

## **7. DAMAGE TO STRUCTURES**

The earthquake on Oct. 1995 killed 145 people and 802 houses and 6 major buildings were collapsed. 3676 houses were heavily damaged and 7147 houses were lightly damaged. Buildings collapsed were built on alluvial deposits and structures founded on firm ground or rock were almost non-damaged. This fact is also another important parameter for assessing damage profiles.

In our site-investigations, it seems that reinforced concrete buildings suffered the most, particularly those which have 4 or more stories. The second type of heavily damaged or collapsed structures are masonry built with hollow bricks. There were only three damaged bridges on the roadways. At other locations no damage to bridges was observed.

Mosques founded on alluvial deposits suffered slight damage while most of them lost their minarets.

### **7.1 Response Spectra of Structures**

The response spectra of the main shock are shown in Figures 7.1, 7.2 and 7.3. The SN spectra have peaks at periods of 0.33s, 0.45s and 0.70s (Figure 7.1). The EW spectra analysis shows peaks at periods of 0.15s, 0.25s, 0.35s, 0.47s, 0.68s and 1.10s (Figure 7.2). The UD spectra yield peaks at periods of 0.06s, 0.15s, 0.32s, 0.35s, 0.47s, 0.68s and 1.10s (Figure 7.3). It is of great interest that the response spectra is very flat for periods between 0.25s and 0.80s. The width of flat response spectra is much more evident for UD component and it ranges between 0.15s to 1.1s.

### **7.2 Natural Period of Structures in Turkey**

Data reported by Bayulke (1978) and with new additional ones are plotted in Figure 7.4. This experimental data were fit to a linear function. The following relations approximately hold between the natural period  $T$  of the building and the number  $N$  of stories:

$$T = 0.05 N \text{ non-damaged}$$

$$T = 0.10 N \text{ damaged}$$

The natural periods buildings with 4,5,7,8 stories will be 0.20s, 0.25s, 0.30s, 0.35s and 0.40s, respectively while the natural period of minarets will be between 0.35-0.40s.

### **7.3 Response Analysis of Structures**

Figures 7.5, 7.6 and 7.8 show acceleration response of structures with natural periods of 0.05, 0.15s, 0.25s, 0.35s, 0.45s, 0.55s. As seen from these figures, buildings with natural periods ranging between 0.25 to 0.55s should be subjected to very large earthquake loading. Therefore, it is expected that these structures having a natural period ranging between 0.25s and 0.55s, founded on alluvial deposits should be more severely damaged if their resistances are not sufficient against the resonance phenomenon.

### **7.4 Domes and Minarets**

Most of the mosques were intact or suffered very slight damage. Damage was generally concentrated at corners (Figure 7.8). Minarets in the region, which are generally 20 to 25 m high (Figure 7.9) are almost non-reinforced except having a steel pipe going through the centre of the structure. The minarets were masonry type with some anchors put tangentially between blocks of rocks. However, there were no anchors between layers of rock blocks. The direction of the collapses was generally towards the epicenter. Photographs of fallen minarets are shown in Figures 7.10, 7.11 and 7.12. The farthest of fallen minarets from the epicenter was 30 km away.

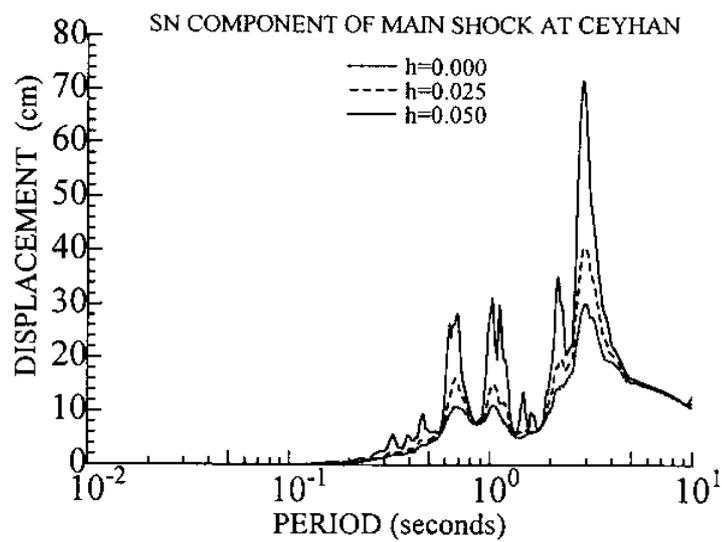
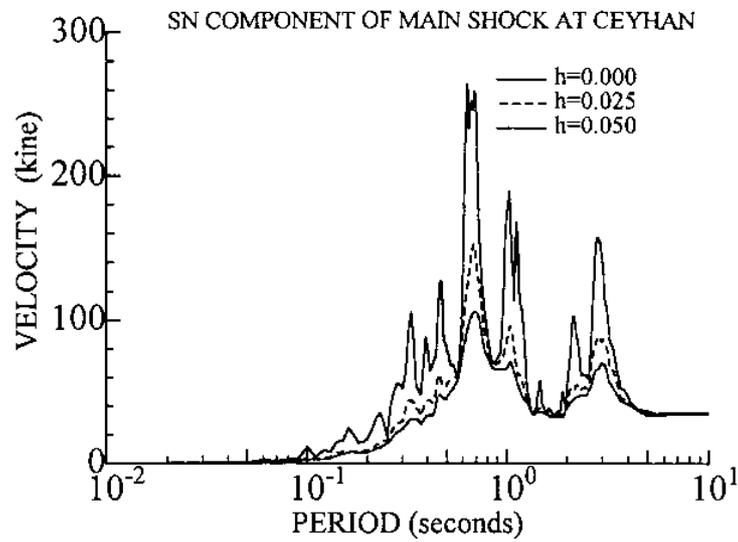
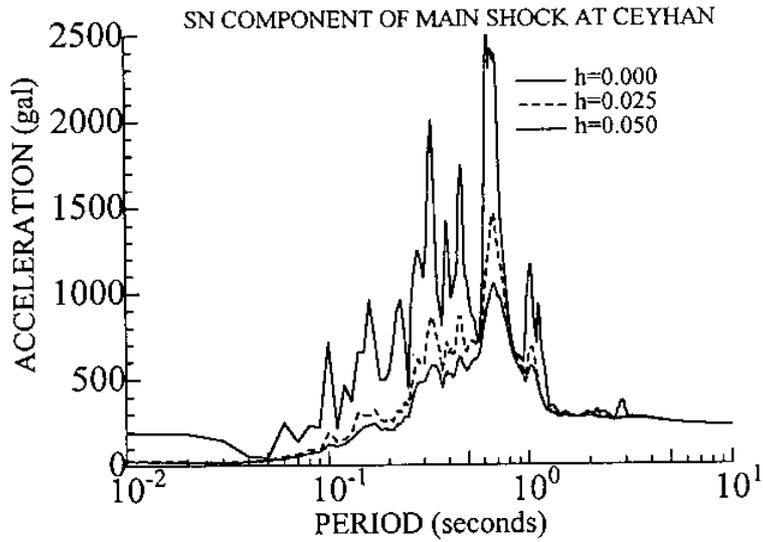


Figure 7.1 The SN acceleration, velocity and displacement response spectra of the main shock.

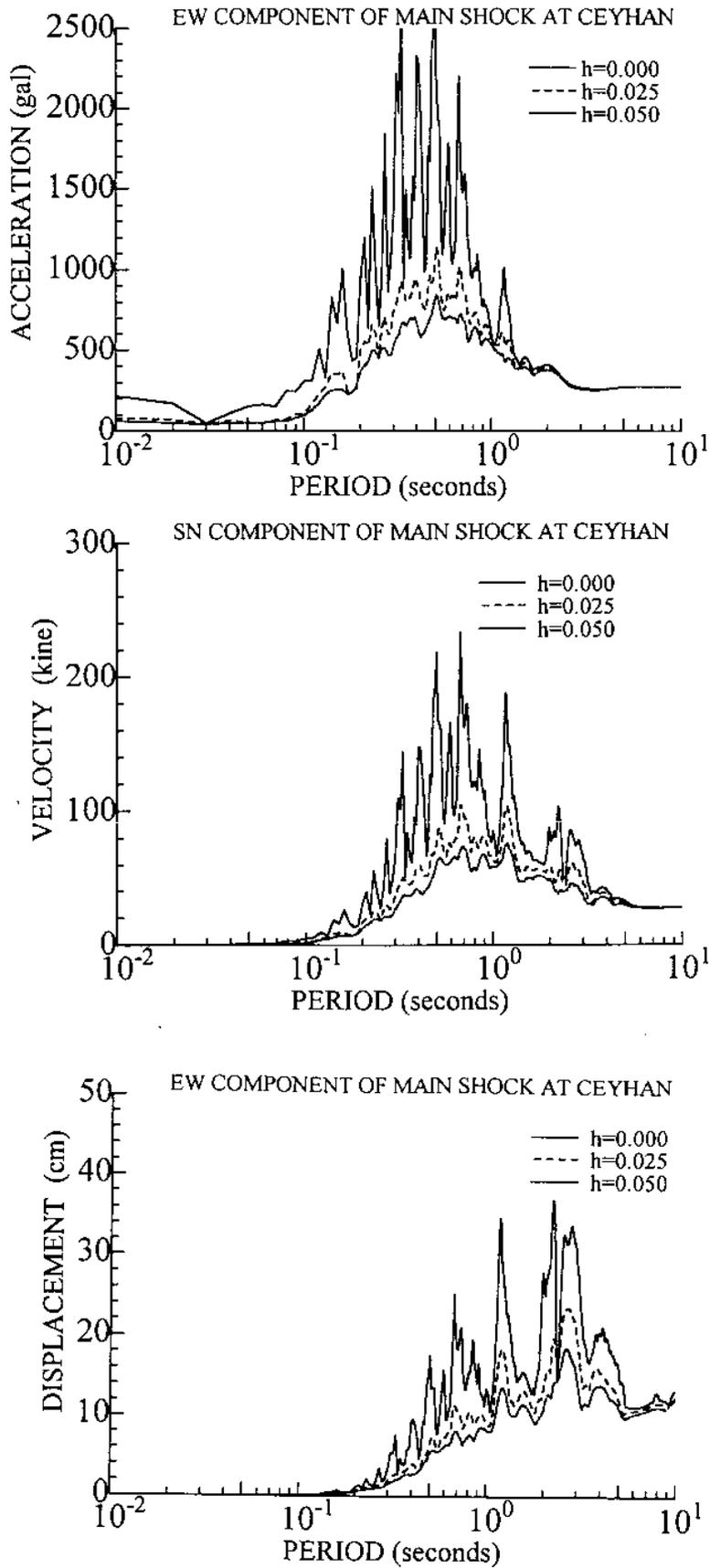


Figure 7.2 The EW acceleration, velocity and displacement response spectra of the main shock.

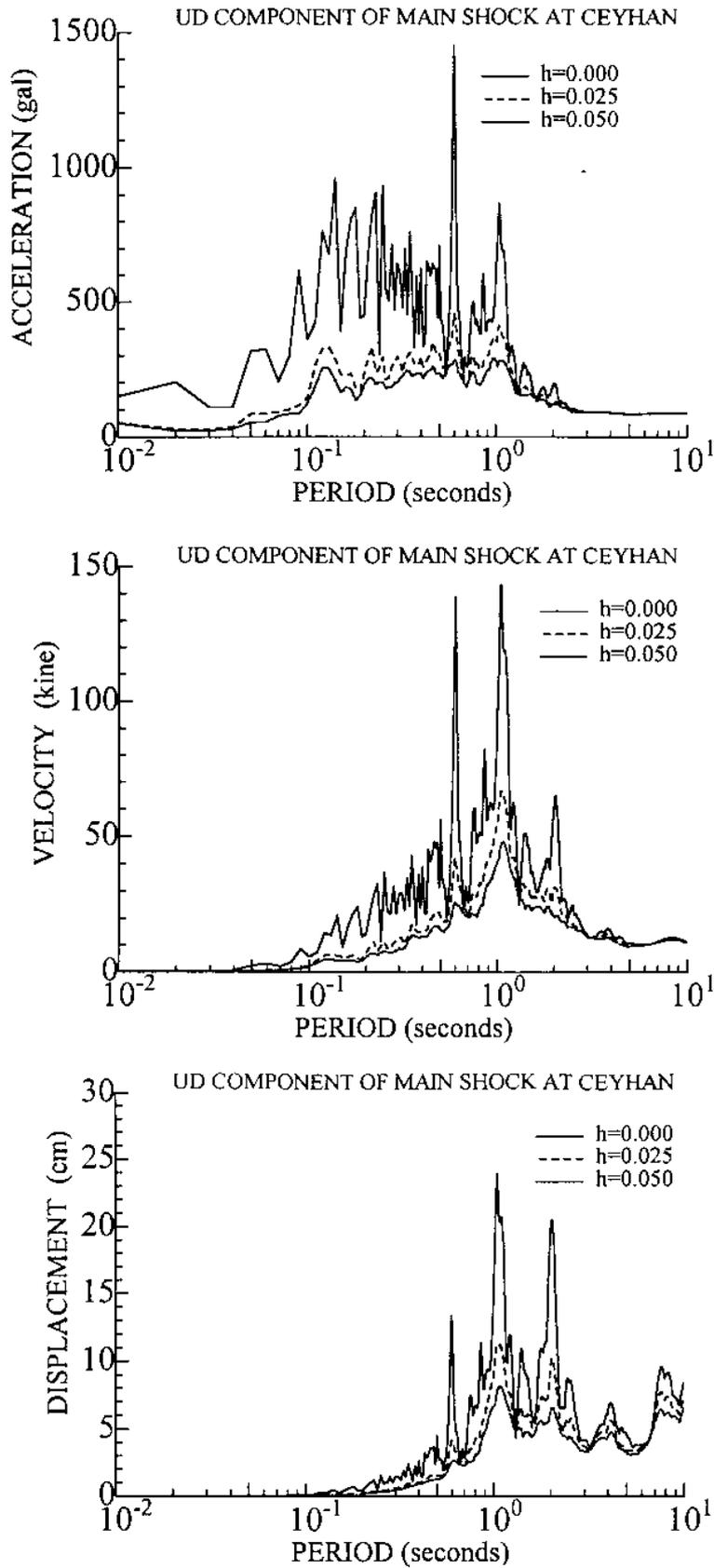


Figure 7.3 The UD acceleration, velocity and displacement response spectra of the main shock.

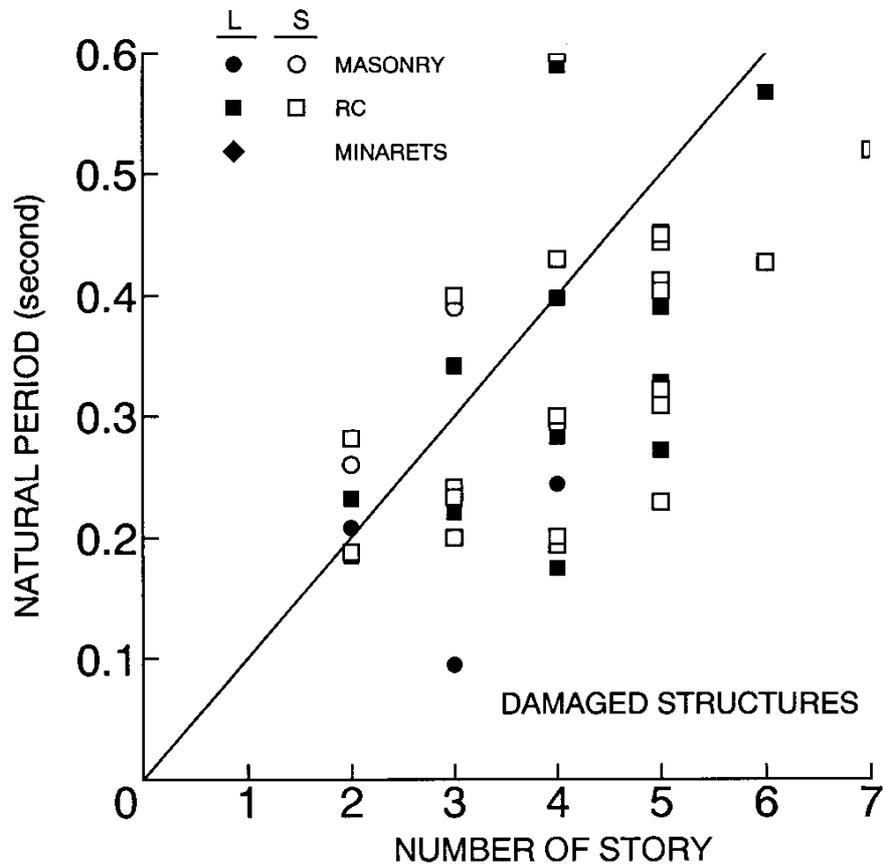
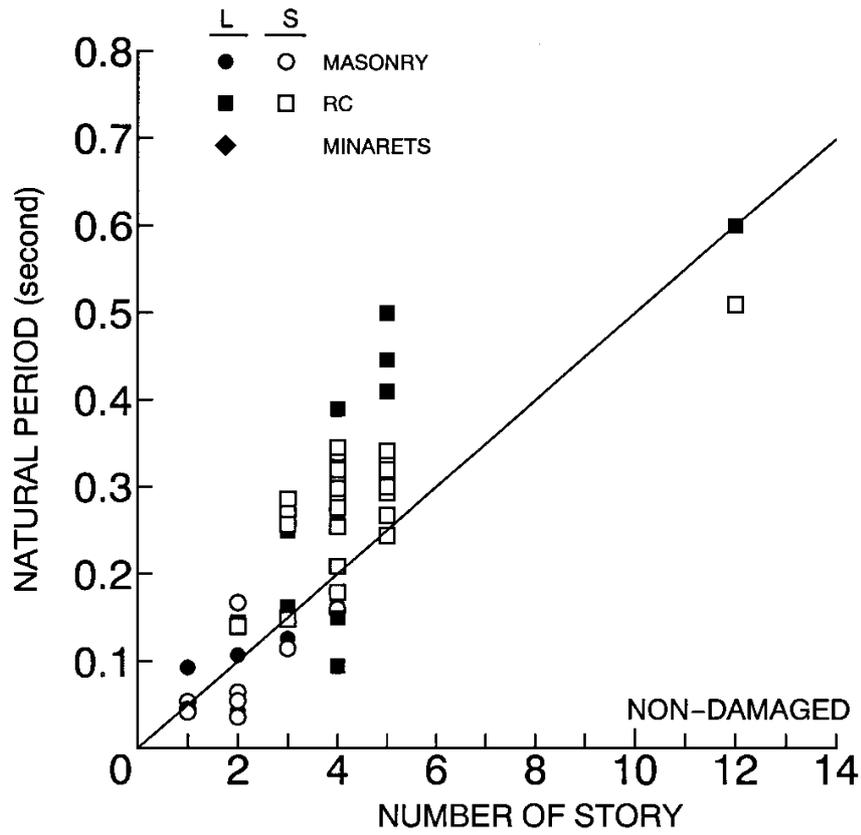


Figure 7.4 The relations between the natural period  $T$  and the story number  $N$  of the structures in Turkey

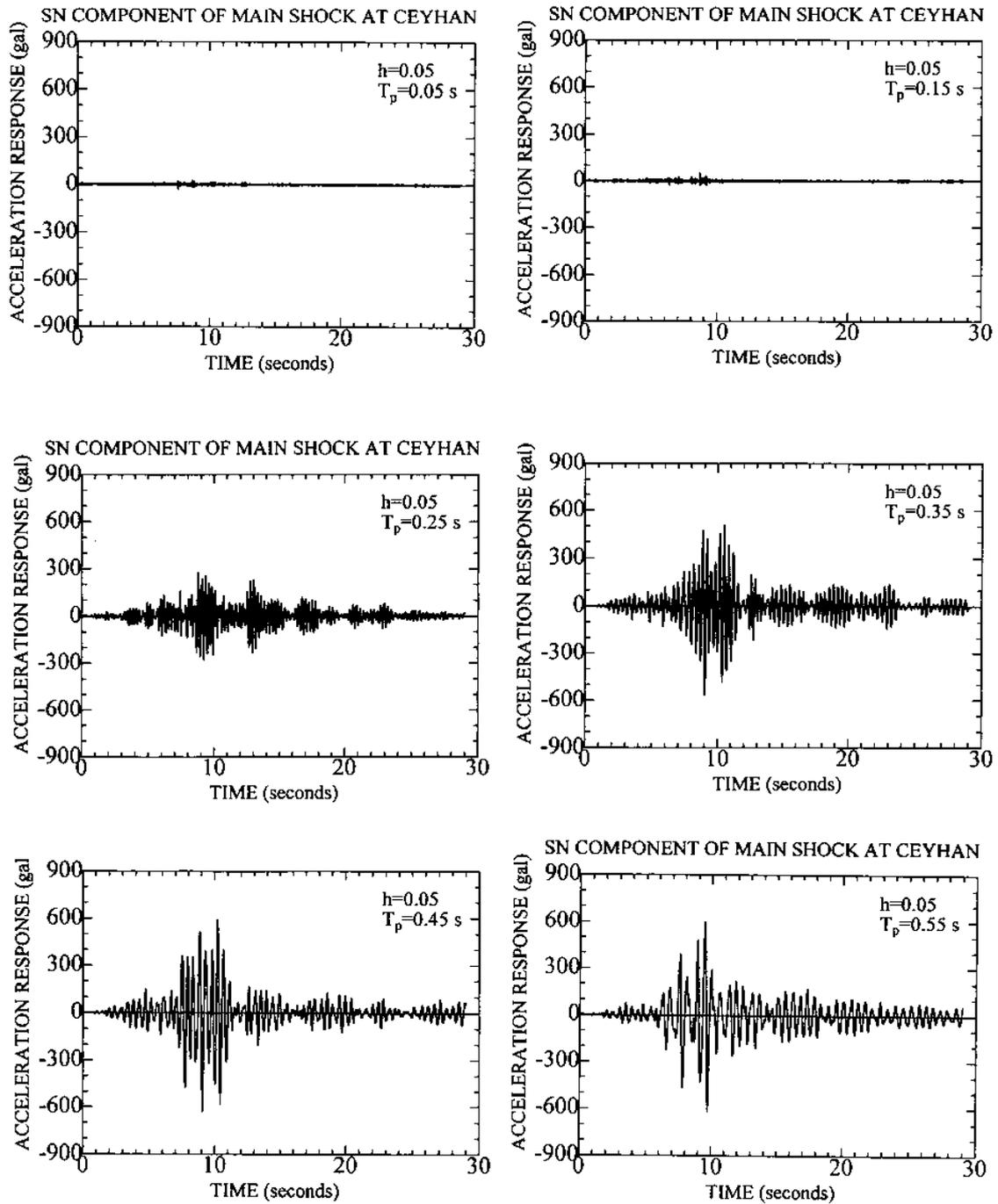


Figure 7.5 SN acceleration response of structures with natural periods of 0.05, 0.15s, 0.25s, 0.35s, 0.45s, 0.55s

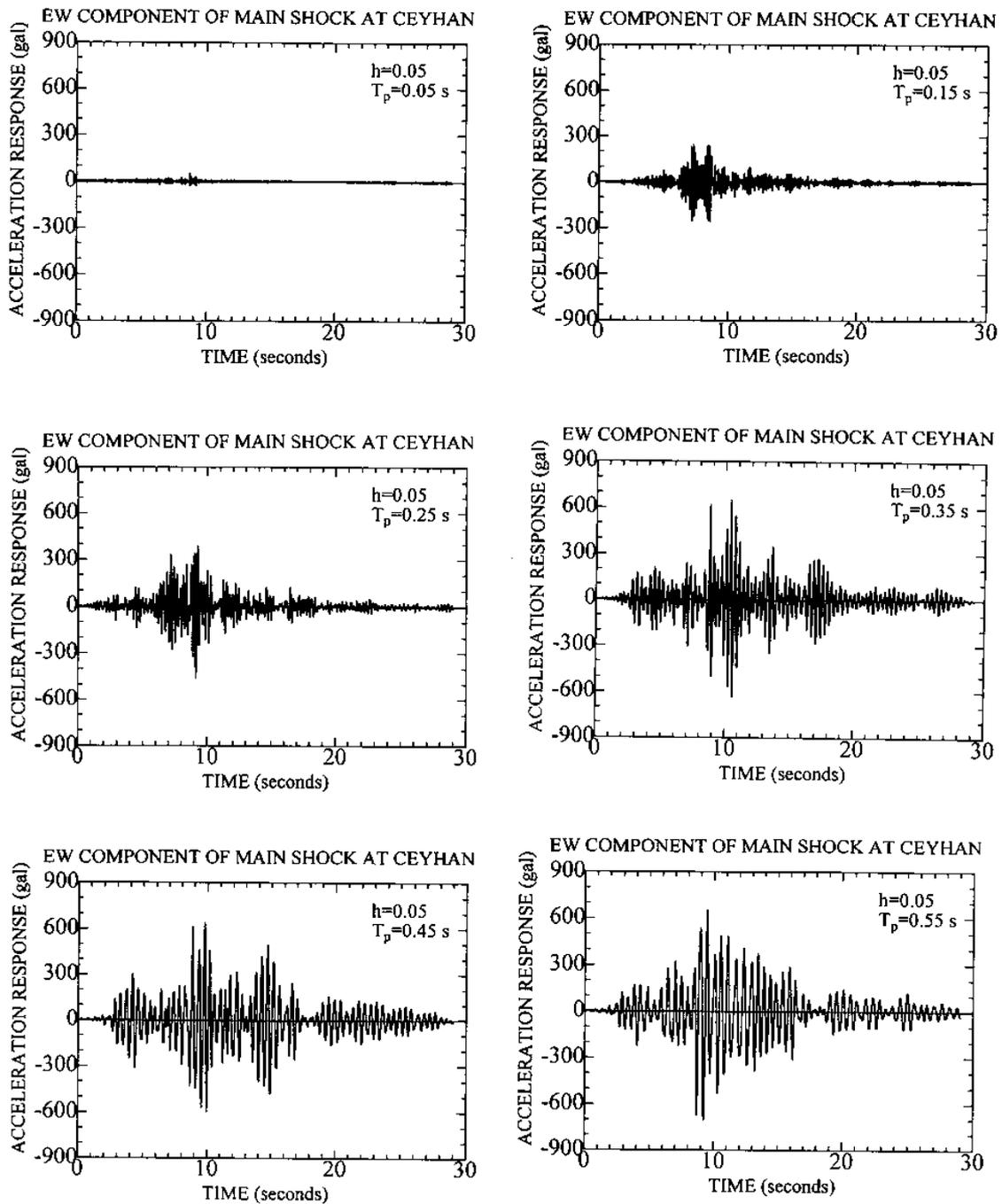


Figure 7.6 EW acceleration response of structures with natural periods of 0.05s, 0.15s, 0.25s, 0.35s, 0.45s, 0.55s

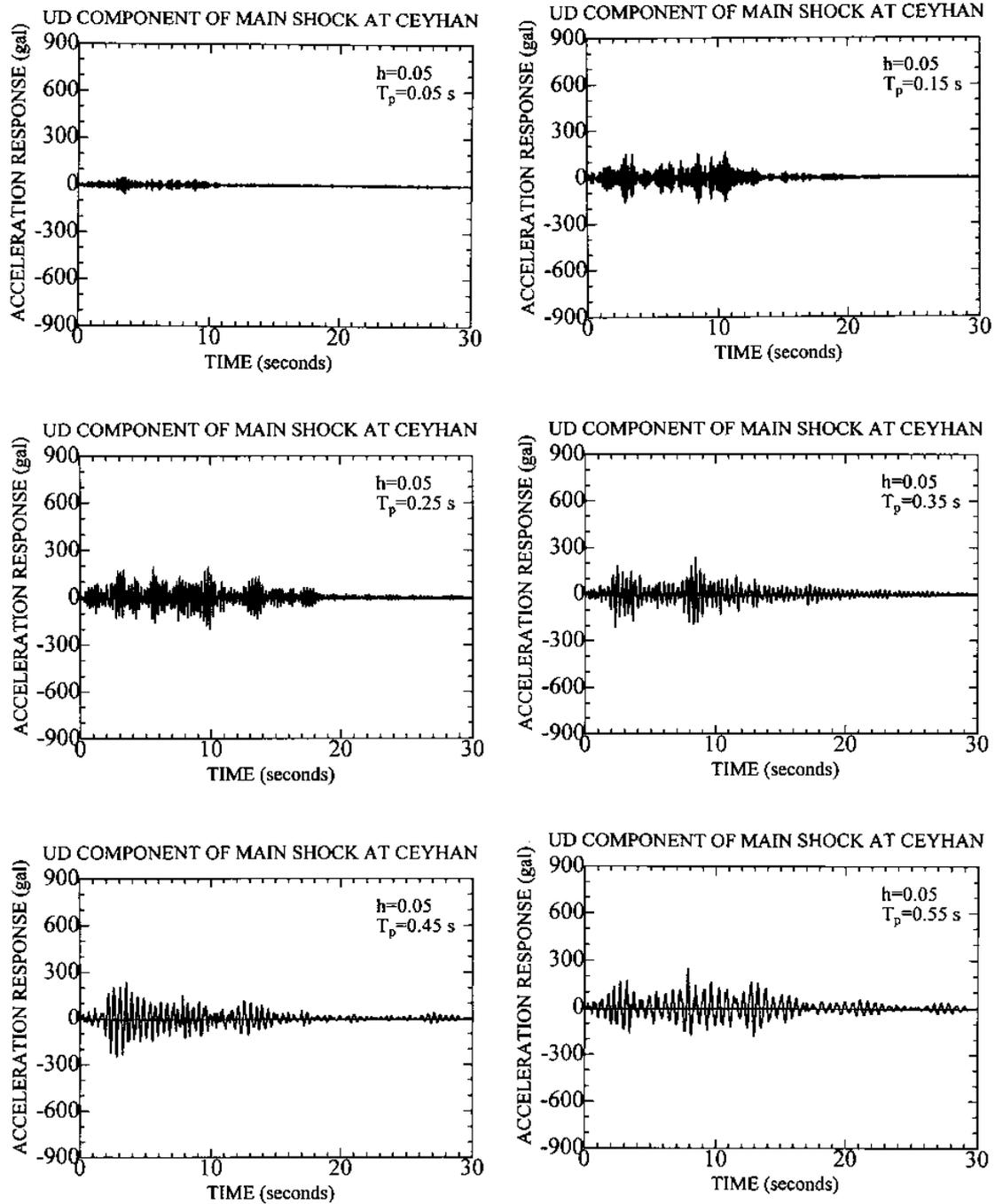


Figure 7.7 UD acceleration response of structures with natural periods of 0.05, 0.15s, 0.25s, 0.35s, 0.45s, 0.55s



Figure 7.8 Slightly damaged mosque at corner in Ceyhan



Figure 7.9 Mosque with damaged minaret at Yakapınar village



Figure 7.10 Toppled minaret of the mosque in Ceyhan, shown in Figure 7.8

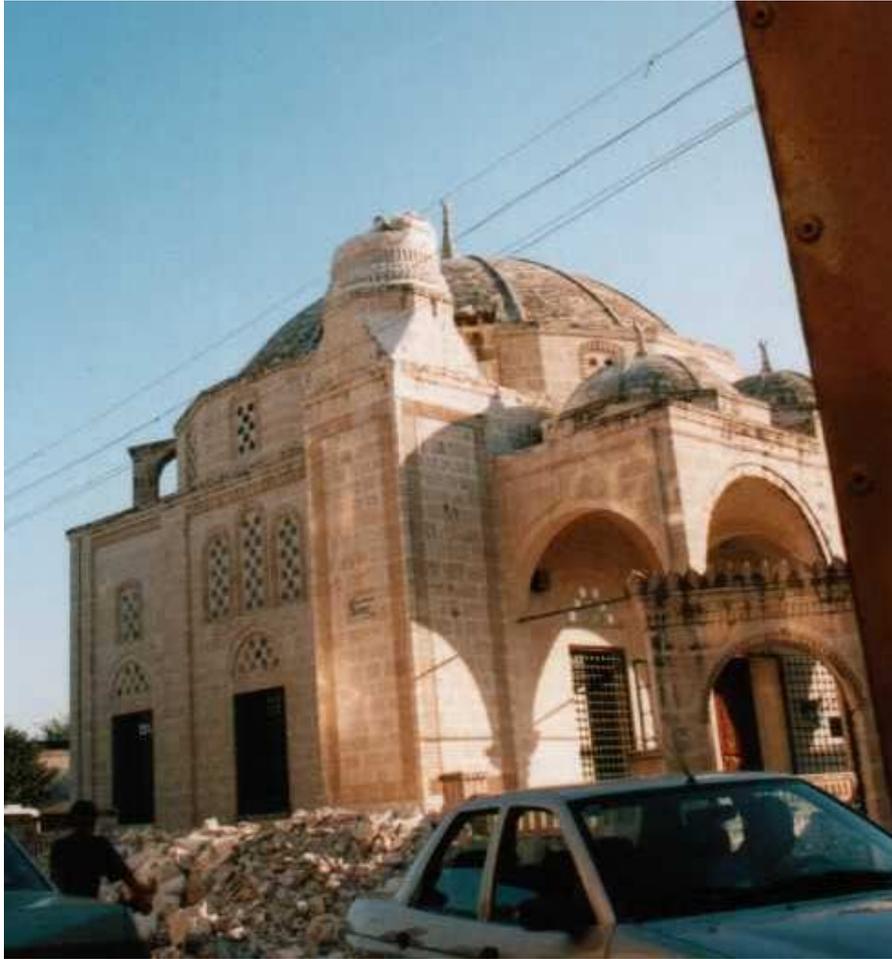


Figure 7.11 Toppled minaret of a mosque in Ceyhan



Figure 7.12 Toppled minaret of a mosque in Ceyhan

## 7.5 RC Structures

The collapsed or heavily damaged apartment blocks had 5-8 stories (Figures 7.13, 7.14, 7.15, 7.16). These structures are designed as moment-resistant structures with in-fill walls made of hollow bricks. The diameter of reinforcing bars and stir-ups are mostly 8-16 mm and 4 mm respectively. Bars were of smooth type. However the use of deformed bars were observed in buildings under construction or new buildings.

The ground floor of collapsed buildings was used as either shops or garages. As a result, this type of usage constitutes a weak-floor situation. Furthermore, many buildings had balconies of cantilever type.

The causes of damage were almost the same as seen in previous earthquakes. The causes listed below are taken from reports by the first author on March 13, 1992 Erzincan earthquake which are as follows (Aydan and Hamada 1992, Hamada and Aydan 1992):

**Poor workmanship:** There are two kinds of poor workmanship. One of them is that the connections of columns and beams were very weak as the connections of steel bars were not properly done and detritus materials at such locations were not cleaned (Figure 7.17 and Figure 7.18).

**Granulometry:** The second one is that the granulometry of the sand and gravels of concrete was very poor and the range was wide. In addition, big gravels blocked the concrete during casting at locations where steel connections were dense and this resulted in very porous and weak connections. During the site investigation, such connections were observed by the authors. During shaking, it seems that concrete at the connections first failed and this subsequently caused the buckling of steel bars at such locations.

**Resonance:** Natural periods of structures mostly coincided with those of the input waves and this resulted in the resonance of structures and their subsequent collapses. For 4 to 8 stories buildings, the natural period are between 0.2s and 0.4s. Since these values are close to those of input waves, the collapse of buildings on the basis of resonance phenomenon is very likely when the resistance of buildings is insufficient.

**Design mistakes:** One of the most striking design mistake was the confinement of concrete at the beam-column connections (Figure 7.19) in-spite of the Turkish design code for seismic regions. As stir-ups were very few at such locations, the failure of concrete was very brittle and it could not absorb the work done by the earthquake forces.

**Weak floor:** Many buildings had shops at their ground floor. Since there are no shear-walls to take up the load during earthquakes, the total load is transferred on the columns. The super structure acts a top-heavy structure on the columns and in-fill walls, which are almost in poor contact with columns and beams, has no effect against the earthquake loading. It was interesting to note that structures having solid bricks or angular rock blocks as in-fill walls and columns constructed after the construction walls performed much better and damage was almost very limited.

**Collision of Structures:** Many buildings were collapsed as a result of collision with the adjacent building (Figure 7.15). The buildings at the corners mainly collapsed.



Figure 7.13 Collapsed 6 stories RC building in Ceyhan with a garage at ground floor



Figure 7.14 Collapsed 5 stories RC building in Ceyhan with shops at ground floor



Figure 7.15 The collapse of collided 5 and 6 stories RC buildings in Ceyhan with shops at ground floor



Figure 7.16 Heavily damaged 8 stories building with balconies



Figure 7.17 Unproper column-beam connections. Note that reinforcing bars are not hooked with each other



Figure 7.18 Poor granulometry and detritus material at column-beam connections in a collapsed 5 stories building



Figure 7.19 Unproper column-beam connections. Note that reinforcing bars with small diameter and large spacing of stir-ups

### 7.6 Pre-fabrique RC Structures

Adana province has been heavily industrialized and there are many big factories. Most of these factories are pre-fabrique structures. Even the ground consisted of travertines or calich was quite firm, some of roof beams of such structure toppled. Figure 7.20 shows such a structure, which was under construction. Roof beams were broken at connections with columns during shaking as a result of either splitting of beam concrete or corbels of concrete columns.

### 7.7 Masonry Structures

The masonry structures in Adana-Ceyhan region may be divided into three categories:

- 1- Kerpiç (Adobe) masonry,
- 2- Tuğla (Brick) masonry, and
- 3- Taş (Rock) masonry.



Figure 7.20 A pre-fabrique structure with fallen roof beams and a close-up view of beam-column connection at ground floor

### 7.7.1 Kerpiç (Adobe) Masonry Structures

Kerpiç or adobe are made of sandy-clay and biofibres (straw) by casting in moulds and dried under the sun-light. The uniaxial strength of these bricks are reported as about 4-5 kgf/cm<sup>2</sup> (Bayülke 1978). The reason that local people prefer to use this type of bricks when other building materials are difficult to obtain geologically and cost. In ovas (basins) where stone could not be found local people will use this kind of material to build their houses.

The interblock friction angle is between 35-40. Observations on collapsed houses indicated that the quality of such bricks was poor and the roof of houses was earthen. If the roofs are light, such houses suffered less damage.

Translational and out of plane failures took place as seen in Figure 7.21. In some houses which are reinforced by concrete and having light roofs, no cracking and no damage were observed even they were founded on alluvial deposits. However, these structures are very few in this region.



Figure 7.21 Out of plane failure of a kerpiç (adobe) house

### 7.7.2 Tuğla (Brick) Masonry Structures

The most severe damage was observed in houses made of delikli Tuğla (hollow bricks). Although the use of this type of brick as a load bearing element was forbidden after the experience in 1992 Erzincan earthquake, its use is wide-spread. It should be noted that this material is very brittle. Once it starts to fail it will fail very quickly as stress-concentrations develop everywhere (Figure 7.22). The houses made with solid bricks and reinforced with concrete slabs for the continuity of structures and having stories less than two performed very well during the earthquake (Figure 7.23 and Figure 7.24).



Figure 7.22 Shear failure of a wall built with delikli Tuğla (hollow bricks)



Figure 7.23 Shear failure of a wall built with Horasan tuğla (solid bricks) with continuous concrete slabs in Abdioglu village



Figure 7.24 Shear failure of a wall built with Horasan tuğla (solid bricks) with continuous concrete slabs in Adana city

### 7.7.3 Taş (Rock) Masonry Structures

Angular and rough surfaced rock masonry structures, adhered by a mortar and with some concrete slabs or layers suffered almost no damage during the earthquake even they were founded on alluvial deposits (see Figure 7.9 and Figure 7.25). These structures are common in the region as stone can easily found in the region. However, when it is dry masonry or soil used as mortar, these structures become very fragile. The mosque, which was initially a church, collapsed together with its minaret and killed 5 people at Geçitli village (Figures 7.26 and 7.27).



(a) Damaged taş masonry house



(b) non-damaged taş masonry building in Abdiöğlü

Figure 7.25 Damaged and non-damaged taş masonry buildings

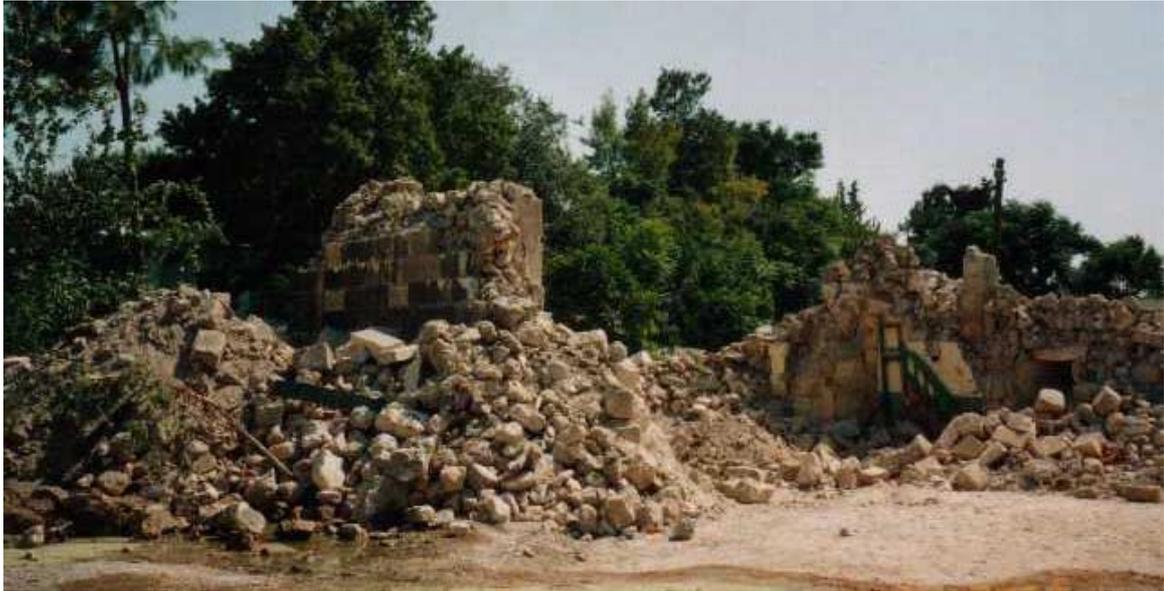


Figure 7.26 Collapsed mosque at Geçitli village (previously was a church)



Figure 7.27 Close-up views of the wall of the collapsed mosque at Geçitli village

## 7.8 Himiř (Wooden) Structures

This type of buildings are generally common when wood is locally available and cheap. The filling material of these type houses is adobe and they are mostly old. Even though these structures were very old, they performed much better than so-called modern RC structures. The damage of these houses was taken place in the form of falling plasters or in-fill walls (Figure 7.28).



Figure 7.28 A close-up view of Himiř house having its plaster and a part of in-fill wall fallen in Adana city

## 7.9 Water Towers, Pylons, Poles, Chimneys and Roofs

### 7.9.1 Water Towers

Water towers are RC structures and their height generally ranges between 25-30 meters. The towers have 6 columns and they are symmetric structures. Figure 7.29 shows a water tower in Adana city next to Seyhan dam. No damage was observed at this water tower. The water tower in Abdiođlu village was only slightly damaged (Figure 7.30). A close examination of the columns showed spalling of cover concrete of columns and the settlement of ground by 5 cm around them due to limited liquefaction.



Figure 7.29 Non-damaged water tower in Adana city next to Seyhan dam



Figure 7.30 Slightly damaged water tower in Abdioğlu village



Figure 7.31 A close-up view of damaged column and settled ground around columns

### 7.9.2 Pylons and Poles

During the earthquake, no pylon was broken or toppled. Figure 7.32 shows a pylon at Asmalı bridge area near Ceyhan town. Although the ground in front and behind of the pylon shown in Figure 7.32 was ruptured and sand boiling was observed wide-spread in this area, there was no visible damage to this pylon. There is no report on damage to any pylons during the earthquake. Poles are generally used to carry electric cables and electric distributions in towns and villages. None of pole was broken during this earthquake.



Figure 7.32 Non-damaged pylon at Asmalı bridge area near Ceyhan town. Note sand boiling around this pylon due ground liquefaction

#### 7.9.4 Chimneys and Roofs

Chimneys of many buildings near epicenter were toppled. Figures 7.33 and 7.34 shows toppled or damaged chimneys observed in Abdioğlu and Geçitli villages. However, many buildings have flat concrete slabs as roofs. As this region receives the sunshine most of the year, the utilization of solar energy is widespread. Figure 7.35 shows a slightly damaged and displaced solar energy system over a 2 stories building in Abdioğlu village.



Figure 7.33 Damaged chimney of a 1 story building in Abdioğlu village



Figure 7.34 A toppled chimney in Geçitli village



Figure 7.35 A slightly damaged and displaced solar energy panels

## **7.10 Dams**

There are 9 dams in the region which are either earth-fill or rock-fill type. (Figure 7.36'). The nearest dam to the earthquake epicenter is 40 km in Hakkıbeyli. The dam is earth-fill with a clay core and its height is about 22 m. It is used for irrigation purposes. A crack occurred at the crest of this dam along its axis. The other nearest dam to the epicenter is Seyhan dam, located on Seyhan river next to Adana city (Figure 7.37). This dam is used for electric generation and irrigation purposes. No damage at this rock-fill dam and its spillways was observed and there is no report on any damage to its turbines or surge tanks (Figures 7.38).

## **7.11 Roadways and Railway**

The Çukurova basin has an extensive roadway network. One of main expressways of Turkey passes through Adana and Ceyhan. During the visit, the site investigations showed no visible damage to the expressway. The author was informed at the headquarters of Turkish Roadway Authority that there was not any damage to main highways in the basin. During the investigation, a settlement of roadway from Yakapınar to Abdioğlu village was observed. The settlement was a result of lateral spreading of ground due to liquefaction (Figure 7.39). On the same roadway, there was fracturing in asphalt. Except this roadway, no damage was seen on any other roadway visited by the authors.

Adana is a junction point for the state railways (DDY). No damage was reported at railway lines.





Figure 7.37 Non-damaged Seyhan dam



Figure 7.38 Non-damaged spillways, power generation house and surge tanks



Figure 7.39 Settlement of roadway embankment near Abdioğlu village

## 7.12 Bridges

During the investigation, five damaged bridges were observed. Two damaged bridges were overpass bridges on the E-5 expressway and highway. The damage were slight so that there was no effect on their function. The damage was due to shaking of girders perpendicular to the axis of the bridge and concrete blocks at abutments between girders were fractured due to bending (Figure 7.40). The third damaged bridge was observed at Sirkeli village. The girders of this bridge was fractured at supports due to bending. However, the damage does not hinder the passage of vehicles (Figure 7.41(a)).

The most severe damage was observed at a stone masonry bridge, called Lokman Hekim Bridge after a Holyman who appears in Qur'an (Figure 7.41(b)) and built in AD 6 century. This is an 10-arched masonry bridge and it is 132.7 m long and 6.50 m wide. The stone blocks are sandstone. There is a permanent relative displacement of the bridge between its abutments. As a result, fracturing and separation of blocks were observed (Figures 6.13, 7.42 and 7.43).

The fifth damaged bridge was on the E-5 highway over Ceyhan river near Ceyhan town. The ground was liquefied in the fields at the both embankments. However, no

settlement of piers was visible. Nevertheless there was some damage at the joints of girders due to shaking. The damage was not of great importance to hinder its function.

There were also steel arched roadway and railway bridges in the region. No visible damage can be observed at the bridges shown in (Figures 7.44 and 7.45).



Figure 7.40 Slightly damaged overpass bridge on E-5 expressway in Ceyhan



(a) Sirkeli bridge



b) Close-up view of the damaged bearing

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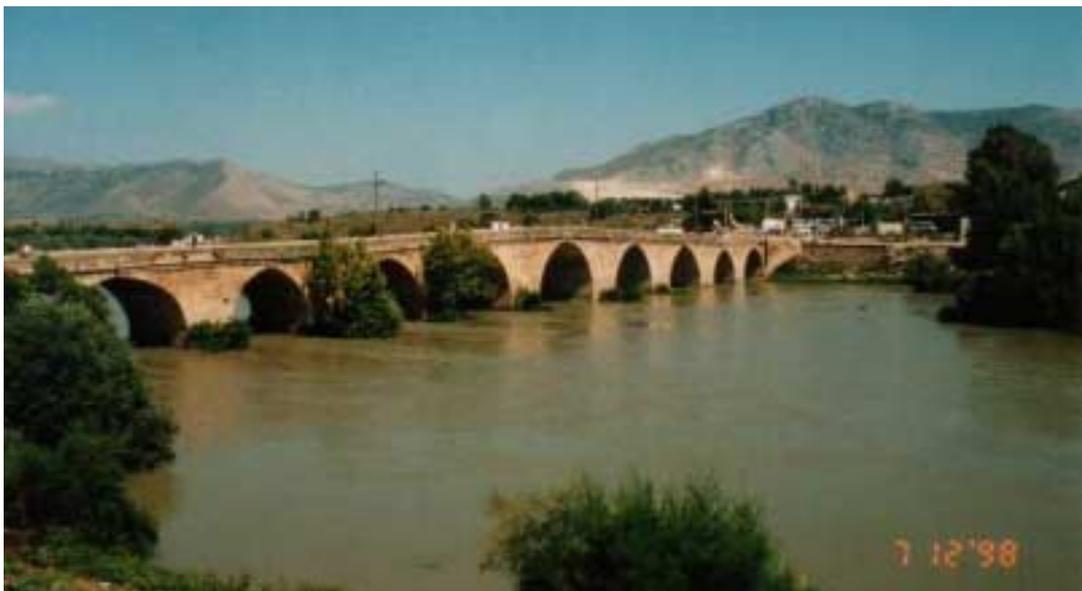


Figure 7.41 Damaged bridges: (a,b) Sirkeli village (b) Lokman Hekim Bridge



Figure 7.42 Fracturing and separation of Lokman Hekim Bridge entrance

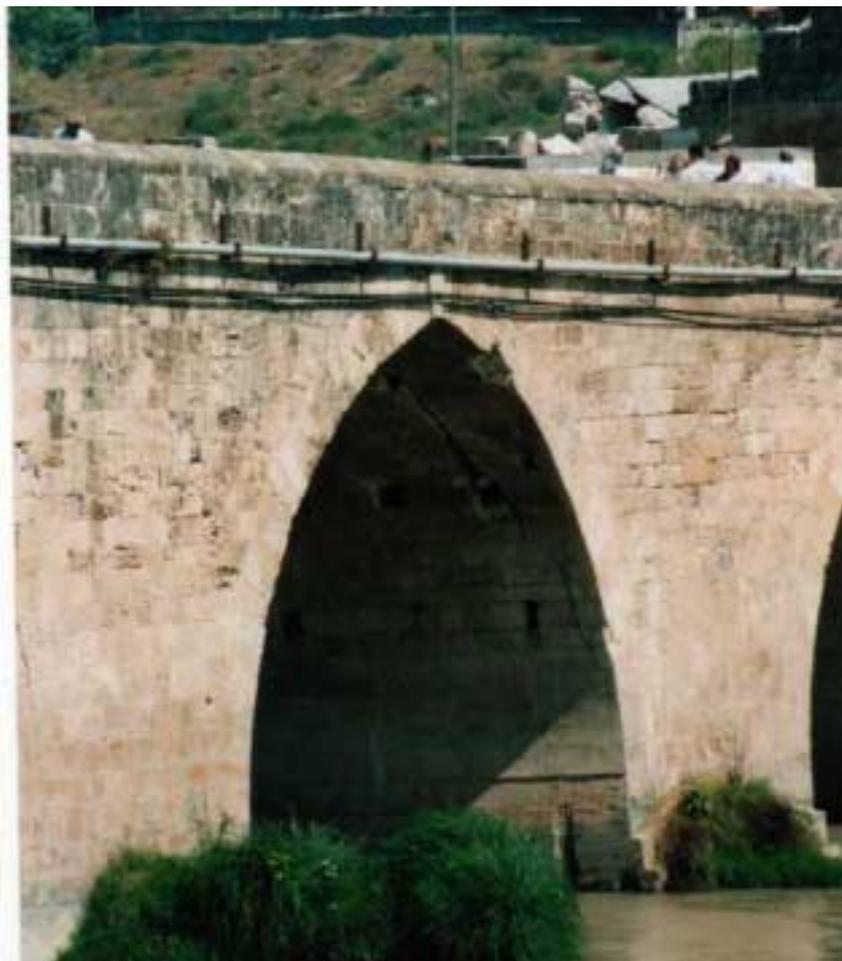


Figure 7.43 Block separation and sliding at one of arches of Lokman Hekim Bridge



Figure 7.44 Non-damaged steel arch roadway bridge over Ceyhan river in Ceyhan



Figure 7.45 Non-damaged steel arch railway bridge over Ceyhan river near Çokçapınar

### 7.13 Canals

Since the Çukurova basin is an important agricultural basin of Turkey, an extensive network of canals was constructed. The canals have an inverted trapezoidal shape and were generally lined with lightly reinforced concrete panels, and some of them were unlined.

During the investigation at several locations, no severe damage to the network was observed. At several locations, where lateral spreading of ground was observed, some concrete panels were slid down or ruptured (Figures 7.46 and 7.47). At a location near Abdioğlu village, there was a relative displacement at a junction between the canal and V-type conduit as a result of lateral spreading of ground (Figure 7.48).



Figure 7.46 Re-construction of fractured canal panels near Abdioğlu village



Figure 7.47 A view of the same canal in operation after re-construction



Figure 7.48 Relative displacement at a canal junction with a V-type conduit

## 7.14 Machinery

During the investigation, some of factories in the organized industry area of Adana province were visited. In factories visited, some of machinery either toppled or slid. When the machinery is not anchored on the floor, machinery with high aspect ratios were toppled. If the aspect ratio is small, then machinery was displaced permanently (Figures 7.49 and 7.50)



Figure 7.49 Toppled machinery at a textile factory



Figure 7.50 Displaced compressor unit at a textile factory

### **7.15 Damage Distributions in Ceyhan Town**

Figure 7.51, provided by the Municipality of Ceyhan town, illustrates locations of collapsed buildings and totally collapsed apartment blocks in Ceyhan town. It was striking that the damage was concentrated on structures built on alluvial deposits and parallel to the meandering of the Ceyhan River. The sediments deposited in the fluvial environment and it consists of fine grained and poorly graded sands and silts which are highly prone to liquefaction.

### **7.16 Spatial distribution of collapse directions of some structures**

The authors measured collapse directions of minarets, walls and the strike of walls with X-cracks and the motion directions of failed banks of Ceyhan River and plotted in Figure 7.52. Minarets are mostly toppled in the direction of NE-SW. This is consisted with the direction of the first largest impact as observed from the traces of acceleration waves shown in Figure 6.8 for Ceyhan. Few minarets are toppled in the direction of NW-SE direction which is consisted with the second largest impact as also seen from Figure 6.8. Similar tendencies are also observed in toppled walls, walls with X-cracks and the motion directions of the failed banks.

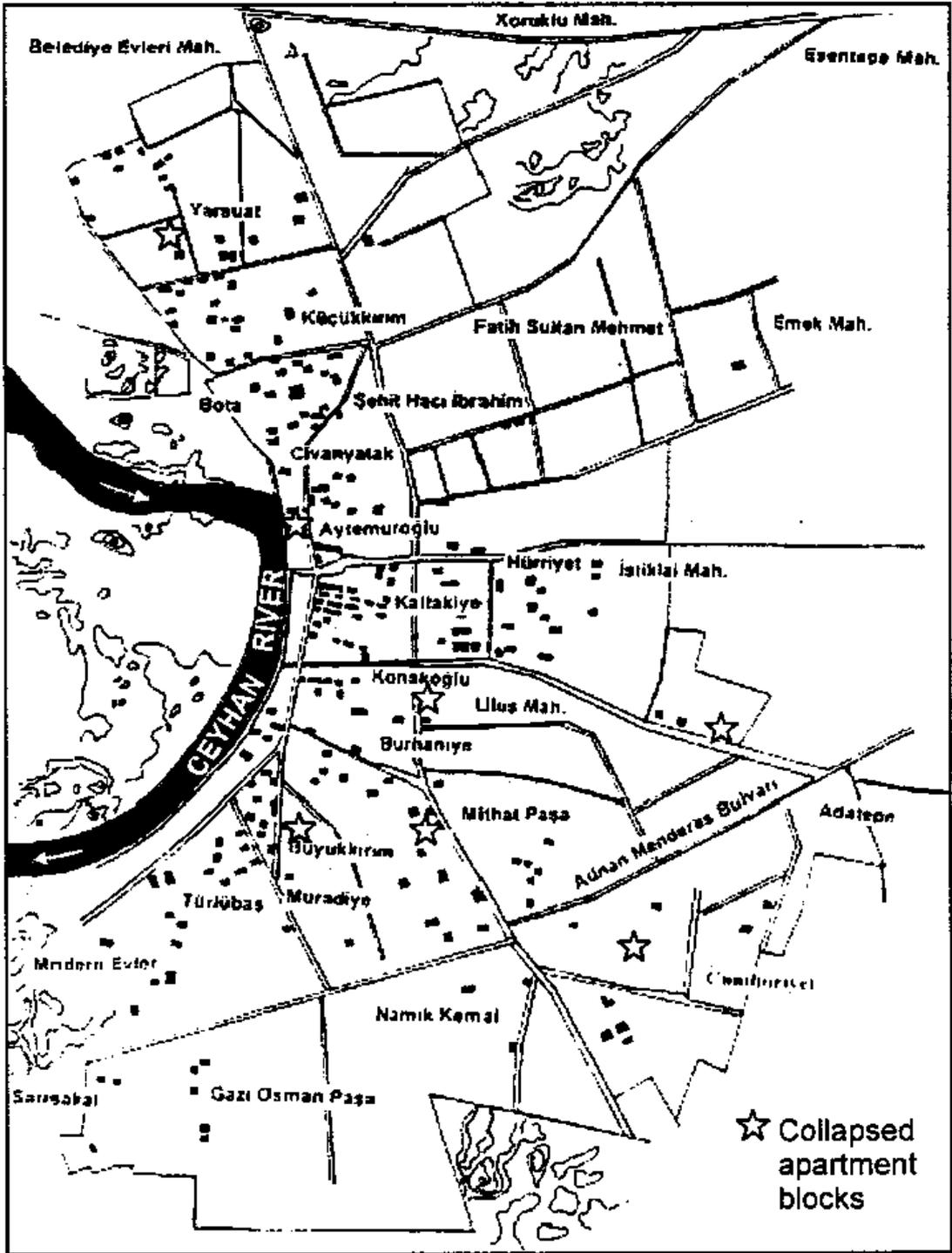


Figure 7.51 Damage distribution in Ceyhan town

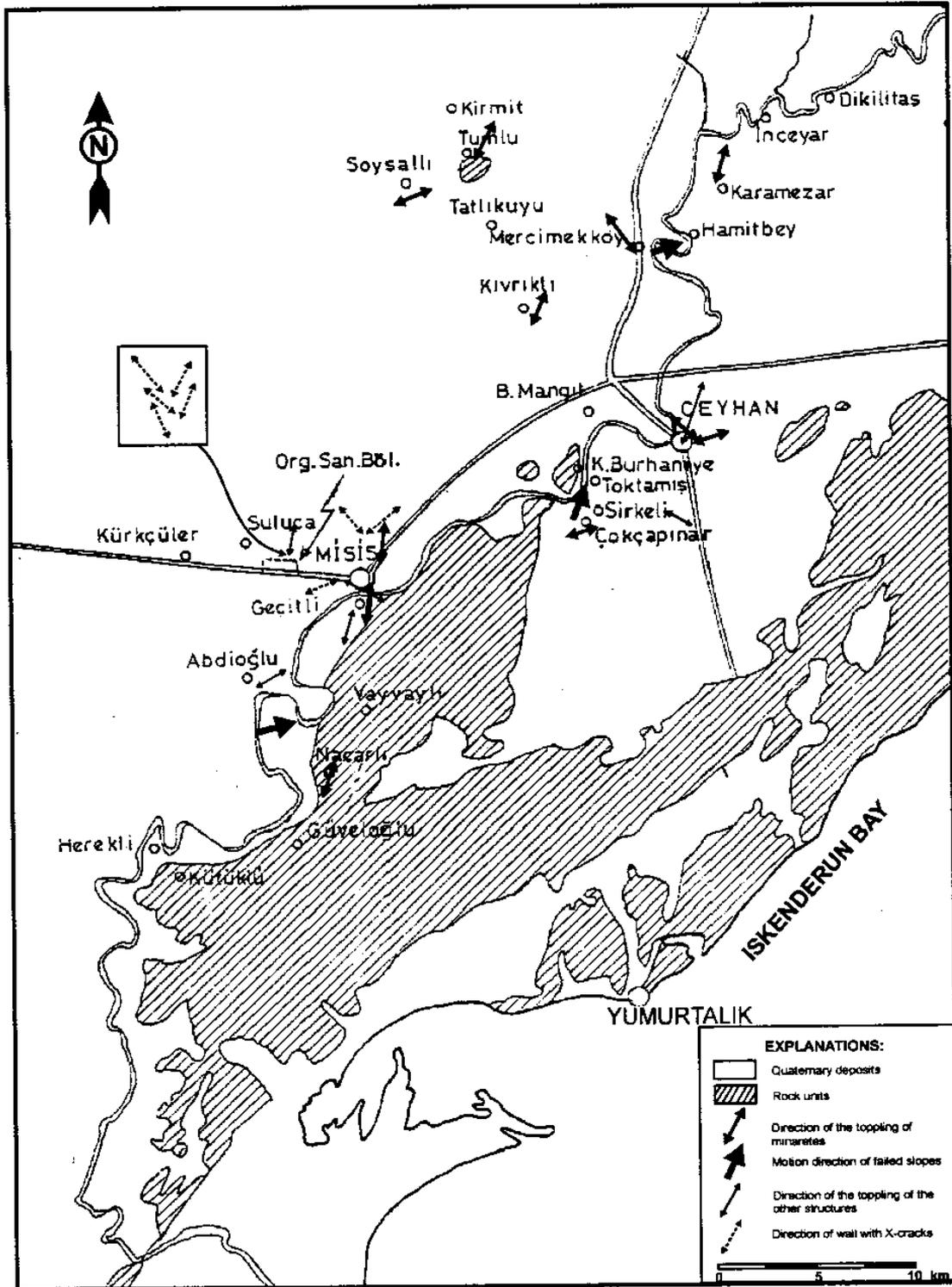


Figure 7.52 Spatial distribution of collapse directions of some structures