake affected area of which some have suffered minor damage.

##### Sefidrud dam

The Sefidrud dam is the most important structure in the earthquake hit area. This dam is located at a site where the earthquake had the maximum intensity, i.e. X (MSK). This dam which is located 3 km northwest of Manjil and 60 km from Rasht is a "buttress dam" (Figure 32). The height of the dam is 106 m and at the time the earthquake occurred it was almost full (only 5 m below the normal level). The construction of the dam was completed in 1967. The earthquake coefficient used for design of this dam was 0.25 and this was considered to be conservative at the time.

Fortunately the dam remained stable though several horizontal and diagonal (repairable) cracks developed at the top of some of the buttresses. Part of the parapet wall in the crest has been tilted in the downstream direction.

##### Water towers

Another important structure which collapsed due to the earthquake was the 1500 m<sup>3</sup> water tower in Rasht which was built over 20 years ago (Figure 34). This tower consisted of a reinforced concrete shaft 6 m in diameter and 30 cm thick supporting a 10.30 m high prestressed concrete tank. The top of the tower was 46.50 m above the ground. There was about 1000 m<sup>3</sup> water in the tank at the time the earthquake occurred. The tower overturned in the earthquake.

In addition to the above tower, two similar but larger water towers in Rasht whose construction had just been completed and were empty at the time of earthquake, suffered some damage. A round crack was developed at the height of about one fifth of the tower from the bottom (Figure 36).

A steel water tower in Manjil behaved well and damage was limited to the bracings (Figure 35).

##### Bridges and other Structures

There are several large reinforced concrete and steel bridges in the earthquake stricken area in which minor

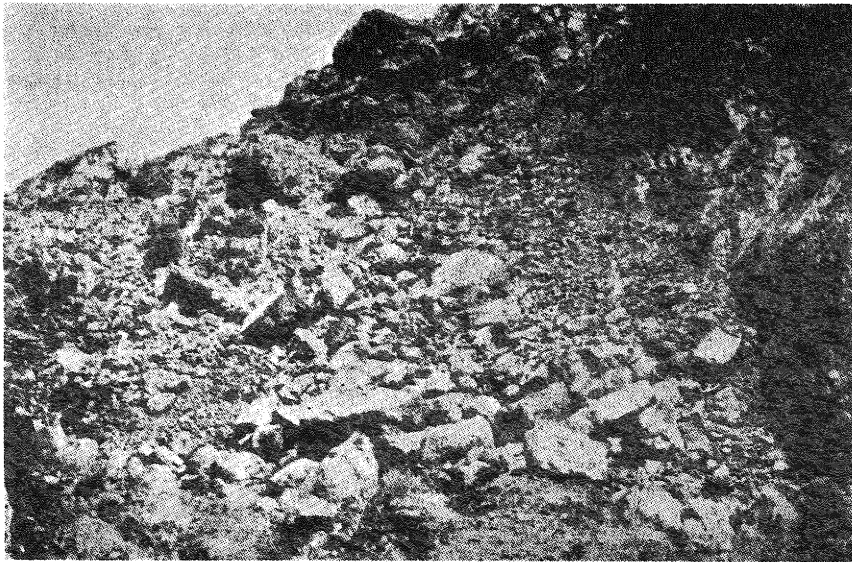


FIGURE 11: ROCKFALL IN HARZEVIL AREA.

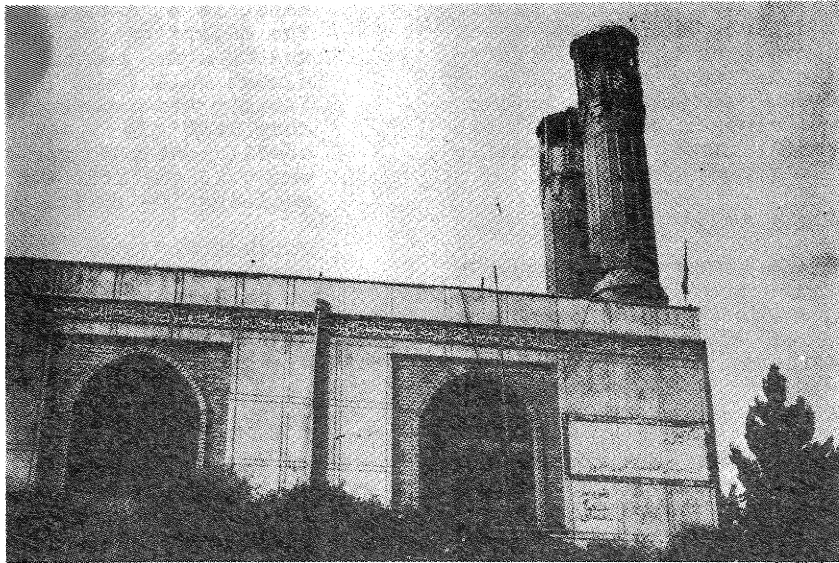


FIGURE 12: A HORIZONTAL CRACK AT THE BASE OF THE MOSQUE'S MINAR IN SANGRUD NEAR JIRANDEH.

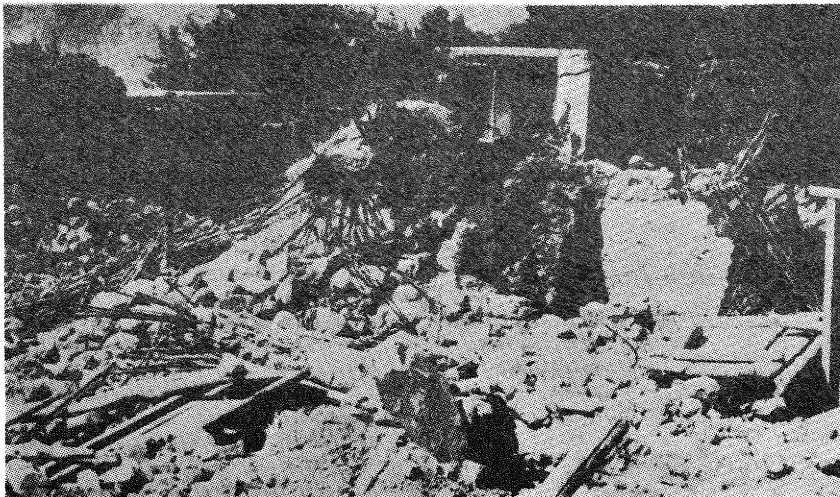
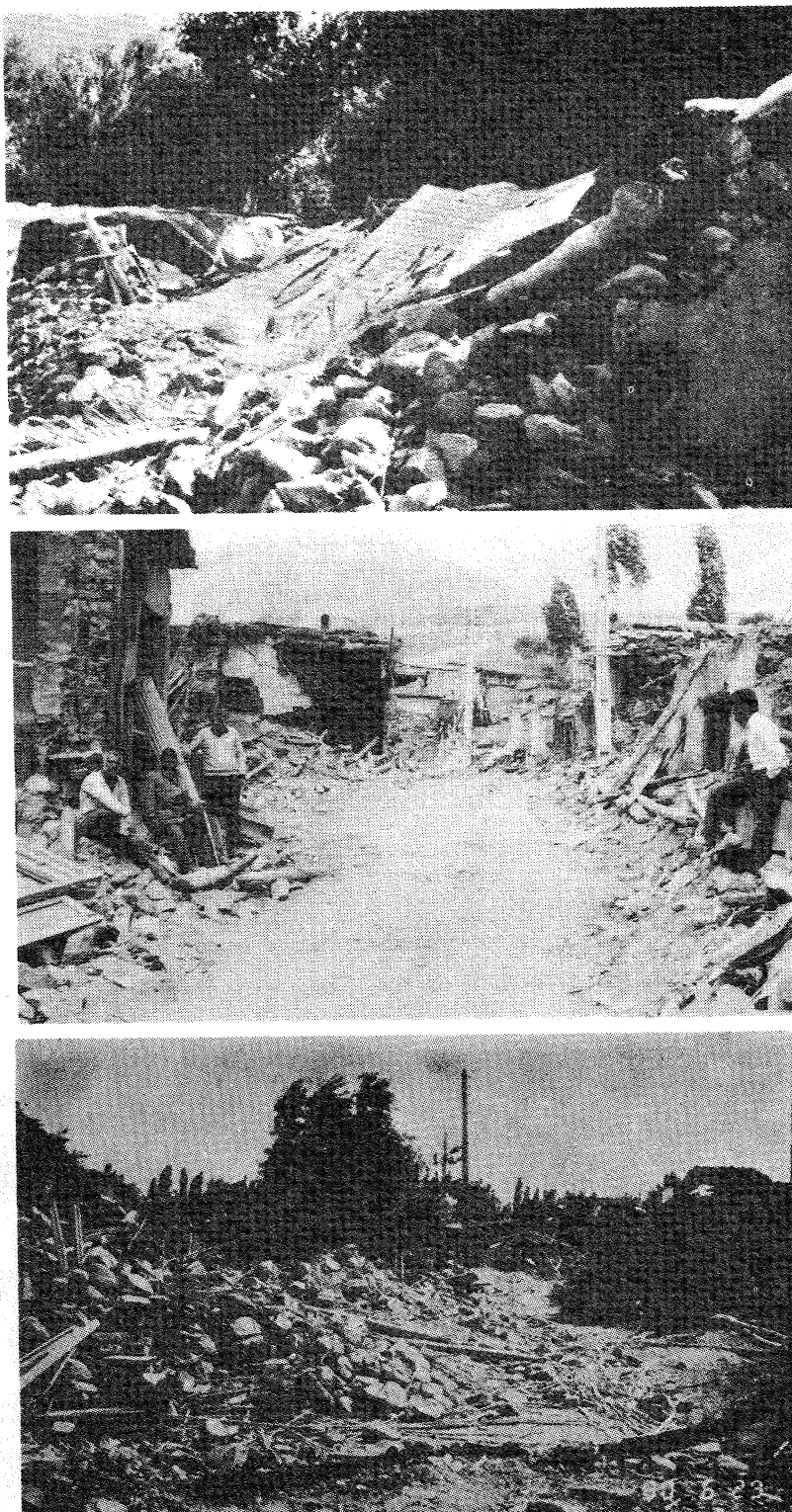


FIGURE 13: COLLAPSE OF TRADITIONAL SUN DRIED BRICK HOUSES IN THE VILLAGE OF HENDI KANDI.

damage (non-structural) was observed (Figures 40-42). Also there were reports on life-line structures where minor damage occurred (Figure 37). Power plants did not suffer structural

damage but it was reported that some minor defects to mechanical and installed equipment occurred. There was also some damage to irrigation and water supply systems (Figures 38-39).



**FIGURE 14: COLLAPSE OF:**  
 (TOP) A TRADITIONAL RURAL HOUSE;  
 (MIDDLE) SUN DRIED MUD-BRICK HOUSES IN THE VILLAGE OF KELISHAM;  
 (BOTTOM) TRADITIONAL BUILDINGS WITH STONE AND SUN DRIED BRICK WALLS AND WOODEN POLE ROOFS IN THE VILLAGE OF HENDI KANDI.



FIGURE 15: EXAMPLES OF THE DESTRUCTION IN MANJIL.

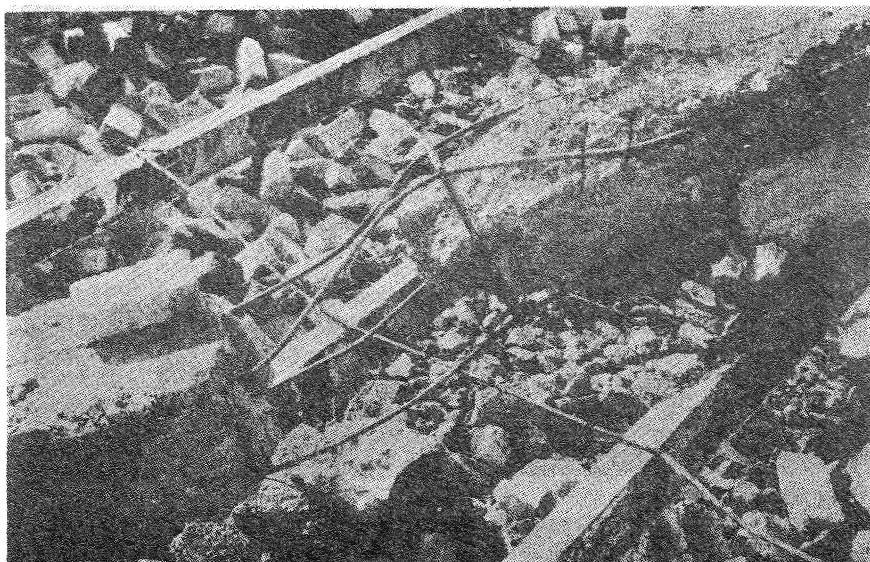


FIGURE 16: DISINTEGRATION OF A TIE BEAM IN A MASONRY BUILDING IN MANJIL.

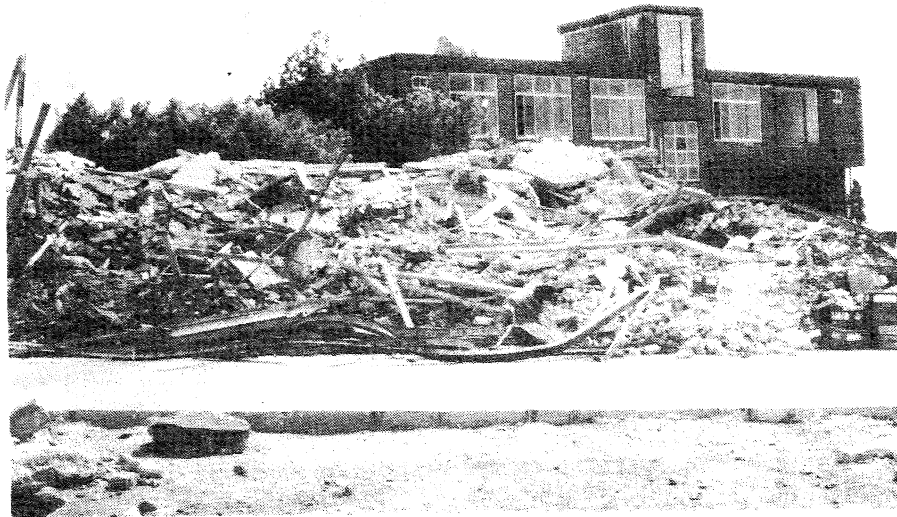


FIGURE 17: AN UNDAMAGED MASONRY BUILDING NEXT TO ANOTHER MASONRY STRUCTURE WHICH HAS COLLAPSED TOTALLY.



FIGURE 18: RUDBAR HOSPITAL AFTER THE EARTHQUAKE (TOP) WITH LONG CANTILEVER SPANS DAMAGED (BOTTOM).



FIGURE 19: A SCHOOL BUILDING IN THE VILLAGE OF HARZEVIL TO THE EAST OF MANJIL WITH STONE WALLS AND LIGHT WOODEN TRUSS ROOF COVERED BY LIGHTWEIGHT IRON SHEETING.

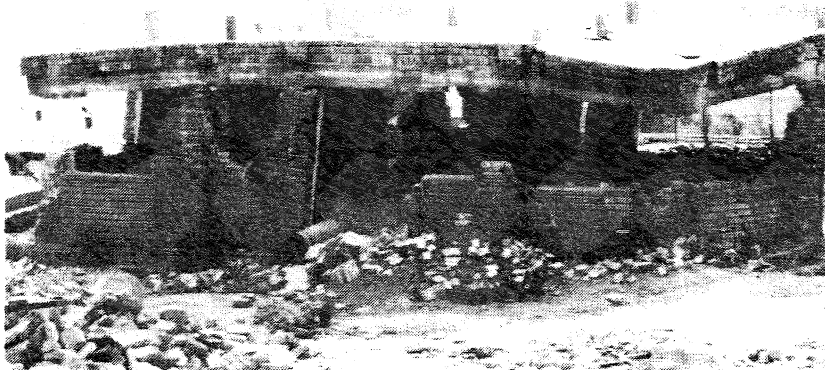


FIGURE 20: THE HORIZONTAL REINFORCED CONCRETE TIE BEAM UNDER THIS ROOF IN MANJIL HAS KEPT THE ROOF INTACT IN SPITE OF THE COLLAPSE OF THE SURROUNDING WALLS.

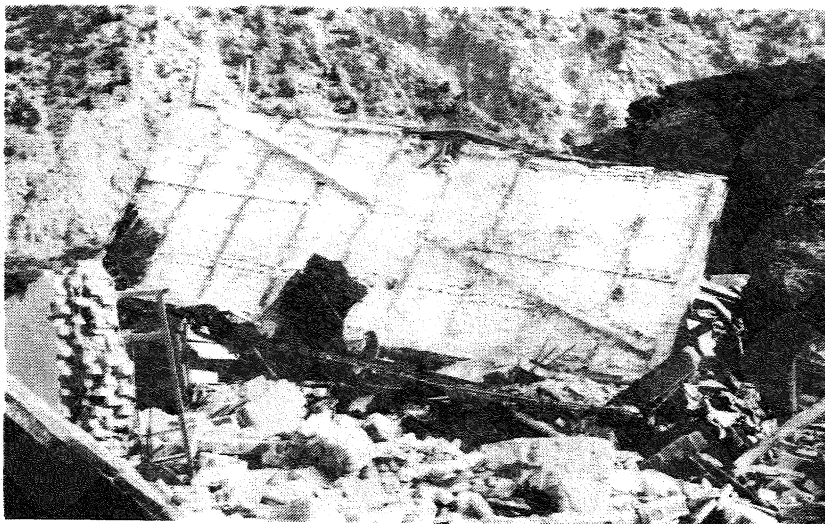
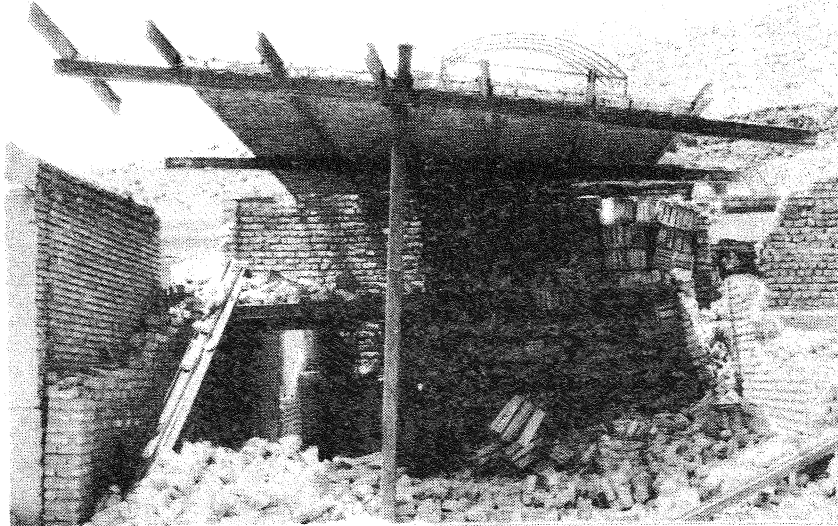
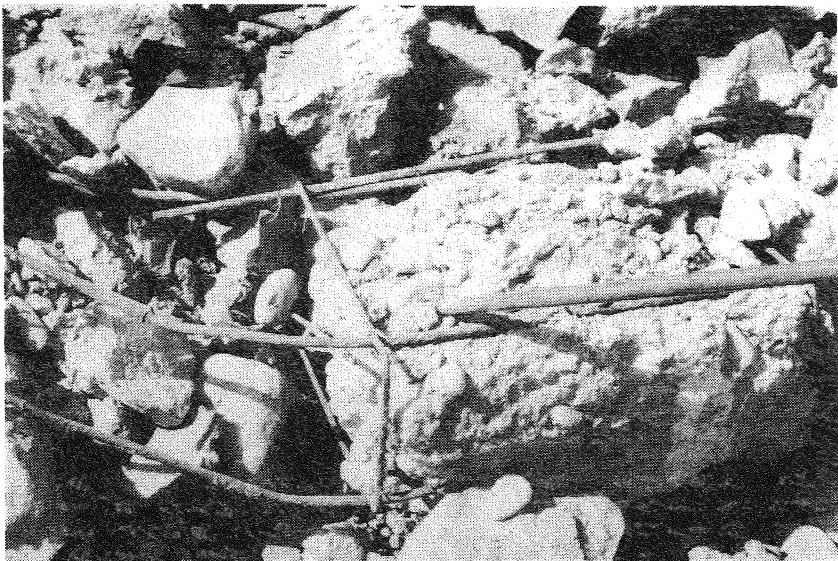


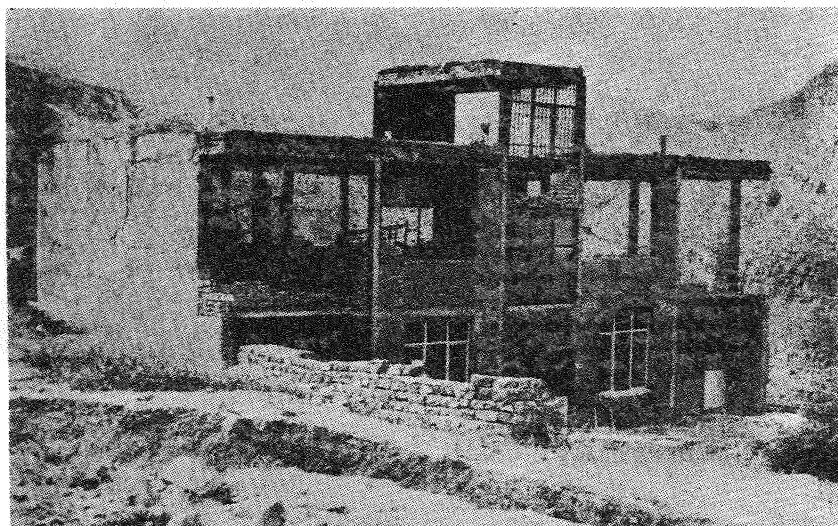
FIGURE 21: A TIED BRICK ARCH ROOF WHICH COLLAPSED AS A UNIT WITHOUT THE ROOF DISINTEGRATING.



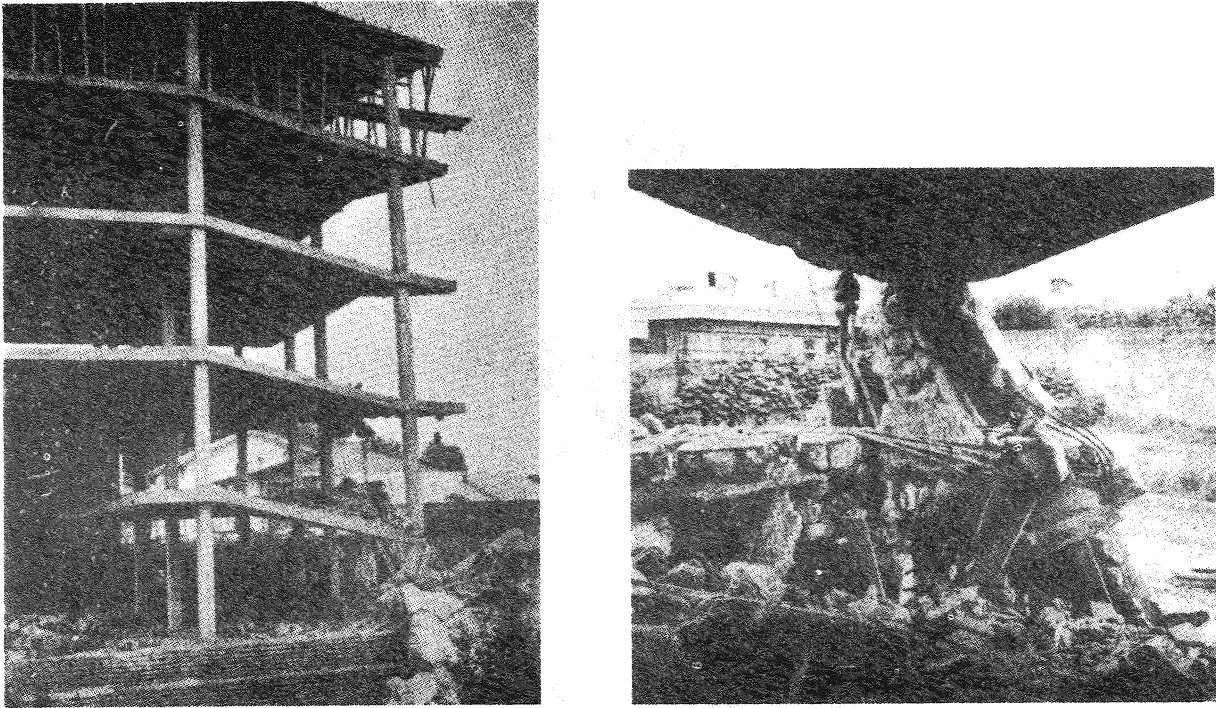
**FIGURE 22: THE BEARING WALLS LOCATED ON BOTH SIDES OF THIS BUILDING IN MANJIL COLLAPSED. THE PERFORMANCE OF THE MIDDLE COLUMN WAS SUCH THAT IT SAVED THE ROOF FROM COMPLETE COLLAPSE.**



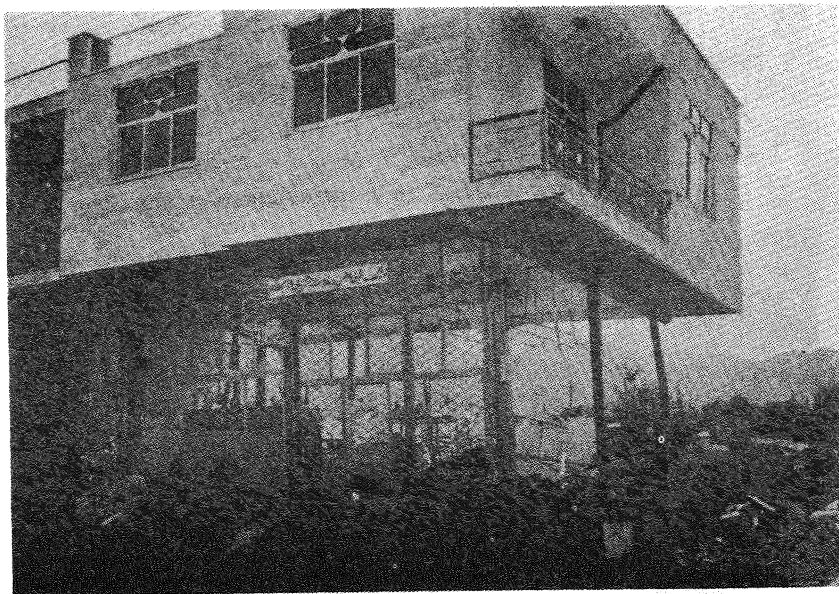
**FIGURE 23: DISINTEGRATION OF CONCRETE IN A REINFORCED CONCRETE TIE BEAM ( NO DUCTILE BEHAVIOUR).**



**FIGURE 24: A STEEL FRAMED BUILDING NEXT TO THE GROUND RUPTURE.**



**FIGURE 25: A FIVE STOREY REINFORCED CONCRETE BUILDING UNDER CONSTRUCTION IN RASHT (LEFT) WITH A CLOSE-UP VIEW OF A FAILED REINFORCED CONCRETE COLUMN (RIGHT).**



**FIGURE 26: THE STEEL COLUMNS OF THIS BUILDING IN MANJIL WERE LEFT BUCKLED BY THE EARTHQUAKE.**

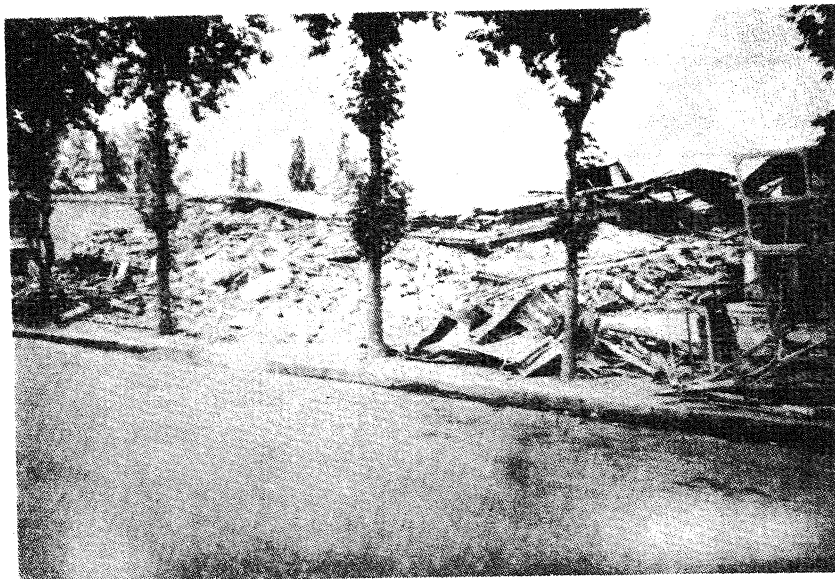


FIGURE 27: COLLAPSE OF A SIX STOREY STEEL BUILDING IN RASHT.

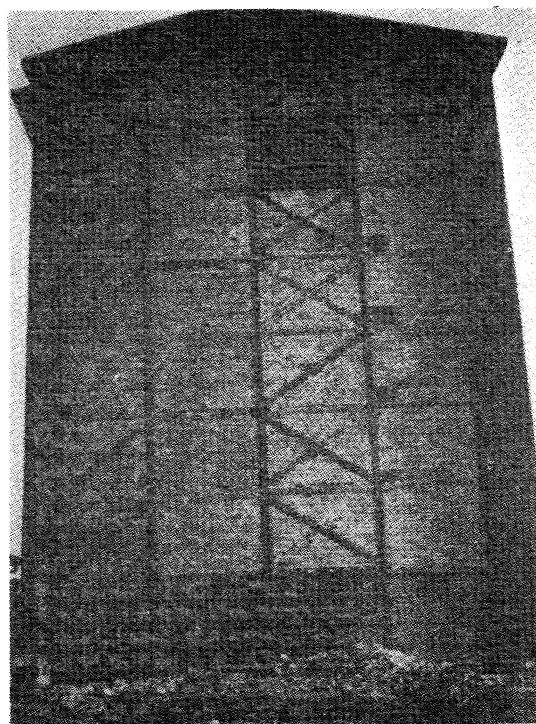
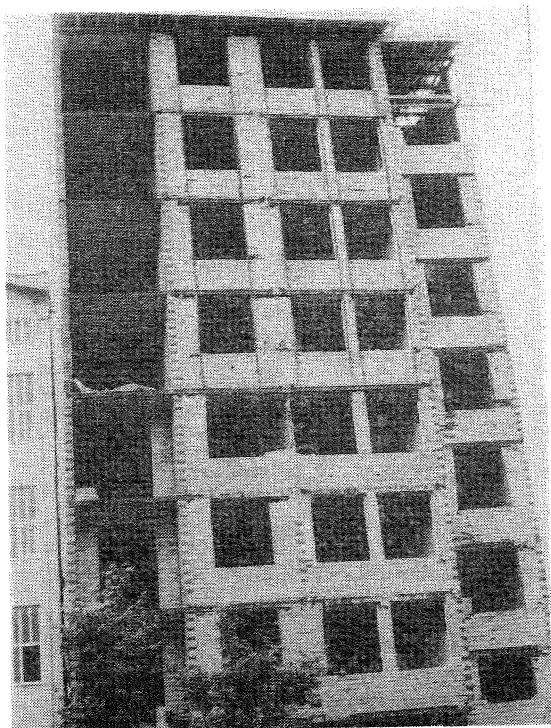
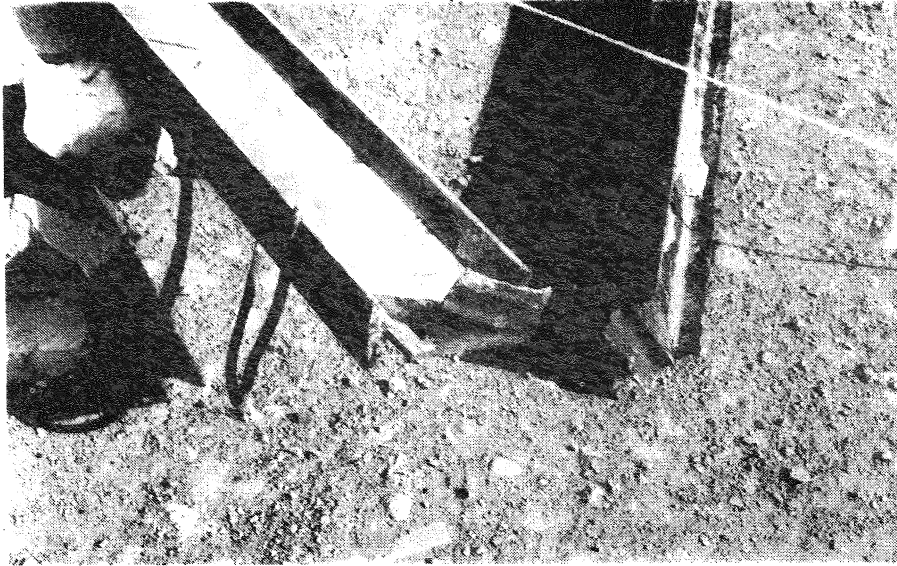
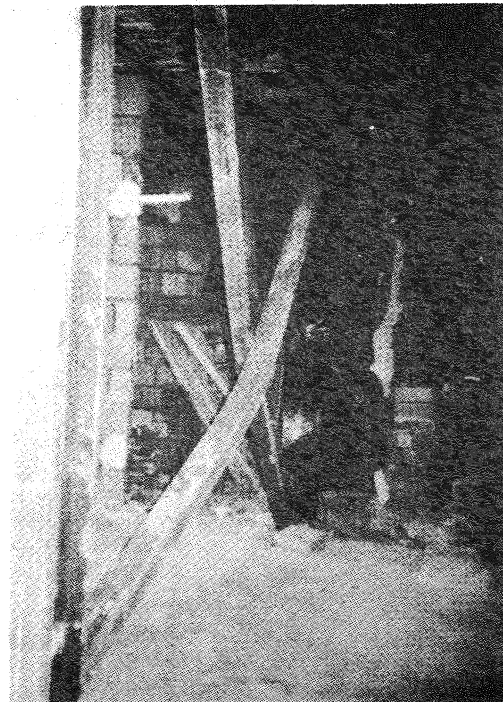
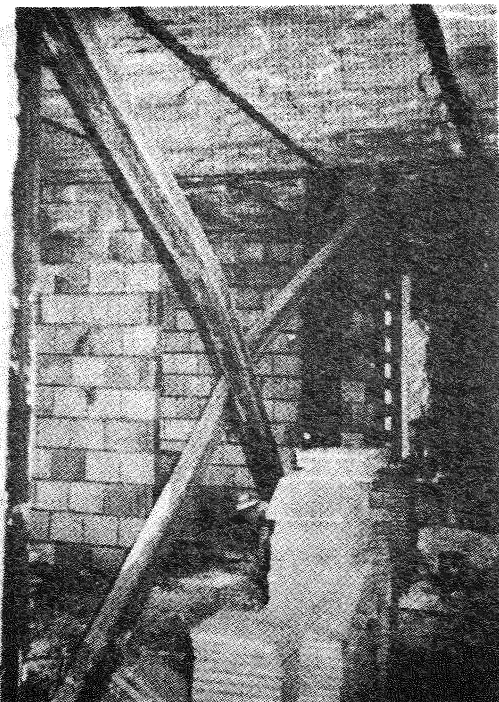


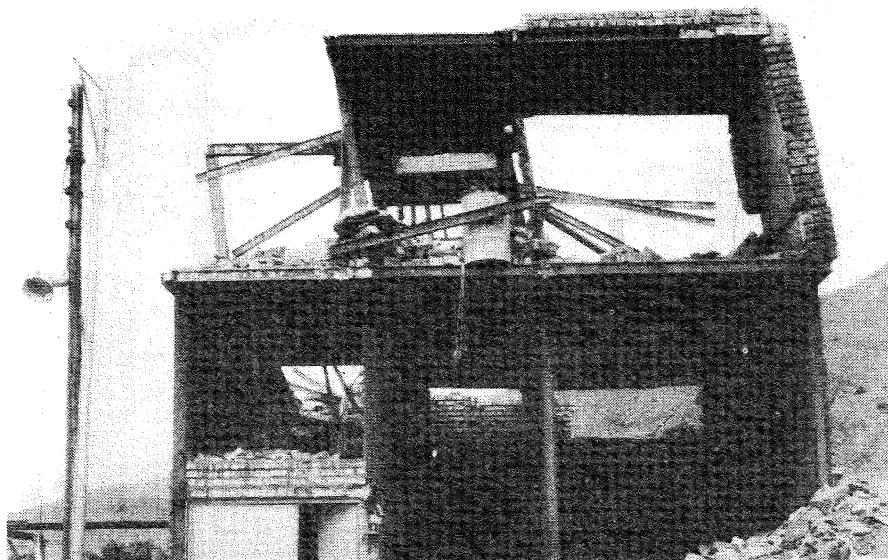
FIGURE 28: A FRONT (LEFT) AND SIDE VIEW (RIGHT) OF AN EIGHT STOREY STEEL FRAME BUILDING UNDER CONSTRUCTION IN RASHT. THIS BUILDING HAS TILTED OVER 30 CM. THE EFFECT OF POUNDING BETWEEN THIS BUILDING AND THE ADJACENT FIVE STOREY BUILDING WAS NOTICEABLE.



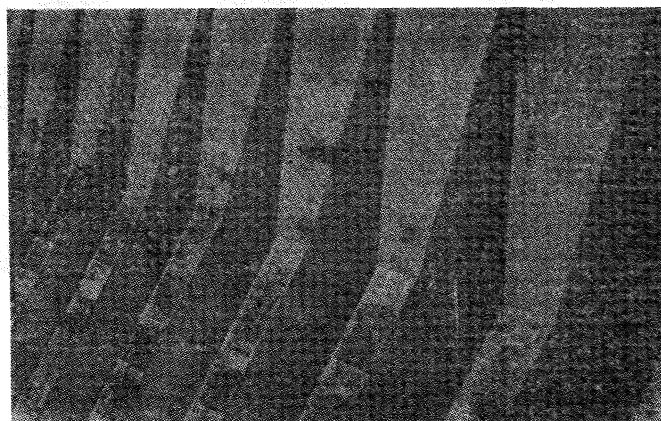
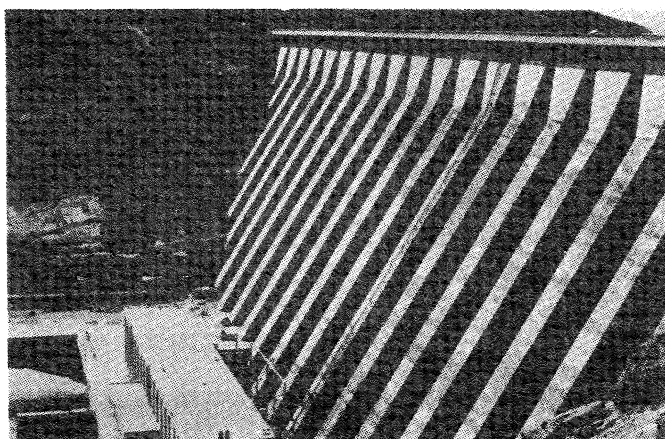
**FIGURE 29: POOR WELDING OF THIS STEEL ELEMENT LED TO FAILURE.**



**FIGURE 30: PERMANENT DEFORMATION IN THE DIAGONAL BRACING OF THIS EIGHT STOREY STEEL FRAME BUILDING UNDER CONSTRUCTION.**



**FIGURE 31: TWO DIFFERENT LOAD BEARING SYSTEMS WERE USED IN THIS BUILDING IN HARZEVIL: THE FIRST STOREY IS A STEEL FRAME WITH INFILLED WALLS WHILE THE SECOND STOREY CONSISTS OF TWO BEARING WALLS ON THE SIDES WITH STEEL COLUMNS IN THE MIDDLE. THE RESULT HAS BEEN TILTING OF THE SIDE WALLS AND PARTIAL COLLAPSE OF THE SECOND STOREY.**



**FIGURE 32: SEFRIDRUD DAM LOCATED ABOUT 300 M FROM THE EARTHQUAKE FAULT (TOP) WITH A CLOSE UP VIEW OF CRACKS IN THE BUTTRESSES. THIS DAM SUSTAINED GENERAL STABILITY AND OPERATIONABILITY AFTER THE 20 JUNE 1990 EARTHQUAKE. SOME HORIZONTAL AND DIAGONAL CRACKS DEVELOPED AT THE TOP (ABOUT 14 M FROM THE TOP) WHICH ARE REPAIRABLE.**

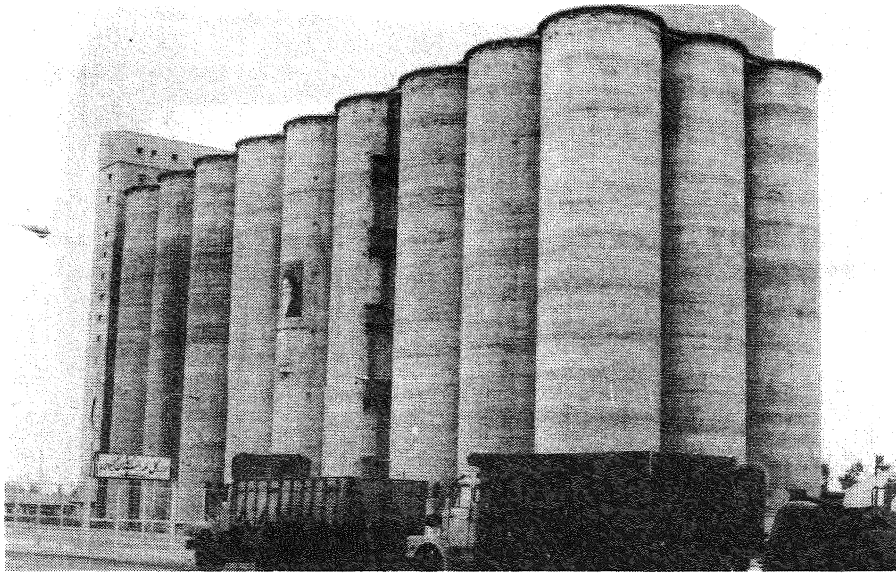


FIGURE 33: THIS 120,000 TON SILO IN SARAVAN NEAR RASHT SUFFERED NO DAMAGE.

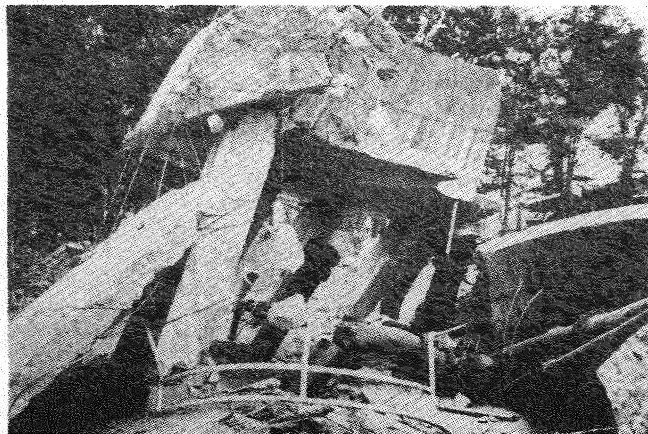
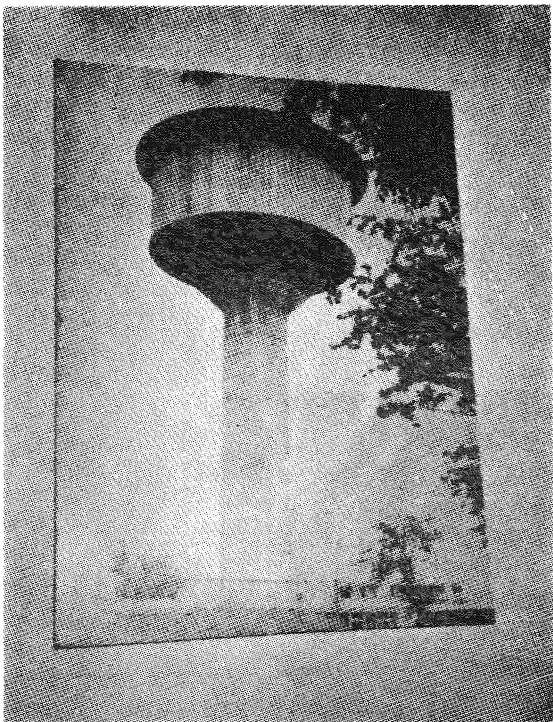


FIGURE 34: A 1500 M<sup>3</sup> WATER TOWER (46 M HIGH) BEFORE THE EARTHQUAKE (LEFT) AND AFTER (RIGHT).



**FIGURE 35: WATER TOWER IN MANJIL. THE DIAGONAL BRACINGS WERE FRACTURED BY THE EARTHQUAKE.**

**FIGURE 36: A NEW 2500 M<sup>3</sup> WATER TOWER (ABOUT 50 M HIGH) IN RASHT WHICH HAD JUST BEEN COMPLETED. A CRACK DEVELOPED AROUND THE SHAFT (BOTH INSIDE AND OUTSIDE) CLOSE TO THE UPPER CORNER OF THE BIGGEST OPENING (JUST ABOVE THE FOUNDATION).**



**FIGURE 37: DAMAGE TO A GAS PIPE IN A BUILDING IN MANJIL.**

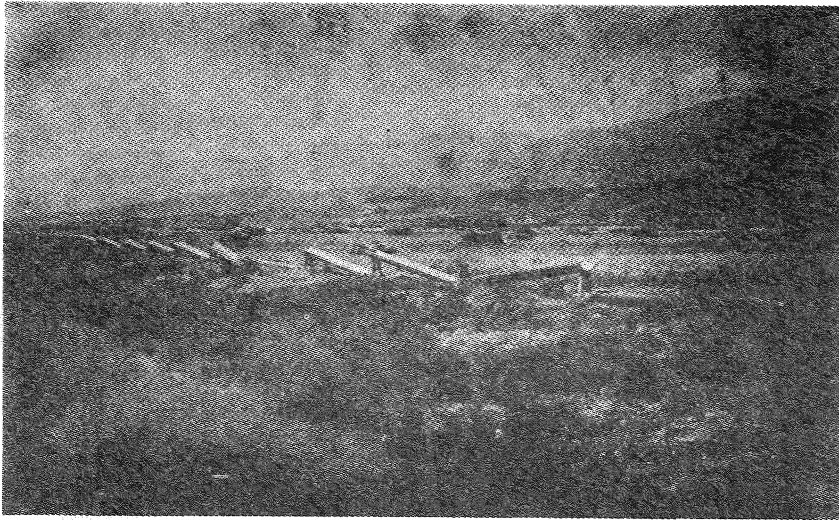


FIGURE 38: FALLEN PREFABRICATED IRRIGATION CANALS NEAR GILVAN.

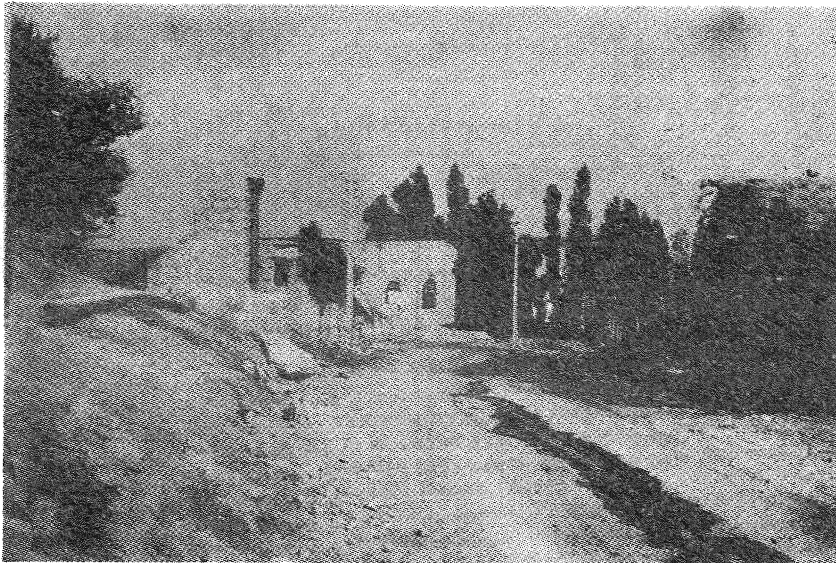


FIGURE 39: A BROKEN VILLAGE WATER PIPE CAUSED A DISRUPTION TO IRRIGATION.

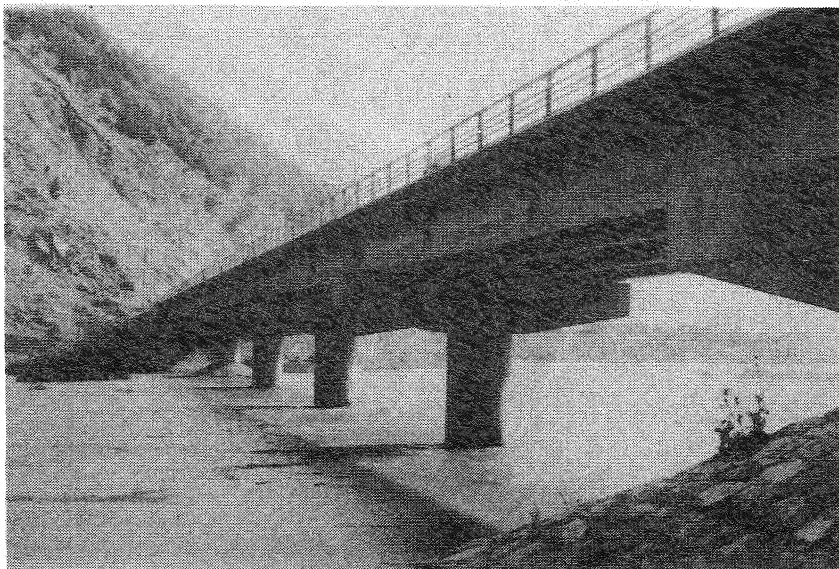
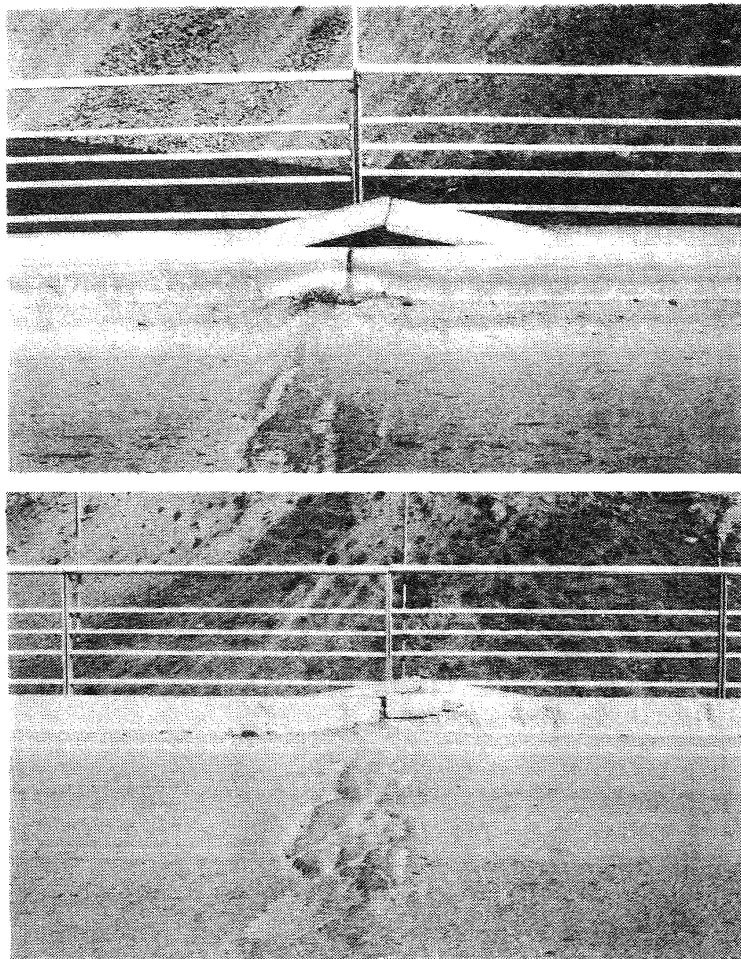
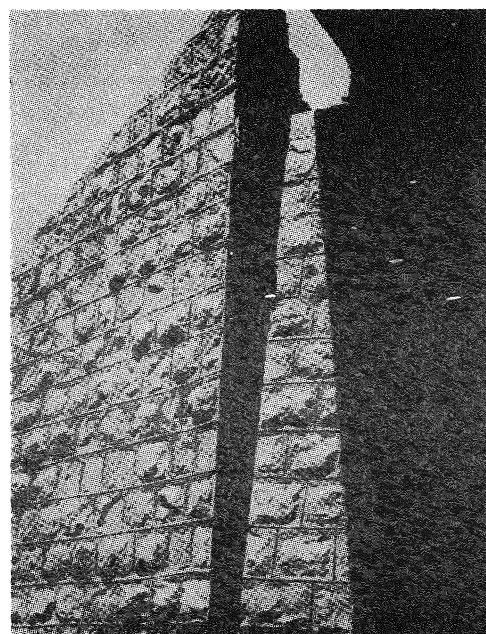


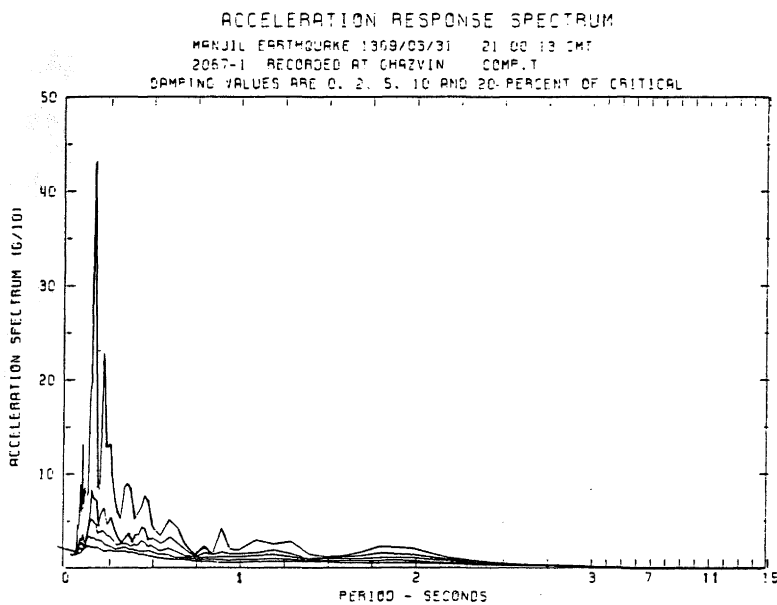
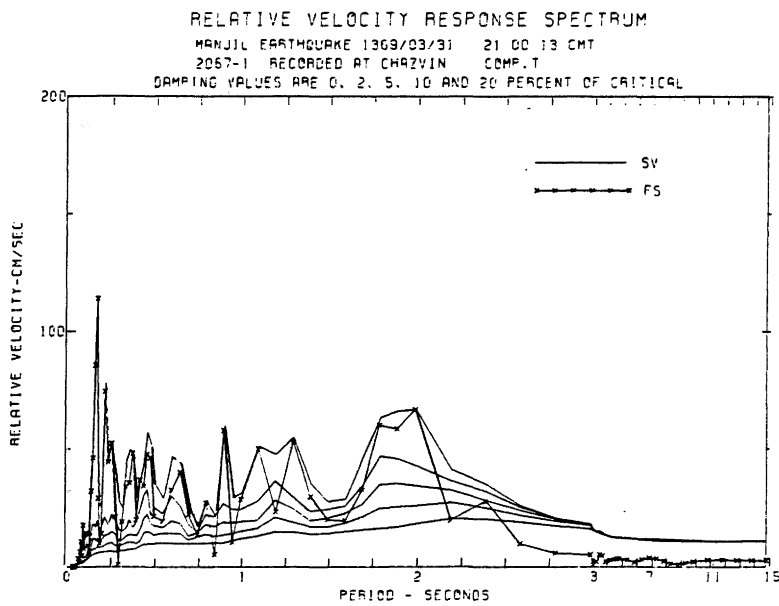
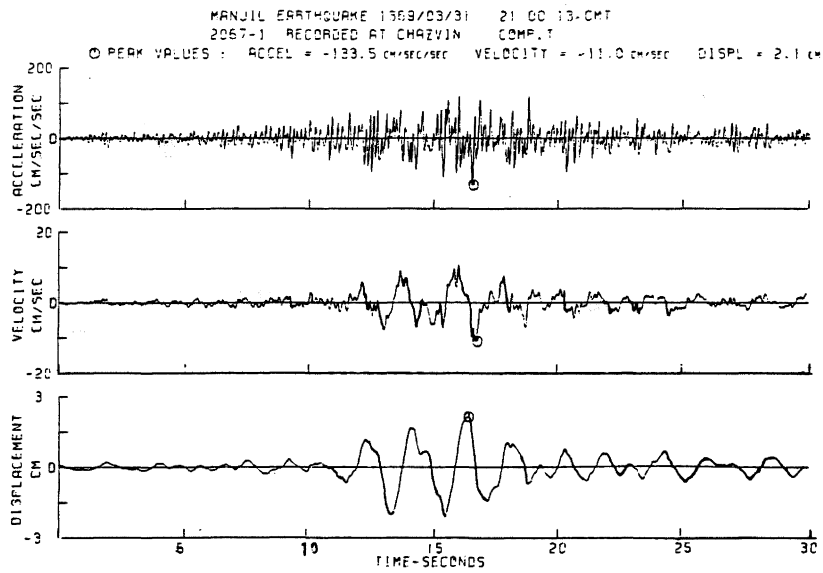
FIGURE 40: RUDBAR BRIDGE WHICH REMAINED OPERATIONAL AFTER THE EARTHQUAKE.



**FIGURE 41: COMPRESSION FAILURE IN THE DECK OF THE RUDBAR BRIDGE DIRECTLY ABOVE THE PIERS.**



**FIGURE 42: THIS BRIDGE ON THE ROAD FROM MANJIL TO GILVAN WAS UNDAMAGED, THOUGH AN ABUTMENT RETAINING WALL HAS UNDERGONE SOME MOVEMENT.**



**FIGURE 43: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE TRANSVERSE COMPONENT RECORDED AT CHAZVIN**  
NOTE: SV = spectral velocity; FS = Fourier spectra.

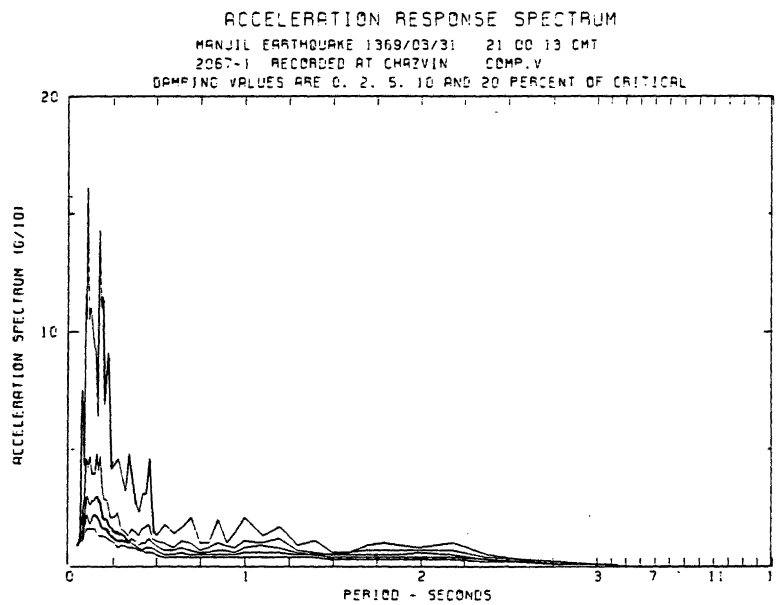
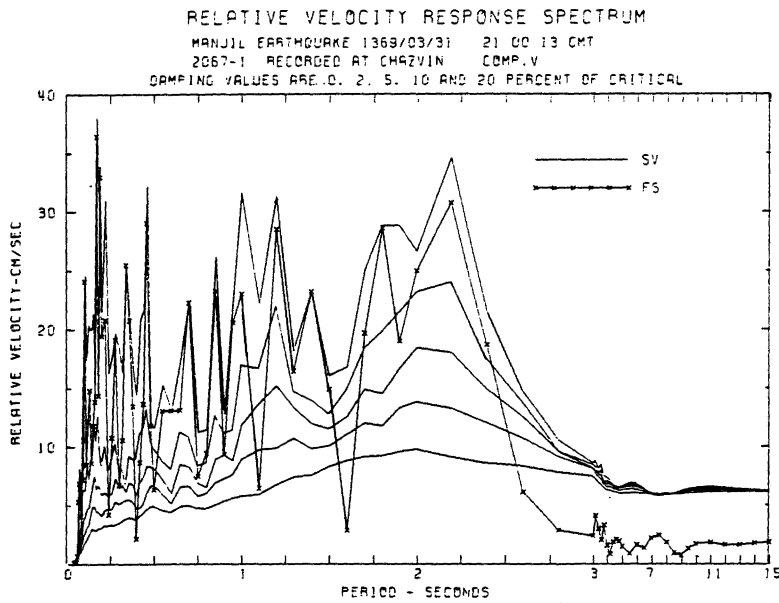
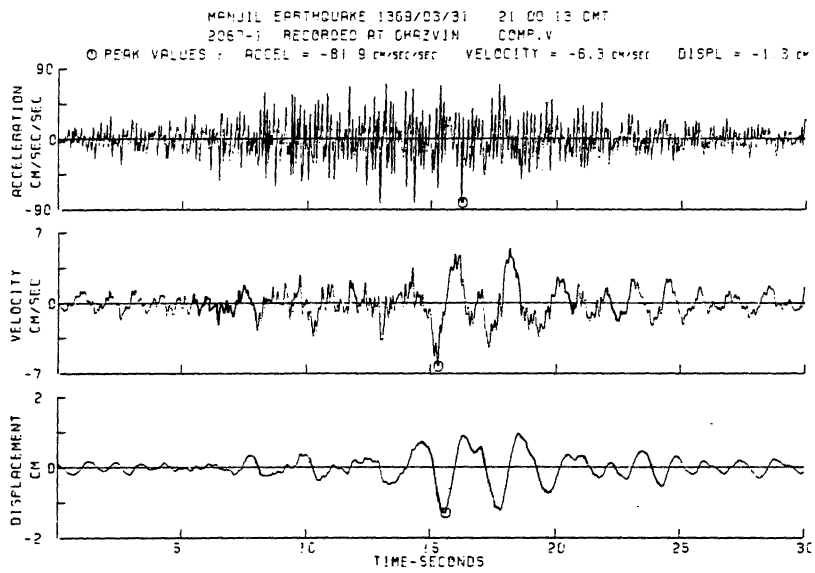
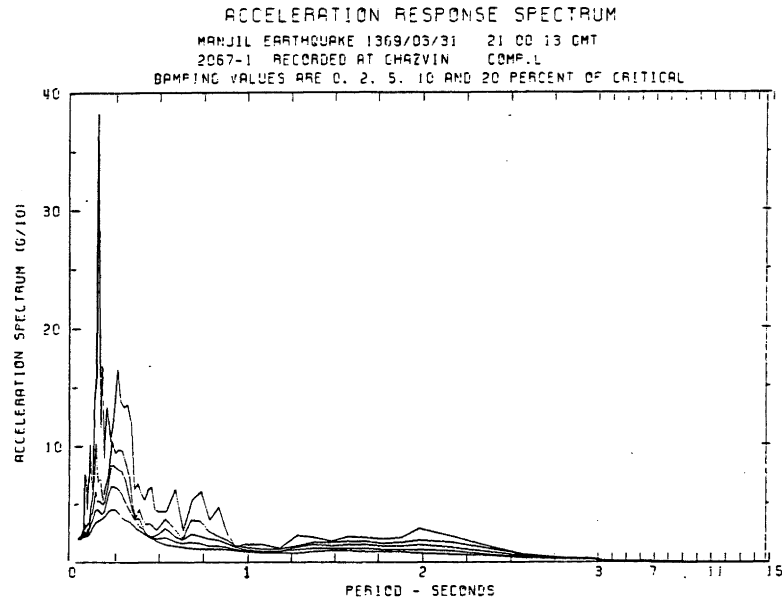
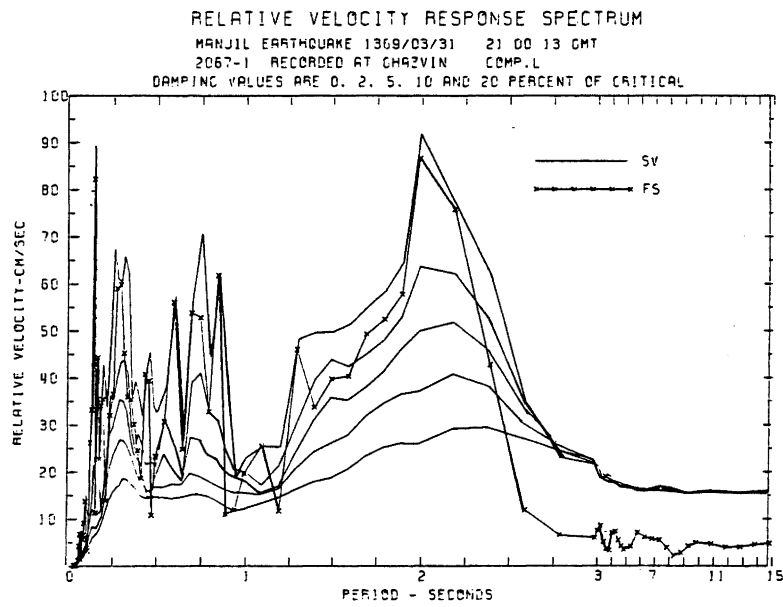
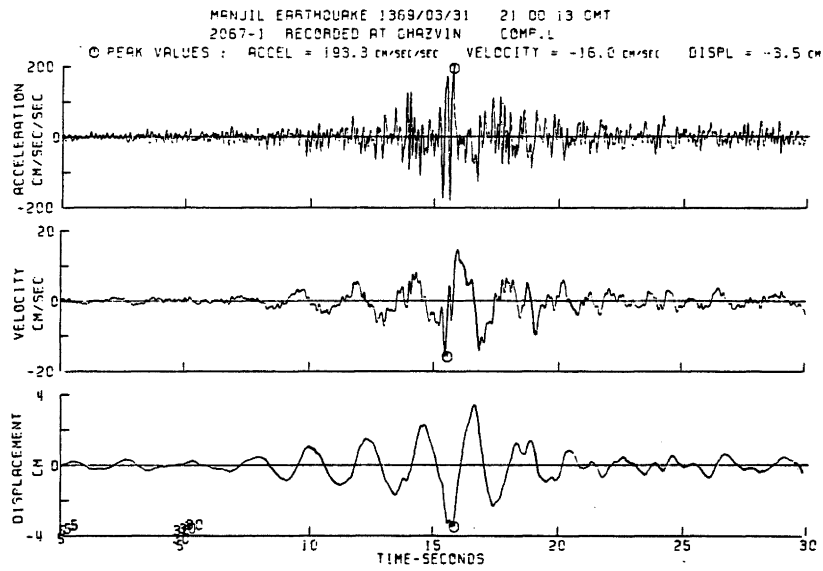


FIGURE 44: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE VERTICAL COMPONENT RECORDED AT GHAZVIN.



**FIGURE 45: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE LONGITUDINAL COMPONENT RECORDED AT GHAZVIN.**

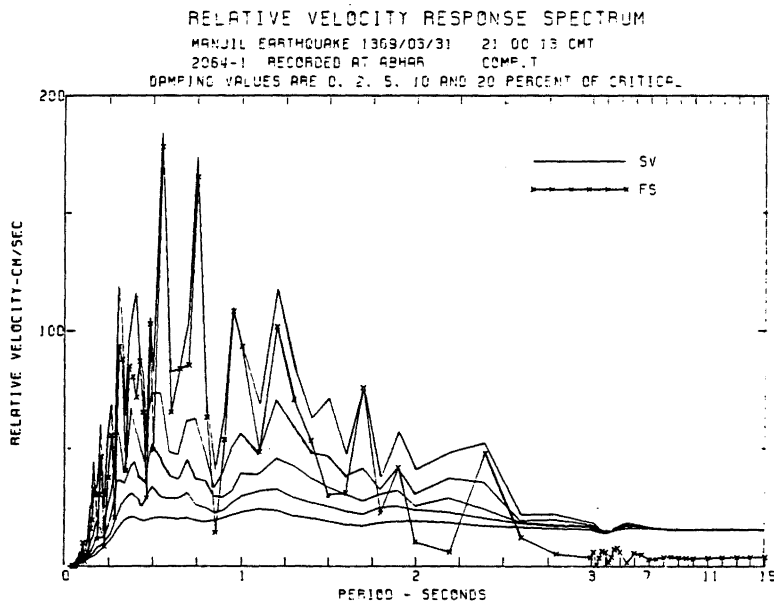
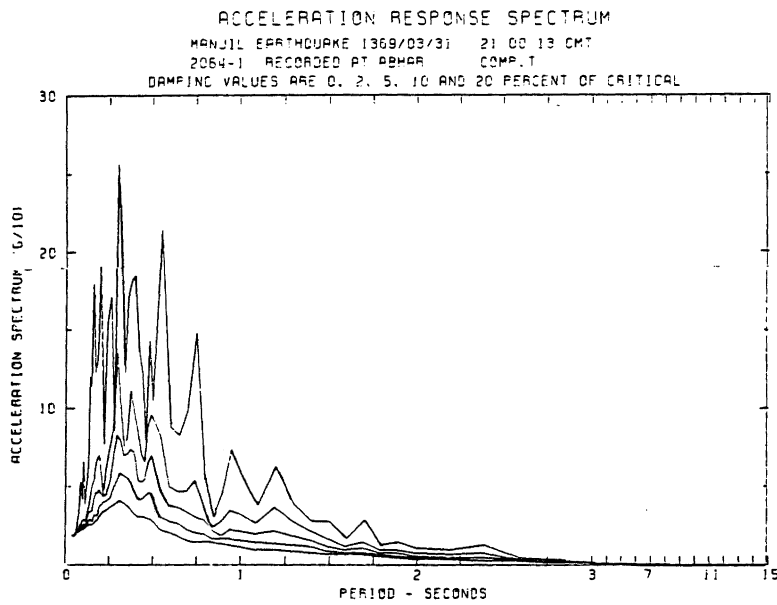
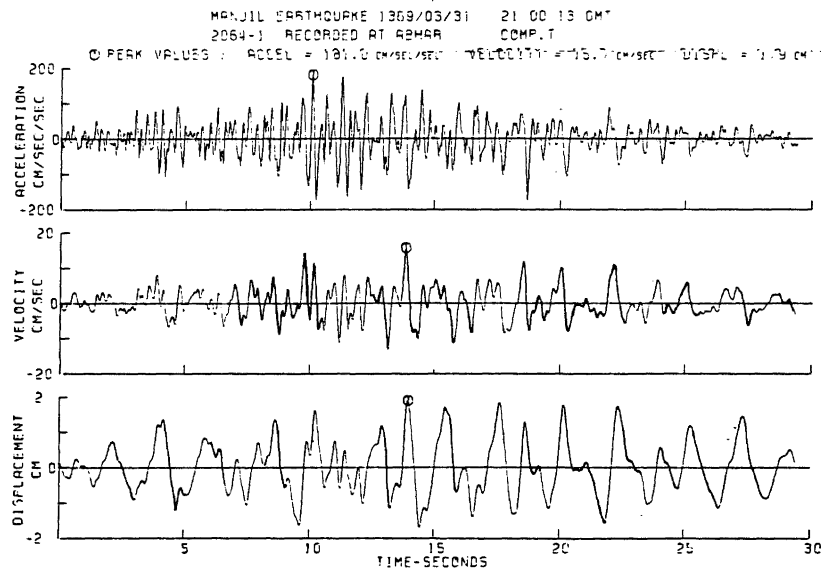
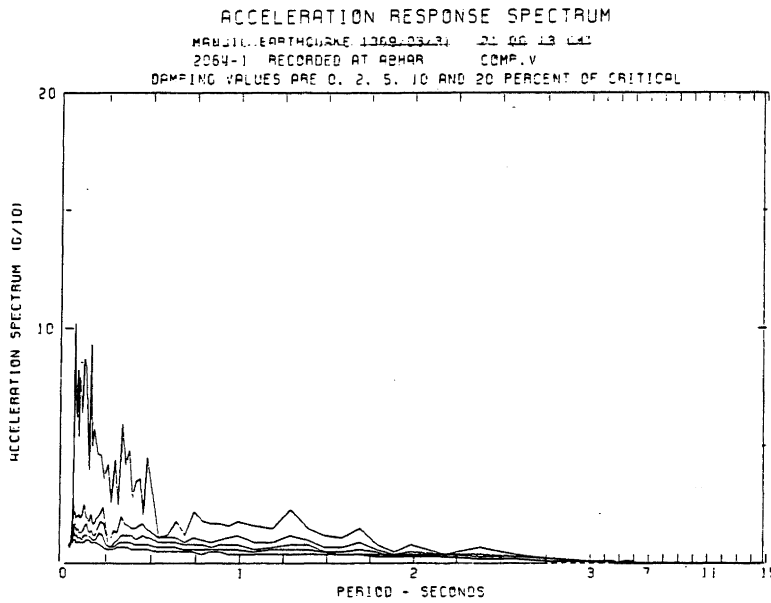
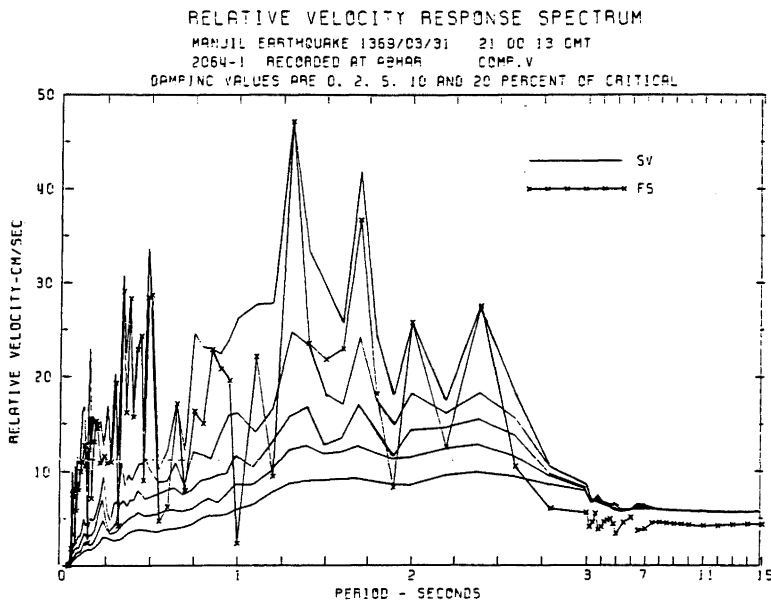
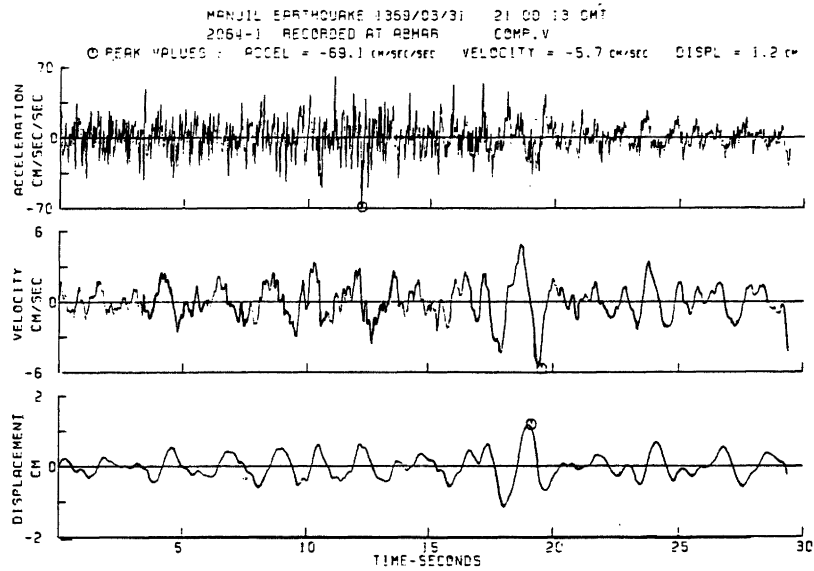
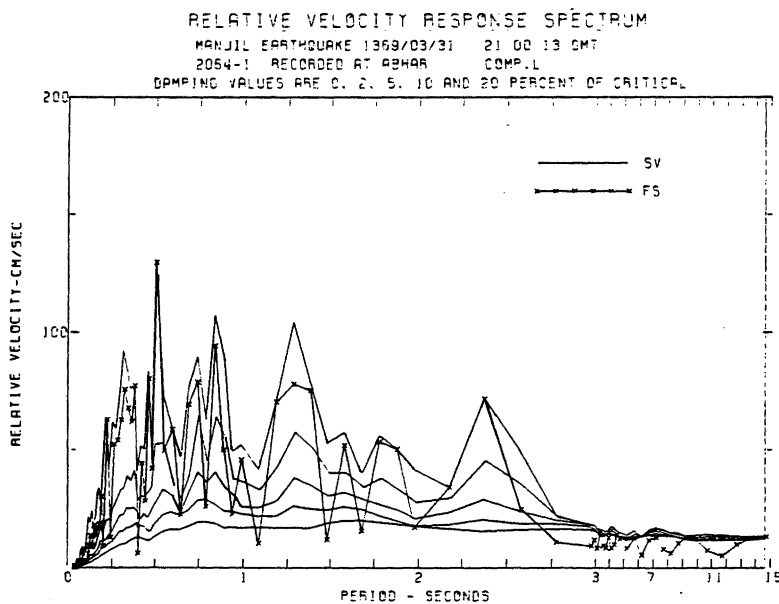
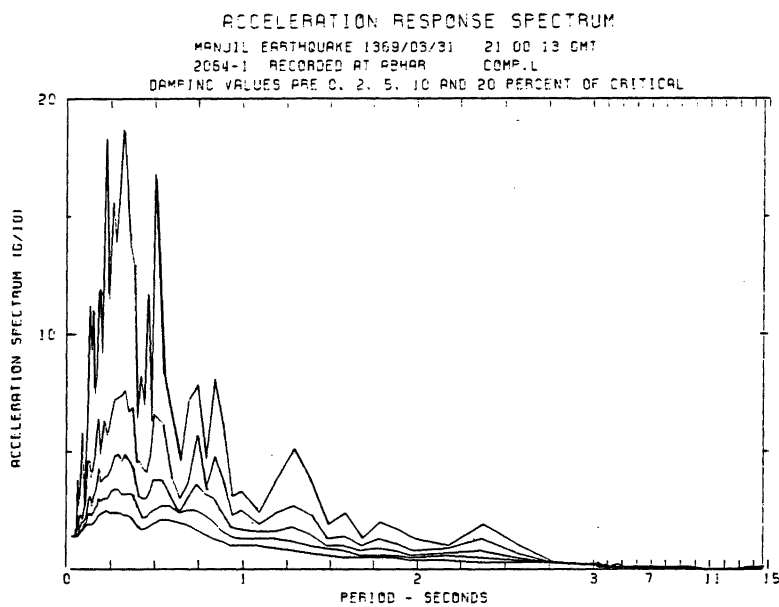
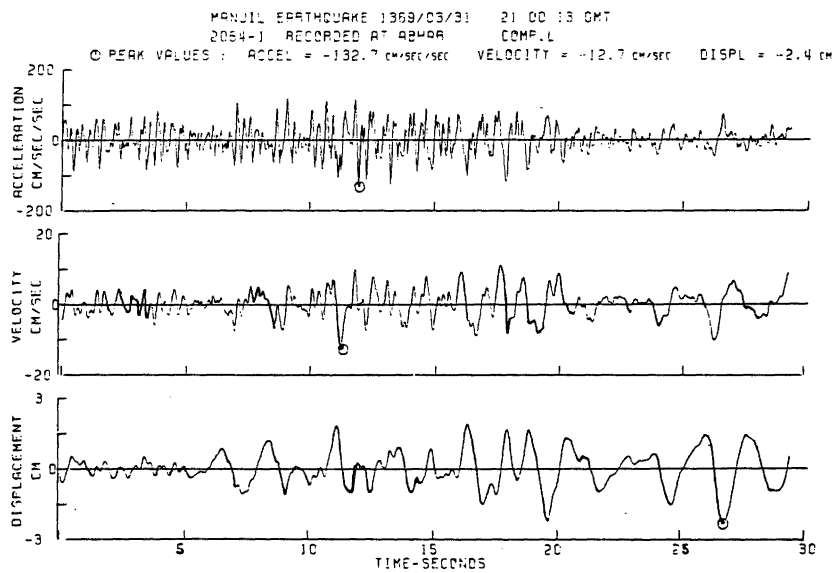


FIGURE 46: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE TRANSVERSE COMPONENT RECORDED AT ABHAR.



**FIGURE 47: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE VERTICAL COMPONENT RECORDED AT ABHAR.**



**FIGURE 48: ACCELERATION, VELOCITY AND DISPLACEMENT TRACES (Top), THE RELATIVE VELOCITY RESPONSE SPECTRUM (Middle) AND ACCELERATION RESPONSE SPECTRUM (Bottom) FOR THE LONGITUDINAL COMPONENT RECORDED AT ABHAR.**