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The Adana-Ceyhan Earthquake of June 27, 1998

**Report on the Reconnaissance Mission from July 6 - 12, 1998
of the Swiss Society of Earthquake Engineering and
Structural Dynamics (SGEB)**

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2 Introduction

2.1 General

On June 27, 1998 at 16.55 local time (13.55 GMT), a strong earthquake of magnitude $m_b=5,9$ resp. $M_w=6,3$ shook southern Turkey. The epicenter was located between the cities of Adana and Ceyhan about 30 km north of the coast of the Mediterranean Sea (Fig. 1). About 150 people were killed, 1500 were injured and many thousands were made homeless. Most of the observed damage occurred in traditional rural buildings, but many new multi-story residential buildings and industrial buildings also suffered heavy damage or even collapsed. The maximum intensity of the earthquake was estimated to reach IX on the EMS-scale.

The Swiss Society of Earthquake Engineering and Structural Dynamics (SGEB) decided to send a Swiss Reconnaissance Mission to the earthquake area. The reconnaissance team consisted of:

Thomas Wenk, dipl. Bau-Ing. ETH, Institute of Structural Engineering (IBK), Swiss Federal Institute of Technology (ETH), CH - 8093 Zurich, Team leader,

Dr. Corinne Lacave, Seismologist, Résonance Ingénieurs-Conseils SA, CH - 1217 Carouge (Geneva),

Kaspar Peter, dipl. Kult.-Ing. ETH, Institute of Structural Engineering (ISS), Swiss Federal Institute of Technology (EPFL), CH - 1015 Lausanne.

This report summarizes the observations and measurements made during the Swiss Reconnaissance Mission and makes recommendations based on the assessment of the collected data suggesting how the seismic risk could be mitigated in the future.

2.2 Objectives of Reconnaissance Mission

The objectives of the Swiss Reconnaissance Mission were:

- Assessment of local seismic hazard within selected areas
- Assessment of the vulnerability of structures within selected areas
- Recommendations for seismic risk mitigation
- Awareness of government agencies and the general public to seismic risk and the benefits of modern earthquake-resistant design
- Further the education of seismic experts.

2.3 Mission Schedule

- 6.7.98 Flight to Istanbul. Meeting with Prof. Dr. M. O. Altan, Prof. Dr. Melike Altan, and Prof. Dr. M. Aydogan, Faculty of Civil Engineering, Istanbul Technical University, Istanbul.
Arrival in Adana, Turkey.
Meeting with the members of the German Task Force (M. Raschke, F. Wuttke, Weimar) at the Adana airport together with Prof. M.O. Altan, Prof. M. Altan, and Prof. Aydogan.
- 7.7.98 Visit of the Ministry of Public Works and Settlement in Adana. Meeting with Mr. Recep Kalen, Regional Director of the Ministry of Public Works and Settlement, Adana, Mr. Oktay Ergünay, General Director of the General Directorate of Disaster Affairs, Ankara, Mr. Rüchan Yilmaz, Director of the Earthquake Research Department of the General Direc-

torate of Disaster Affairs, Ankara.

Visit of major damaged areas in Abdioglu, Yakapinar, Misis, Suluca, and Ceyhan under the guidance of Prof. M.O. Altan, Prof. M. Altan, and Prof. Aydogan.

- 8.7.98 Meeting with Mr. Rüchan Yilmaz, Director of the Earthquake Research Department at the Ministry of Public Works and Settlement, to select the target areas for the installation of the three strong-motion instruments of the Swiss Reconnaissance Mission.

Installation of two strong-motion instruments in Ceyhan and Suluca with the support from Mrs. Tülay Ugras and Mr. Gökhan Gebi, both from the Earthquake Research Department at the Ministry of Public Works and Settlement, Ankara.

- 9.7.98 Visit of the Stock Exchange building in Adana with Prof. M. Altan.

Installation of a third strong-motion instrument in Suluca (rock site). Nakamura measurements and building damage assessment in the selected areas.

- 10.7.98 Continuation of Nakamura measurements and building damage assessment in the selected areas. Visit of the southern rural areas (Yumurtalik, Kaldirim) for Nakamura measurements.

- 11.7.98 Retrieval of the three strong-motion instruments. Observation of damage in Adana.

- 12.7.98 Return flight to Switzerland

2.4 Acknowledgments

The Reconnaissance Mission was financially supported by the Swiss Disaster Relief Unit and the Swiss Federal Institutes of Technology of Lausanne and Zurich. The authors gratefully acknowledge this support.

Dr. M.G. Koller, President of the Swiss Society for Earthquake Engineering and Structural Dynamics, organized the Reconnaissance Mission in collaboration with B. Künzi, Dr. J. Studer and S. Tiniç.

The authors would like to thank Geosys AG, Glattbrugg, Zurich, for the strong motion recording instruments, and Résonance SA, Carouge, Geneva, for the micro-tremor recording equipment.

Special acknowledgments and thanks are due to Prof. M.O. Altan, Prof. M. Altan, and Prof. M. Aydogan, Istanbul Technical University, and to R. Yilmaz, T. Ugras, G. Gebi, Earthquake Research Department, Ankara, who provided valuable support and advice during this mission.

The critical review of the report by J.A. Branco, Branco & Zroka Engineering, Chicago, is gratefully acknowledged.

3 Seismological Aspects

3.1 Introduction

The earthquake parameters of the main shock on June 27, 1998 provided by the Earthquake Research Department of Ankara (ERD) indicated a strike slip earthquake along a 65 degree SE dipping fault plane. The epicenter was located approximately 30 km southeast of Adana at a depth of 23 km. Fig. 1 shows a map with the location of the epicenter and surrounding area. A strong motion acceleration recording of the main shock was made by ERD in the local branch building of the Agricultural Ministry in Ceyhan located approximately 35 km from the epicenter, as shown in Fig. 2. The peak horizontal ground acceleration was 274 mg. Astonishingly, the building experienced only minor damage (Fig. 3).

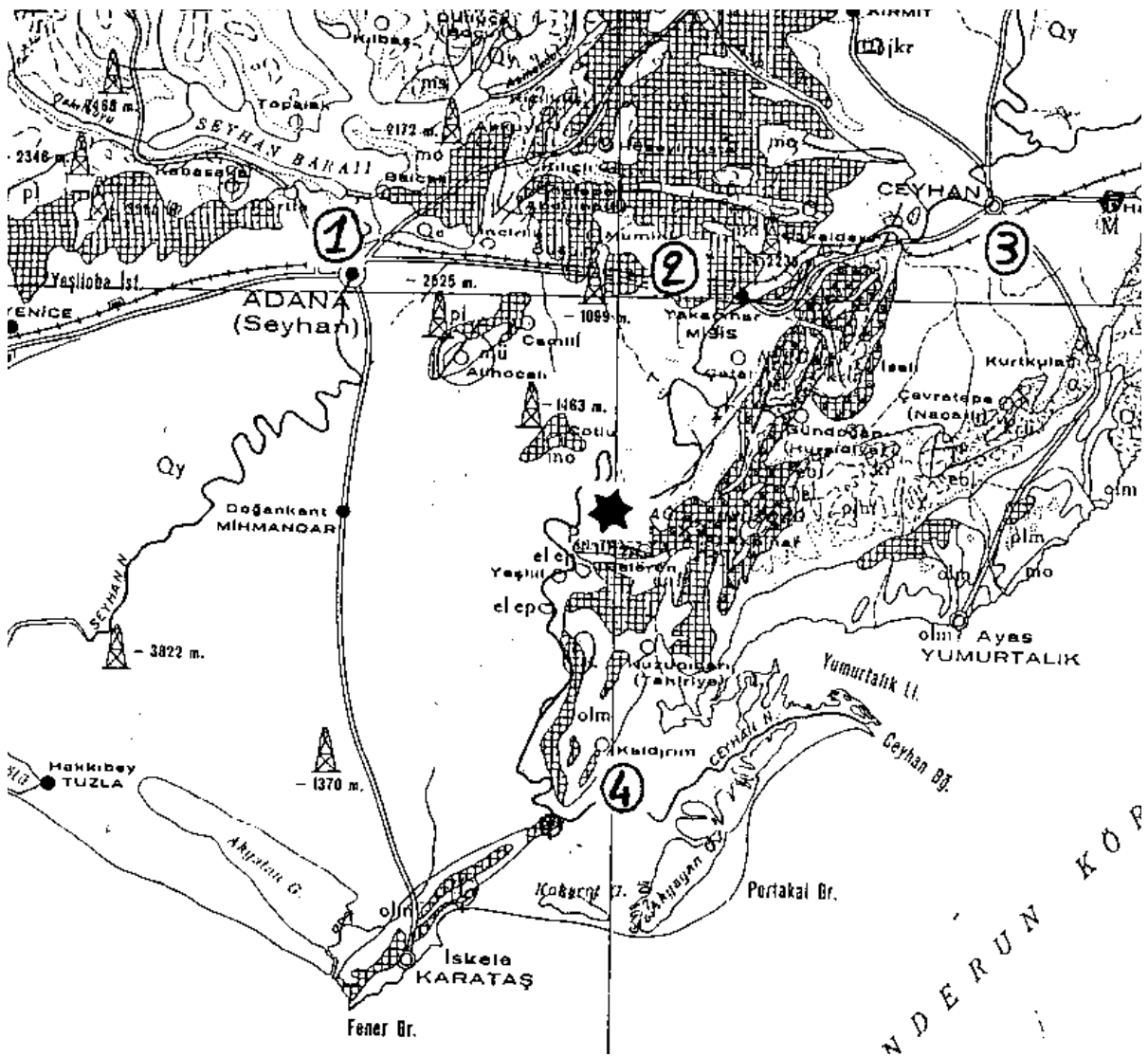


Fig. 1 Geological map of the Adana basin. Qy indicates quaternary deposits and the squared areas are travertine formations. The star identifies the location of the epicenter determined by ERD The map also shows the following four zones where Nakamura measurements were made: 1) Adana - 2 sites; 2) Adana Hacı Sabancı Industrial Park - 4 sites; 3) Ceyhan - 8 sites; and 4) Kaldırım - 1 site

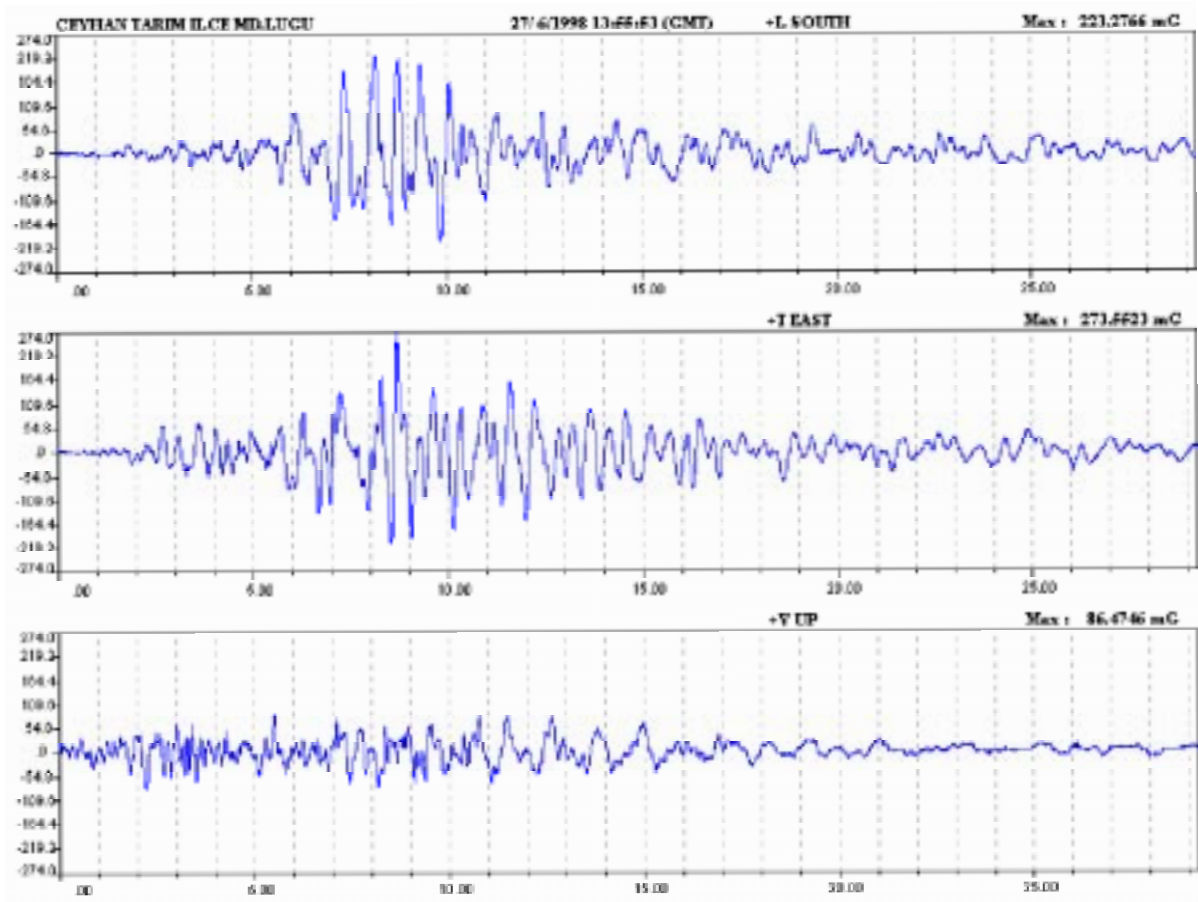


Fig. 2 Acceleration recording of the main shock by a strong motion station located in the local branch building of the Agricultural Ministry in Ceyhan (ERD 1998)



Fig. 3 Front view (left) and roof view (right) of the local branch building of the Agricultural Ministry in Ceyhan (damage grade 1)

3.2 Objectives and Methodology

3.2.1 Site Effect Investigations

The main objective of the mission from a seismological aspect was to determine whether or not site effects, characterized by local amplification of the ground motion due to sub-soil conditions, play an important role in the Adana region. Particularly, our interest was focused on a possible correlation between measured site effects and observed damage. To achieve this goal, the following instruments were used: three Geosys GSR-16 recorders with strong motion acceleration sensors and a very sensitive Lennartz LE-3D/5s sensor, connected to a Geosys GCR-16 recorder for micro-tremor measurements (Nakamura method).

3.2.2 Selection of the Sites

Based on a preliminary damage assessment of the area and in collaboration with Mr. R. Yilmaz, Director of the Earthquake Research Department of the General Directorate of Disaster Affairs, Ankara, two main zones for the site studies were selected:

- The southeast district of Ceyhan (Cumhuriyet Mahallesi district shown in detail in Fig. 33 and located in zone 3 of Fig. 1) was selected because most of the severe damage was observed here and a significant portion of the district is now under construction.
- The Adana Haci Sabanci Industrial Park (located between Adana and Ceyhan in zone 2 of Fig. 1) was selected because it is a main economic center in the region and substantial damage was also observed. Many damaged factories were closed for long periods of time, resulting in major loss of production.

3.2.3 Classical Spectral Ratio Technique

The classical spectral ratio technique is commonly used for site effect investigations. It consists of recording earthquakes as aftershocks at soft sediment sites, where site effects might be expected, and simultaneously at a reference rock site. Fourier amplitude spectra are then computed for each component of motion at each site. Finally, the spectral ratio between one site of interest and the reference site is calculated for each component. This ratio corresponds to the transfer function of the site, and it indicates the resonance frequency of the soil and the level of amplification.

3.2.4 Nakamura Method

The indication of the fundamental resonance frequency of a site is of great interest for microzonation studies. The aim of such studies is to obtain detailed information about the local soil amplification. Previous studies have shown that the Nakamura method gives a reliable indication of the fundamental resonance frequency of the soil (Nakamura 1989). Only a qualitative and relative indication of the amplification level is obtained by the Nakamura method. Experimental results have shown that the amplitude obtained tends to be a lower bound estimate of the actual linear amplification level at a site. Practically, the Nakamura method consists of ambient noise recordings and subsequent calculation of the horizontal to vertical spectral ratio (H/V ratio) for each site. A very sensitive sensor connected to a recorder is necessary to record micro-tremors. Measurements at a total of 15 sites were conducted in the studied areas. These sites were located in the four zones shown on the map in Fig. 1: Adana (2 sites); Adana Haci Sabanci Industrial Park (4 sites); Ceyhan (8 sites); and Kaldirim (1 site). At each site, 10 recordings of one minute each were taken to calculate 10 separate H/V ratios, which were then averaged in order to get a H/V ratio curve for each site with the corresponding standard deviation.

3.3 Geological Context

The area of Adana is characterized by a very large alluvial basin with a delta shape, which extends more than 100 km east-west and approximately 70 km north-south. Most of this basin is filled with quaternary recent Holocene deposits. In the southeast part of the basin, some limestone formations from the Miocene, Oligocene and Eocene Ages are visible at the surface. In the northern part of the basin, between Adana and Ceyhan, outcrops of travertine formations were also visible. The following sites were considered:

- Adana and Ceyhan on quaternary deposits
- Adana Haci Sabanci Industrial Park on travertine and quaternary deposits.

Fig. 1 shows a part of the geological map covering the studied area. The main fault is oriented in the north-east direction, which is consistent with the focal mechanism proposed by the ERD (strike N207).

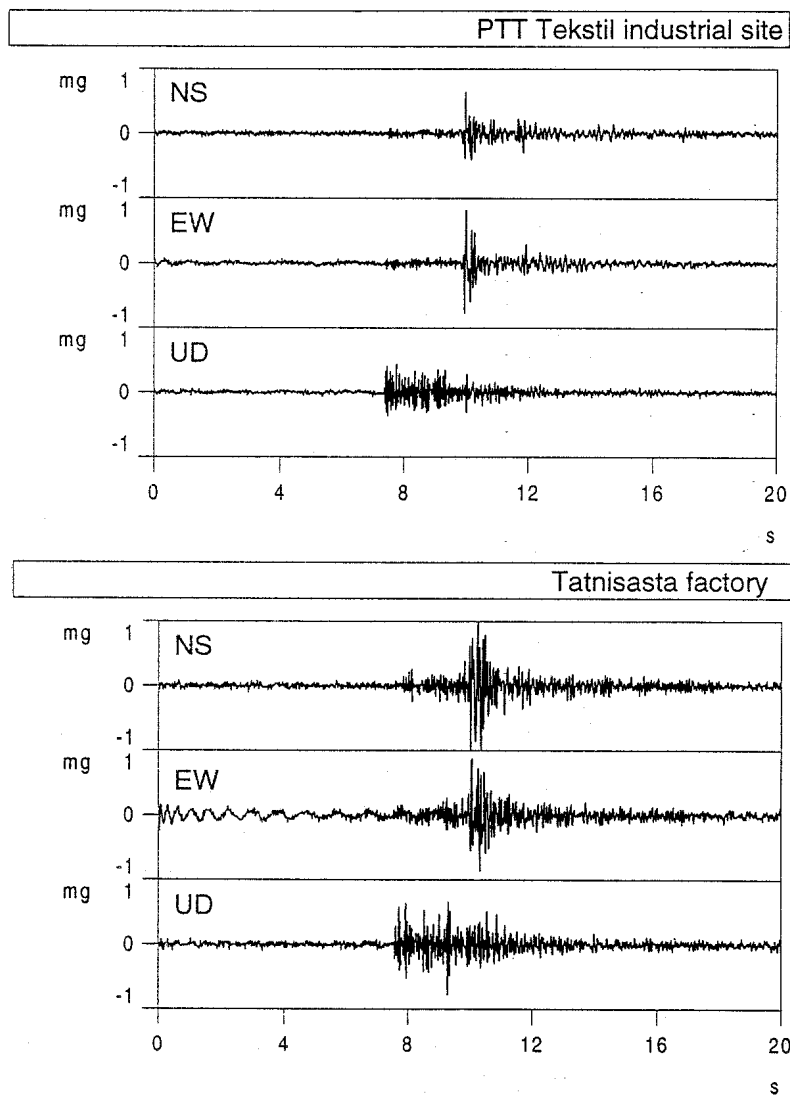


Fig. 4 Acceleration recordings of the three components of motion of July 9, 13:38 GMT aftershock at station PT (PTT building and station TA (Tatnisasta factory) both in the Industrial Park

3.4 Recording of Aftershocks

The three Geosys GSR-16 recorders with strong motion acceleration sensors were installed at the selected sites. The first station was installed in an undamaged technical school building in the south of the Cumhuriyet Mahallesi district of Ceyhan (Fig. 21). The second station (site PT) was installed in the Post Office building of the Industrial Park close to a main administration building, which suffered significant damage. The third station served as the reference station and needed to be installed on a rock site. The hills located south-east of Ceyhan would have been the preferred rock site, but due to the need for electrical power supply, the instrument needed to be installed in a building. Unfortunately, all the buildings on the hills were located in operating quarries, which were very noisy environments. Therefore, the third site was located in one of the buildings founded on travertine within the Industrial Park (Tatnisasta factory, site TA).

Two days were required to install the three stations due to the need for electrical power. In addition, the post-earthquake seismic activity decreased exceptionally fast after the main shock. Consequently, only very few aftershocks with small magnitudes (2-3) occurred during the operational time. This differs with the post-seismic activity after comparable events (e.g., the Egridir, Greece, earthquake in 1995, where hundreds of aftershocks still occurred 15 days after the main shock). Initial trigger level settings of the recording instruments were too high and needed to be lowered after the first day without making any recordings. In the end, only one event was recorded at sites PT and TA: an aftershock on July 9 at 13:38 GMT. Fig. 4 shows the three components of motion (NS, EW and UD) of the acceleration recordings at both sites.

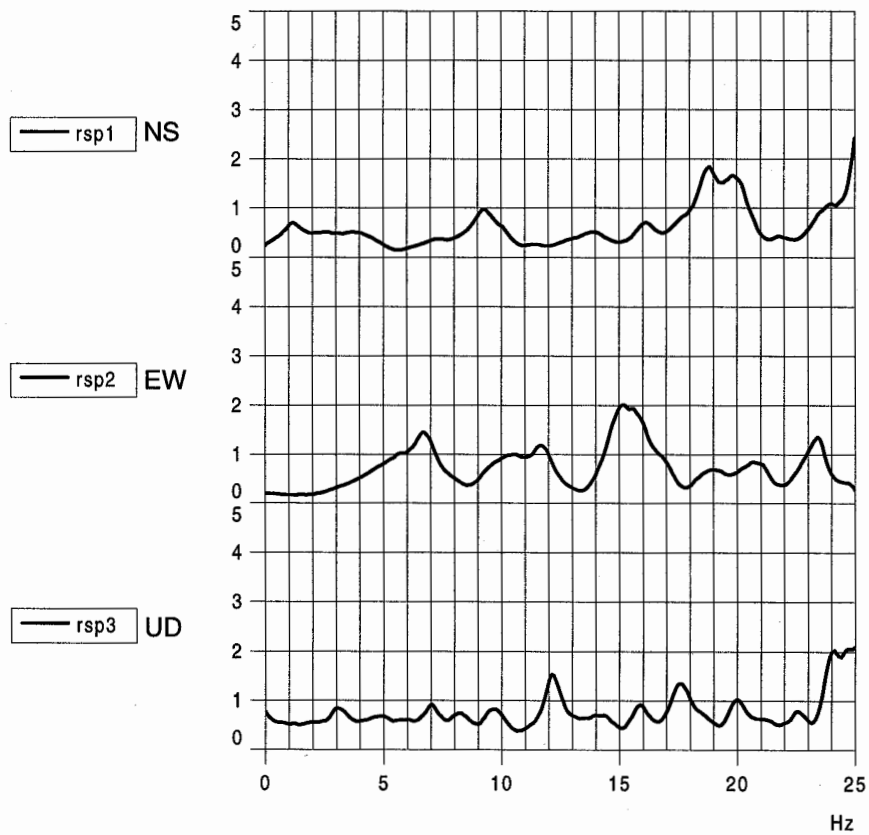


Fig. 5 Spectral ratios between station PT (PTT building) and station TA (Tatnisasta factory, reference site) for the three components of motion

3.5 Results of the Site Effect Study

3.5.1 Adana Hacı Sabancı Industrial Park

Classical Spectral Ratios

Using the recordings of the aftershock of July 9, 13:38 GMT, the spectral ratios between sites PT (PTT building) and TA (Tatnisasta factory) were calculated. Fig. 5 shows the spectral ratios for the three components of motion. No pronounced amplification can be observed. Spectral ratios remain around 1.0 or even a de-amplification occurred. This tends to indicate that site PT is built on the same type of soil (travertine) as the reference site TA. The sub-soil conditions were not clearly visible at site PT. As a consequence, the observed damage at sites PT and TA cannot be attributed to site effects, but rather to the relative proximity to the epicentral area (around 25 km) or specific building characteristics.

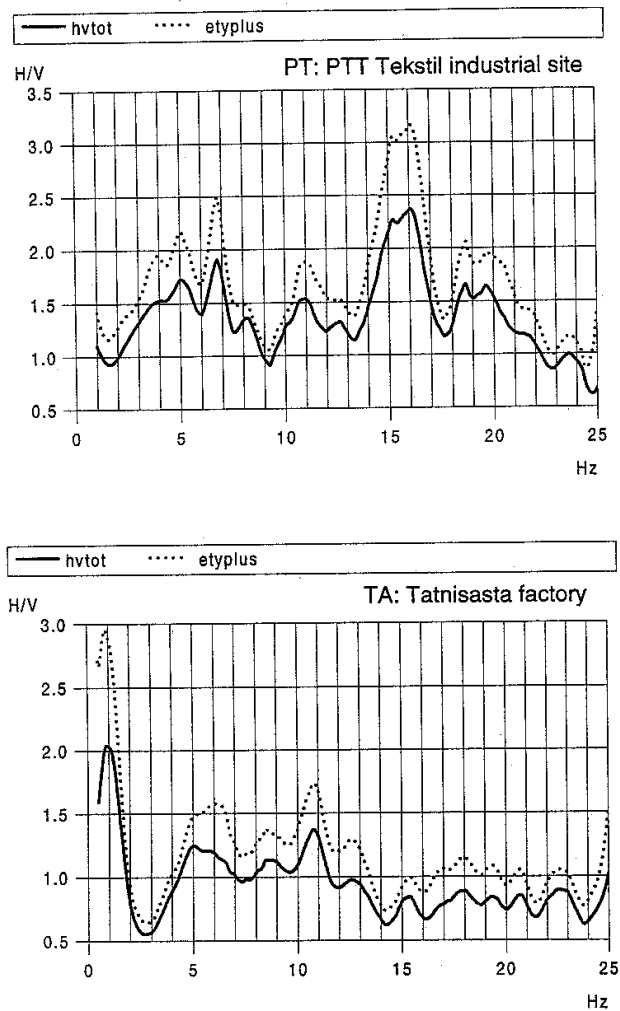


Fig. 6 Average noise H/V ratios (solid line) and average plus one standard deviation (dotted line) for sites PT and TA

H/V Ratios

Ambient noise measurements according to the Nakamura method were made at the same sites (PT and TA) to compare results with the classical spectral ratio method. Fig. 6 shows the H/V ratios obtained for the two sites. Again, no pronounced amplification can be detected. The amplitude of the H/V ratios remains near 1.0 for the entire frequency band considered. Within the Industrial Park, ambient noise measurements were recorded at other locations where damage was observed. Presented in Fig. 7 are the results for the Onur Tekstil and the Bossa Denim factories. In contrast to the sites TA and PT, a clear amplification at 0.7 Hz can be observed for site Onur and in the frequency band of 0.7 to 4 Hz for site Bossa Denim, which suffered considerable damage. The peak amplitudes of the H/V ratio were very high (around 6 to 10), indicating that site effects are particularly pronounced at these sites. Other nearby sites located at distances of less than 1 km showed virtually no site effects. The reason why the amplitudes of site effects were rather different between neighboring sites is that travertine and soft sediments alternately reach the surface (see geological map in Fig. 1).

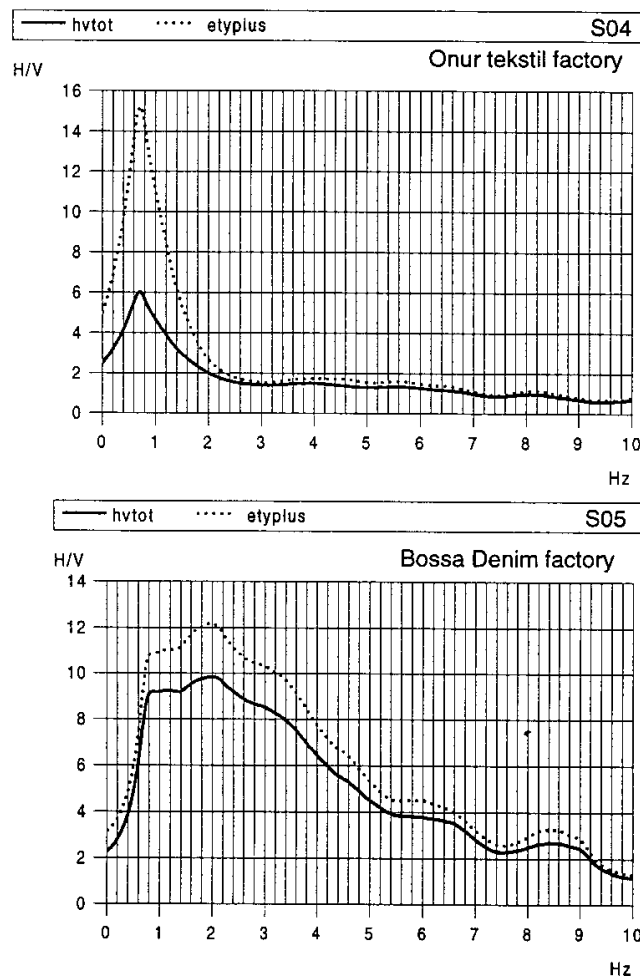


Fig. 7 Average noise H/V ratios (solid line) and average plus one standard deviation (dotted line) for sites Onur Tekstil and Bossa Denim in the Industrial Park

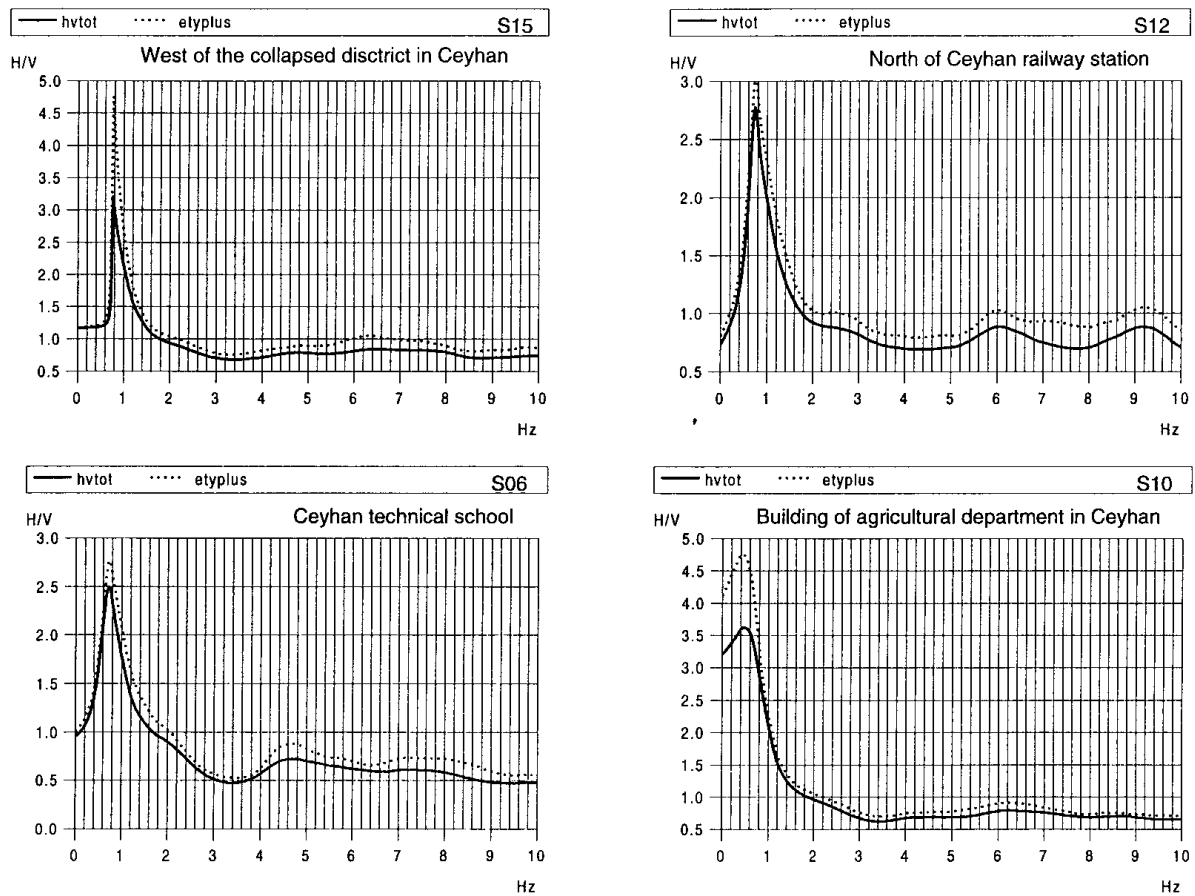


Fig. 8 Average noise H/V ratios (solid line) and average plus one standard deviation (dotted line) for four sites in Ceyhan

3.5.2 Ceyhan

The second major zone of investigations was the city of Ceyhan. Nakamura measurements were made at eight sites, of which some were taken in the southeast district of Ceyhan (Cumhuriyet Mahallesi) where the detailed damage evaluation was conducted (see Section 5). For all sites, similar results showing a clear amplification peak at 0.7-0.8 Hz were obtained (Fig. 8) indicating this area is built on homogeneous soil conditions (quaternary deposits as shown on the geological map). This frequency of 0.7-0.8 Hz can probably be attributed to the fundamental resonance of the whole sedimentary basin.

3.5.3 Adana

Further ambient noise measurements were taken at two sites in Adana. The first measurement was made at the Hotel Takav, 86 Baraj yolu, and the second at the Stock Exchange Building on Ataturk Road. The H/V ratios for these two sites are contained in Fig. 9. A first peak at 0.7 Hz as well as another amplification in the frequency band 4 to 8 Hz can be seen for both locations. These preliminary results indicate that site effects can be expected in Adana.

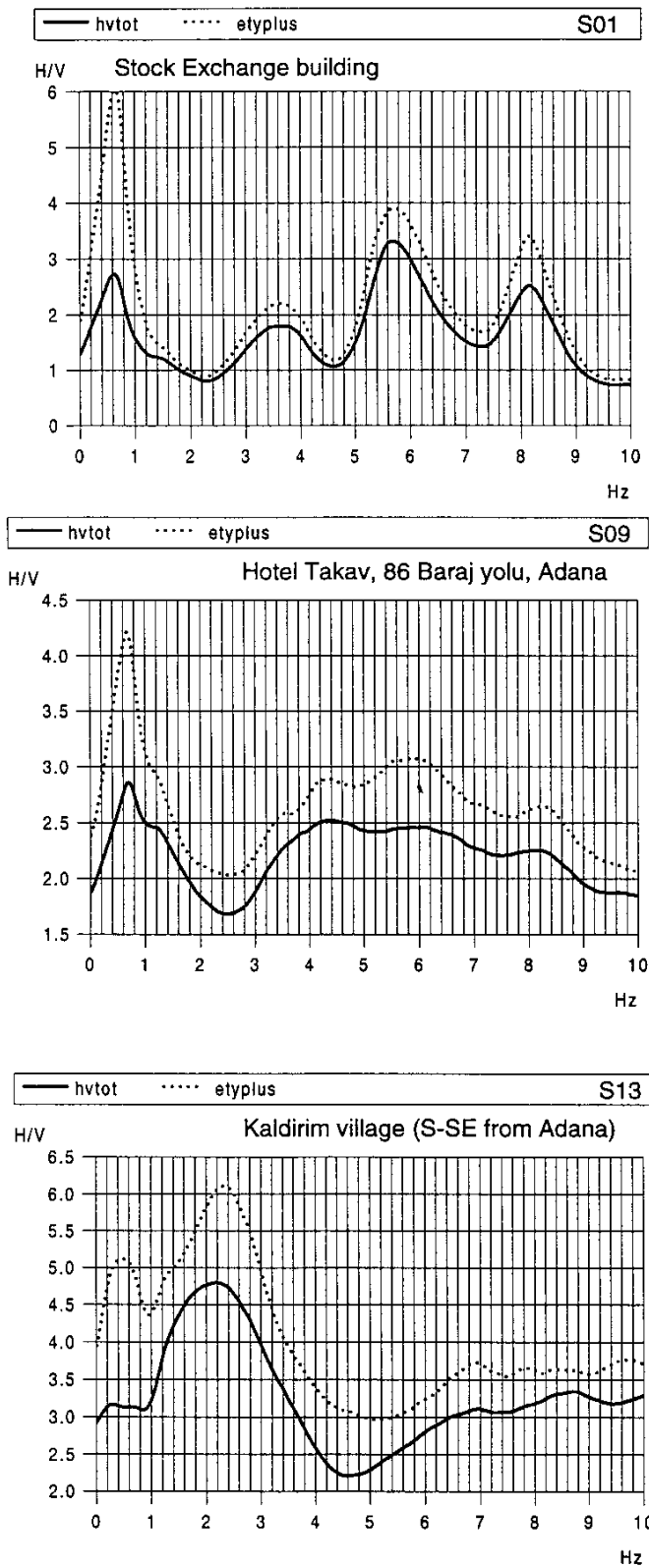


Fig. 9 Average noise H/V ratios (solid line) and average plus one standard deviation (dotted line) for sites at the Stock Exchange Building in Adana, at the Hotel Takav in Adana, and in Kaldirim

3.5.4 Kaldirim

Finally, one site located in the southern part of the Adana basin, near the village of Kaldirim, was measured. The fundamental frequency obtained at this site is around 2 Hz and is shown in Fig. 9. For a simple basin structure with increasing depth of the deposits towards the coast, a resonance frequency below 0.7 Hz would be expected for the Kaldirim site. The measured fundamental frequency of 2 Hz indicates that the basin structure is more complex and a correlation with geological profiles should be investigated.

3.6 Evidence of Soil Deformation

3.6.1 Soil Liquefaction

Clear liquefaction traces along the banks of the Ceyhan River were observed west of Ceyhan. This phenomenon is due to the presence of fine-grained alluviums, that liquefied during the main shock, leading to the formation of sand boils in the nearby fields. Fig. 10 presents a picture of one of these cracks, about 10 meters long, through which very thin sandy alluvium particles were pushed up in the plantation fields. This phenomenon is a clear indicator of strong non-linear effects that occurred in this region. Such effects can significantly reduce the peak ground acceleration and should be considered in seismic hazard assessment.



Fig. 10 Sand boils due to soil liquefaction along the Ceyhan River banks, west of Ceyhan

3.6.2 Landslide

Small landslides, another important soil deformation phenomenon, were observed along the Ceyhan River. Part of a lemon tree plantation, located on the river bank, slid towards the river, as shown in Fig. 11. A vertical subsidence of 2 to 3 m and a horizontal displacement of about 1 to 2 m towards the river were observed. The landslide occurred in recent soft alluvial deposits. These observations confirm the general experience that a very specific soil behavior can be expected particularly in fine-grained recent alluvium deposits, such as river banks.



Fig. 11 Landslide in lemon tree plantation on the Ceyhan River bank, southwest of Ceyhan

4 Description of Building Damage

Typical damage patterns of various building categories are described in this section. The description is limited to a few selected buildings which are discussed as representative examples. The design of these buildings is critically reviewed from the aspect of modern earthquake engineering, and possible failure mechanisms under seismic action are explained.

4.1 Residential and Commercial Buildings

4.1.1 Typical Damage to Residential and Commercial Buildings



Fig. 12 Typical damage to masonry infills in the form of X-cracks (damage grade 3)

Most of the residential and commercial buildings in the Adana Province were constructed during the last few decades. Practically all these buildings have a structural system of reinforced concrete frames with masonry infill walls. The columns form a rectangular pattern with a bay width of 3 to 4 m in both directions. The columns have a wall-like rectangular cross section of 0.30 to 0.40 m width and 0.80 to 1.10 m length. A detailed description of a typical residential building is given in Section 5.4. The European Macroseismic Scale of 1992 (EMS-92) and its revision of 1998 (EMS-98) was used to rate the extent of building damage (Grünthal 1993 and 1998). Its damage scale consists of five damage grades. Damage grade 1 corresponds to negligible to slight damage, damage grade 5 to the collapse of entire building parts.

Fig. 12 shows large X-cracks in the masonry infills of a residential building in Ceyhan. In Fig. 13, also a residential building in Ceyhan, the damage is less severe. The cracks follow the joints between the masonry infills and the reinforced concrete frame. This is an indication for the incompatible horizontal deformation behavior of the two building elements.



Fig. 13 Cracks between the reinforced concrete frame and the masonry infills showing the incompatible deformation behavior of the two elements (damage grade 2)



Fig. 14 Total destruction of the masonry infills by large differences between the horizontal displacements of top and bottom slabs (left), detail view of the upper part of the reinforced concrete column (right), (damage grade 3)

The larger the interstory drifts are (i.e., the difference between the horizontal displacement of the upper and the lower slab), the more the masonry infills are damaged, sometimes up to total collapse, as shown in Fig. 14. In this example, the frame columns of reinforced concrete are damaged substantially, while no damage of the slabs was observed.

The typical damage pattern is a consequence of the construction type. The load carrying frame is relatively soft under horizontal seismic action. In contrast, the in-plane loaded masonry infills are up to brittle rupture stiffer than the frame. As a consequence, the deformation behavior of the two elements is not compatible. During the first small excitation cycles of the building, the masonry infills take a relatively high amount of the actions, which often exceeds their resistance and leads to diagonal cracks due to shear failure. Due to the reversal of loading, the shear cracks develop in both directions forming an X (see Fig. 12). No failures due to out-of-plane loading of masonry infills were observed in this type residential building.



Fig. 15 Shear damage to a wall-like frame column in the ground floor of an eight-story building (damage grade 3)



Fig. 16 With few exceptions only the damage is found in the ground floor or in the ground floor and the second floor (damage grade 2)



Fig. 17 Partially collapsed residential buildings in the Cumhuriyet Mahallesi district of Ceyhan; one residential building shows a partially collapsed ground floor while the upper floors remained relatively stable (damage grade 4)

The frame columns were damaged by shear action. Fig. 15 shows a wall-like column with serious shear damage in the ground floor of an eight-story building.

With few exceptions, most of the damage observed in all inspected buildings was concentrated in the ground floor, or in the ground and the second floor (see Fig. 16). Inspected buildings with a damage grade of 4 or 5 showed relatively intact upper stories while often the ground floor was totally destroyed (Fig. 17 and Fig. 19). Explanations for this typical pattern of damage localization in the ground floor are given in Section 5.2.3.



Fig. 18 This building seems nearly undamaged from the outside (left), while the partition walls inside are completely destroyed (damage grade 3)

Often the building damage is not visible from the outside. Such a building is shown in Fig. 18. From the outside, the building seems to be only slightly damaged, while inside several partition walls were totally destroyed. Cracks in other partition walls show that the structural system experienced considerable remaining deformations.

4.1.2 Two Adjacent Residential Buildings with Very Different Damage

Fig. 19 shows two adjacent residential buildings in the Ceyhan suburbs with very different damage. The ground floor of the building on the left side has completely collapsed (damage grade 5). The damage to the building on the right side was limited to some shear cracks in structural reinforced concrete walls and damage to nonstructural masonry infills (damage grade 3). The two buildings have a lot of similarities: both buildings have six stories, are about the same age, have similar configurations in plan, and have similar facades. It can be assumed that the structural system of both buildings is similar, however their longitudinal axes are perpendicular to each other (Fig. 19). The completely different seismic response of the two buildings may be explained either by directional effects of the ground motion or by different configurations of the masonry infill walls in the first story. The addition or elimination of infills may have resulted in an irregular stiffness distribution with the consequence of localized overloading of certain reinforced concrete columns.



Fig. 19 Two adjacent similar buildings with very different damage pattern. The building on the left totally collapsed in the ground floor (damage grade 5) while the building on the right has slightly to moderately damaged structural walls and masonry infills (damage grade 3)

4.1.3 Reinforced Concrete Frame Buildings in Adana

In Adana, the observed damage to reinforced concrete buildings were significantly less than in Ceyhan. This observation may be explained by the larger distance between Adana and the fault line. Damage was usually limited to cracks in masonry infills. As a typical example, the TV-room of the Hotel Takav in Adana is shown in Fig. 20. While the masonry infill walls cracked (damage grade 1), the reinforced concrete column next to the TV suffered no visible damage.



Fig. 20 Damaged masonry infill in the second story of Hotel Takav, a reinforced concrete frame building in Adana (damage grade 1)

4.2 School Buildings

Modern seismic building codes provide a higher level of protection for important buildings. One category of these important buildings are buildings with high public occupancy like schools, theaters, stadiums, etc. The Turkish seismic code implements this philosophy by an importance factor of 1.4 for schools (IAEE 1996), (ERD 1975), (ERD 1996). Two schools in Ceyhan were inspected as examples for the seismic behavior of important buildings.

A new four-story school building (Fig. 21), built in 1996, is located at the south end of Ceyhan in the district Cumhuriyet Mahallesi where reinforced concrete buildings, only a block away, suffered very



Fig. 21 Undamaged new technical school building in the Cumhuriyet Mahallesi district of Ceyhan

heavy damage including collapse (Fig. 33). The school building consists of a reinforced concrete frame with masonry infill walls. The columns were connected by deep beams in contrast to the residential buildings where the beams were, in general, integrated in the slab (see Section 5.4). The cross sections of the columns in the school buildings were also larger even though the bay width was about the same as in the residential buildings. The infill walls had smaller openings. No damage to the reinforced concrete elements nor to the infills could be found in the school building (Fig. 21). The seismic performance of this school building was excellent.

The second school, consisting of three separate buildings, is situated about 1 km west of Ceyhan (Fig. 22). The buildings were constructed about five years ago in a manner similar to the residential buildings, with comparable cross sections and span width. Two of the buildings have three stories and the third has four stories. The two three-story buildings suffered substantial damage (grade 3) and the four-story building moderate damage (grade 2). The columns of one three-story building suffered



Fig. 22 School buildings west of Ceyhan with damage of grade 2 to 3



Fig. 23 School buildings west of Ceyhan: Reconstruction of a destroyed masonry infill wall

substantial damage. This building was initially constructed as two stories; the third story was later added. The other three-story building suffered only slight structural damage, but several infill walls were totally destroyed. The remaining lower part of the masonry infill in Fig. 23 has the shape of a triangle formed by diagonal shear cracks. The reinforced concrete beam can be seen above the location of the missing infill wall; the beam and the columns seem to have performed well during the earthquake. As seen in Fig. 23, the reconstruction of the unreinforced infill wall is already under way in the same unsatisfactory manner as previously constructed.

4.3 Industrial Buildings

This section describes the damage of different administrative and industrial buildings in the Adana Haci Sabanci Industrial Park between Adana and Ceyhan. Typically, the administrative buildings were two stories high and constructed as reinforced concrete frames with masonry infills. In the administrative buildings, damage up to grade 3 was observed. A few factory buildings partially collapsed thereby destroying machinery (damage grade 4, see Fig. 27).



Fig. 24 Typical industrial buildings under construction showing precast reinforced concrete pin-connected frames

Factories and warehouses were often built of precast reinforced concrete elements. The columns were fixed at the foundation and the beam-to-column connections were pinned, as shown in Fig. 24. The span width varied between 15 to 25 m. Metal sheeting formed the roof. The side walls were made of masonry infills or metal sheeting.

The workmanship and the material quality of the precast reinforced concrete elements were significantly improved over those of the residential buildings. Schmidt-Hammer measurements of the concrete elements yielded a mean value for the compressive strength of $f_{cwm} = 60 \text{ N/mm}^2$. The yield strength of the reinforcement steel is assumed to be $f_y = 420 \text{ N/mm}^2$.

One factory building (Onur tekstil) measured 66 m wide and 130 m long. Its roof is carried by a number of three-span frames. Of a total of 45 beams, three fell off their supports and destroyed the equipment



*Fig. 25 Column top of precast pin-connected frame;
the roof beam fell off the left column corbel*

below. Some masonry walls infill a frame and separate different spaces. Between these infills and the columns, cracks of up to 0.10 m in width were observed. Since the infills have squat proportions and remained intact, these cracks represent the large remaining in-plane deformation of the reinforced concrete frames. Out-of-plane deformations of the frames were limited by the masonry infills forming the side walls of the factories.

In several other industrial buildings, the pinned connection of the precast reinforced concrete elements was clearly the weak spot. The roof beams were supported on corbels at the top of the columns (see Fig. 25). Two vertical reinforcement bars were used to center the beam on the corbel. The roof beams either fell off their short support due to differential transverse displacements of the columns (Fig. 27) or tilted over longitudinally due to lack of horizontal bracing in the roof plane (Fig. 25).

4.3.1 Loss of Production

At two industrial sites, roof collapses were observed which destroyed the equipment below and terminated production. The equipment was not only damaged indirectly by collapsed building elements but also directly by the seismic excitation of the ground. In most places, the machinery was in disarray from the earthquake shaking. Spinning machines shown in Fig. 26 even toppled. The loss of production will probably cost much more than the repair of the building damage.

Two weeks after the earthquake, the production in the Onur tekstil company had still not resumed. The repair work of the roof was in progress. In the Bossa Denim company, a relatively small part of the roof collapsed and destroyed one of two dye work production lines completely (Fig. 27). A total repair time of several months is anticipated by the company.

Intensive repair work in the Industrial Park seemed to engage most of the construction workers of the region two weeks after the earthquake. This is most likely the reason why no reconstruction work was observed in the residential districts of Ceyhan. In addition, no activities were seen at new construction sites in Ceyhan.



Fig. 26 Toppled spinning machines caused directly by the earthquake shaking interrupted production for several weeks



Fig. 27 The collapsed roof destroyed one of two dye work production lines (damage grade 4)



Fig. 28 Two story concrete frame building with partial masonry infill (left), detail of shear failure of reinforced concrete column by the short-column effect (right), (damage grade 3)

4.3.2 Short Columns

A carpet company occupied a cast-in-place two-story frame building with masonry infills. The building suffered substantial damage in the first story. All bays of the first floor except one were partially filled with masonry (Fig. 28). The masonry infill completely changed the failure mechanism of the reinforced concrete columns. Instead of forming a more ductile frame mechanism with plastic hinges at beam-to-column connections, the columns experienced a brittle shear failure in the short free length left open above the infill (Fig. 28 on the right). This phenomenon is known as short-column effect. The bay with a complete masonry infill wall over the full height of the columns (shown in the foreground of the left photo in Fig. 28) failed in a different manner. A diagonal crack formed over the full height of the wall.

4.4 Mosques

The mosques in the Adana region were usually made from natural stone masonry. About 60 mosques suffered damage from this earthquake (DMC 1998). In general, the main building of the mosque performed well, but the slender minarets collapsed partially or even completely as shown in Fig. 29. In Gecitli the dome of a mosque collapsed.



Fig. 29 Mosque with collapsed minaret in Ceyhan

4.5 Traditional buildings

4.5.1 Rural Areas

Most rural buildings have one or two stories. Often these buildings are constructed of field stones or adobe masonry. The older, unreinforced masonry buildings are especially vulnerable. They typically belong to vulnerability classes A and B, the most vulnerable building classes according to (Grünthal 1998). Many totally destroyed buildings could be observed in smaller village (see Fig. 30 for an example of rural buildings with damage grade 5). Newer buildings often contain reinforced concrete elements and suffered less damage.

4.5.2 Adana

In Adana, there are districts with older traditional buildings made of fieldstone, adobe or brick masonry. Many of these buildings suffered heavy damage, up to damage grade 5. These buildings may be classified into vulnerability class A or B. They possess significantly lower earthquake resistance than the reinforced concrete buildings in Adana and Ceyhan, which may be classified in vulnerability class C (see Section 5.1). As an example, Fig. 31 shows a completely collapsed older two-story building in the center of Adana (damage grade 5).



Fig. 30 Destroyed rural building made of field stone masonry in the epicentral area near Gecitli (damage grade 5)



Fig. 31 Collapsed older masonry building in the center of Adana (damage grade 5)

5 Damage Evaluation of 65 Buildings in Cumhuriyet Mahallesi District of Ceyhan

A well confined area of 65 buildings was selected to statistically evaluate the extent of damage. The European Macroseismic Scale of 1992 (EMS-92) and its revision of 1998 (EMS-98) was used to rate the building damage (Grünthal 1993 and 1998). The study permitted the determination of the EMS-Intensity of the earthquake and revealed significant characteristics of damage distribution.

5.1 Cumhuriyet Mahallesi District



Fig. 32 View of the Cumhuriyet Mahallesi district of Ceyhan. People are sleeping in tents over night. During the day, they go back to their apartments for cooking and working

The inspected structures are residential buildings of the type described in Section 4.1 and Section 5.4. Only one building, the school shown in Fig. 21, had a different configuration. Most of the residential buildings were built within the last couple of years, some are still under construction. Around the evaluated area, there are many construction sites where residential buildings of the same type are built. In an adjacent district, houses with one to three stories dominate. These buildings suffered only slight or negligible damage (i.e., damage grade 1 or 2) and they are not included in the statistical damage analysis.

A schematic plan view of the evaluated area is given in Fig. 33. The buildings are represented, in general, by rectangular icons and identification number. From a total of 65 buildings, 43 buildings had 5 or 6 stories; 17 buildings had 8 to 10 stories; and 4 buildings had 4 stories or less. Some of the buildings had a basement which reached up to 1 m above the surface.

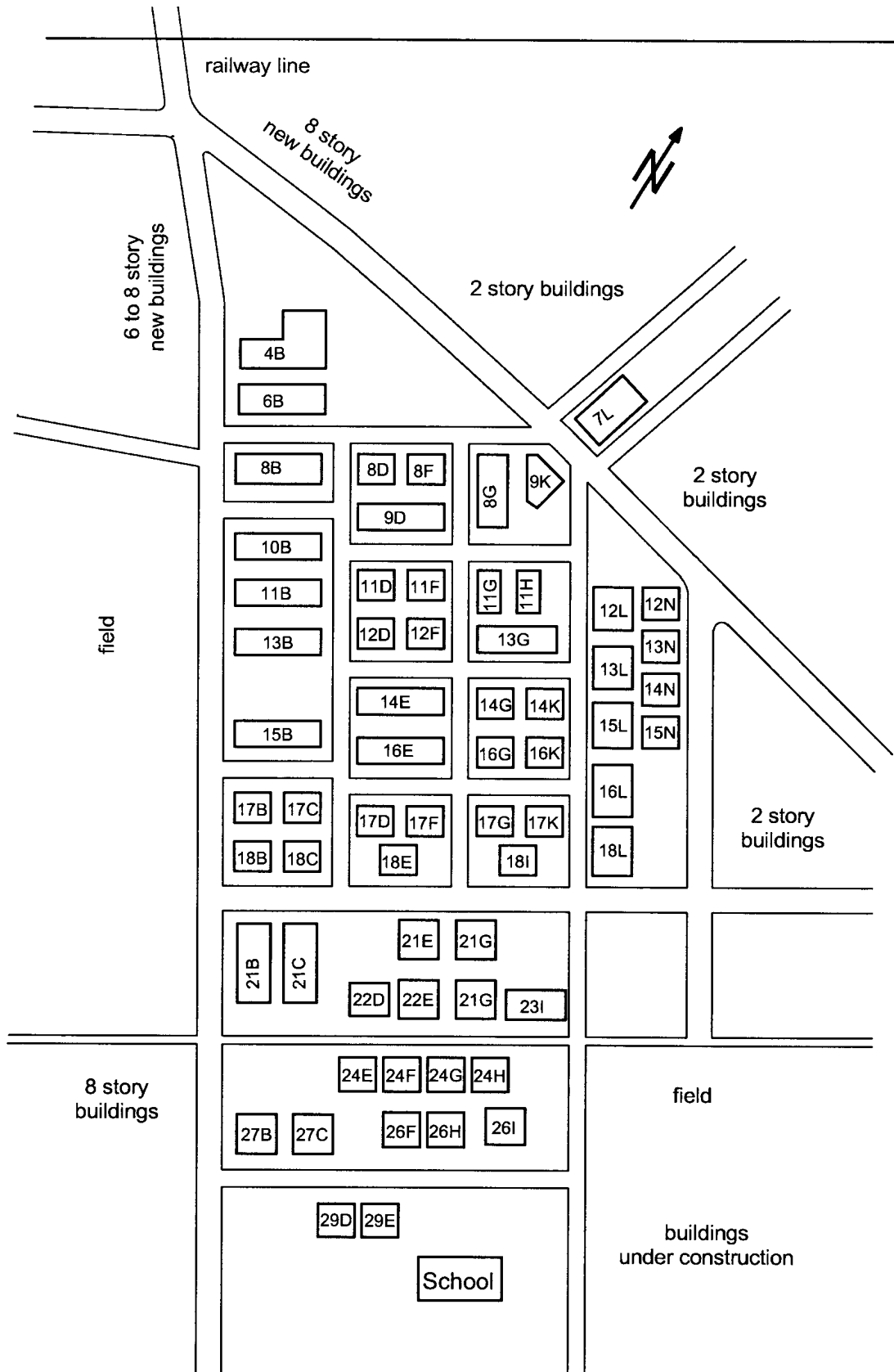


Fig. 33 Schematic plan view of Cumhuriyet Mahallesi district of Ceyhan showing the 65 evaluated buildings

5.2 Damage Grade vs. Number of Stories

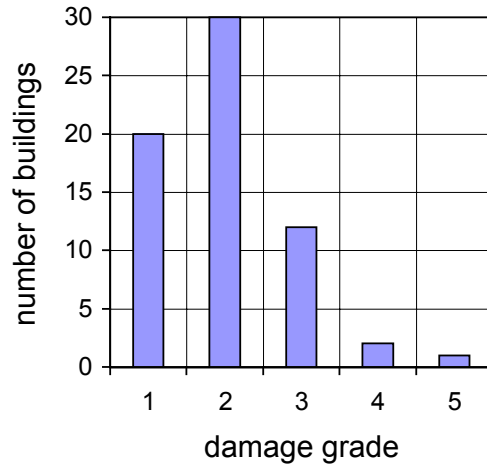


Fig. 34 Number of buildings vs. damage grade of 65 buildings in the Cumhuriyet Mahallesi district of Ceyhan

The damage grade was rated based on the EMS-98 intensity scale. Some examples of the buildings were already discussed in Section 4.1 (e.g., Fig. 19: damage grade 5; Fig. 17: damage grade 4; Fig. 12: damage grade 3; and Fig. 13: damage grade 2). The number of evaluated buildings as a function of the damage grade is shown in Fig. 34. It can be seen that most buildings had only negligible to moderate damage (damage grades 1 and 2). Fewer buildings suffered substantial (damage grade 3) to very heavy damage (damage grade 4) or even collapsed (damage grade 5).

For the graphic of Fig. 35, the buildings were divided into two groups of damage grades:

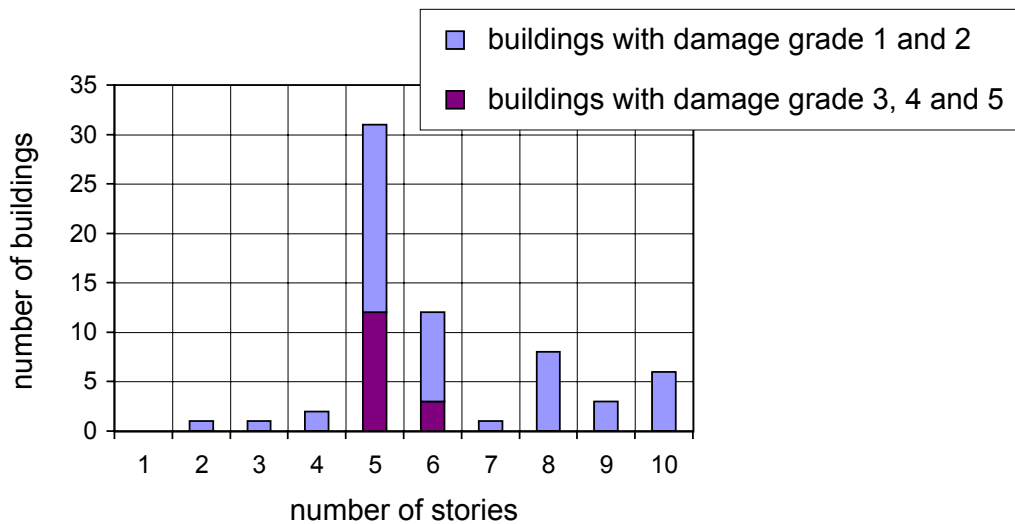


Fig. 35 Number of buildings classified into two groups of damage grades vs. number of stories of 65 buildings in the Cumhuriyet Mahallesi district of Ceyhan

- Buildings with negligible to moderate damage (damage grades 1 and 2),
- Buildings with substantial to very heavy damage or even collapse (damage grades 3, 4, and 5).

As an important result of this evaluation, Fig. 35 shows that all buildings belonging to the higher damage group were five- and six-story buildings. Buildings with less than 5 stories or more than 6 stories only experienced damage grade 1 or 2. If the dominantly two- and three-story buildings of the adjacent district would have been included in the statistic, the conclusion on the damage distribution would be confirmed, because these buildings had only damage grade 1 or 2.

A more detailed presentation of the damage grade statistic is given in Fig. 36. It shows that of the 65 buildings evaluated, buildings with 5 or 6 stories most often suffered damage grade 2 followed by damage grade 3. The buildings with 7 to 10 stories more often had damage grade 1 than damage grade 2; no buildings of 7 to 10 stories experienced damage greater than grade 2. The three buildings with damage grade 4 and 5 were located on the same block, had the same architectural style of the facade, and were probably constructed by the same contractor (buildings 11G, 11H, and 13G in Fig. 33).

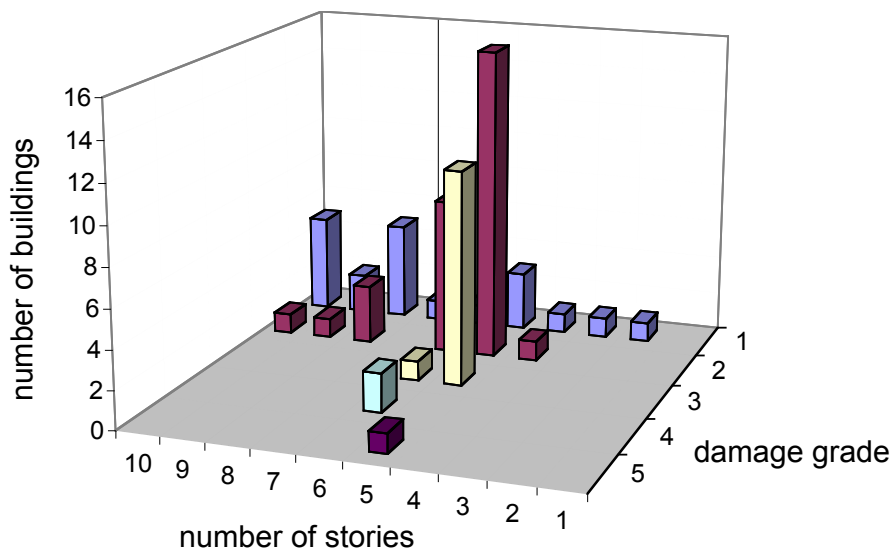


Fig. 36 Number of buildings vs. damage grade and number of stories of 65 buildings in the Cumhuriyet Mahallesi district of Ceyhan

The evaluated damage distribution cannot be explained exclusively by a particular vulnerability of the five- to six-story buildings. It is more likely that these buildings came in resonance with the foundation subsoil and, as a consequence, experienced very strong earthquake shaking. A rather constant fundamental resonance frequency of 0.7-0.8 Hz of the alluvial subsoil was measured by the Nakamura method at different sites in the district (see Fig. 8, lower left). The fundamental frequency of the five- to six-story buildings may drop in the same range of 0.7-0.8 Hz considering the softening effect of the progressing damage in structural and nonstructural elements (see Tab. 4). The concurrence of the fundamental frequencies of the buildings and the subsoil resulted in significant amplification of the building excitation from resonance.

5.3 Earthquake Intensity According to EMS-98

To determine the EMS-intensity of the earthquake, the buildings must be classified into Vulnerability Classes. Since the residential buildings had the same configuration and were about the same age, they are assumed to belong to the same EMS-98 Vulnerability Class. The criteria for the classification into a Vulnerability Class are summarized in Tab. 1. The residential buildings are constructed of reinforced concrete frames with masonry infills. A priori, reinforced concrete frames with moderate earthquake resistant design are classified into Vulnerability Class D. Weighing the positive and negative attributes listed in Tab. 1, the buildings were judged to be more vulnerable than Vulnerability Class D and assigned into the next higher Vulnerability Class C.

Criteria according to EMS-98	Positive	Negative
earthquake-resistant design level	wall-like columns	observed hinges found in columns, not in beams or slabs
		columns are not designed to perform ductile deformations
		beams are integrated in slab
		large spaces between confinement rebars (0.3 m)
		no stabilizing ties for vertical bars in the middle of a face
		varying concrete consistency and cover of reinforcement
	slabs are relatively light	
		influence of masonry infills
quality of workmanship and material		average to poor
state of preservation	good, new buildings	
regularity of stiffness and mass distribution	good in the vertical axis as in the plan view	some infills may have been removed in the first story
ductility		low
position	free standing buildings	
earthquake retrofit		not available
Summary	Classified into Vulnerability Class C	

Table 1: Criteria for the classification of the residential buildings (reinforced concrete frames with masonry infill walls) into a EMS-1998 Vulnerability Class

Due to the lack of other observations, the earthquake intensity was directly estimated based on the building damage described in Section 5.2. The criteria for the damage grade distribution are summarized in Tab. 2 for intensities VIII and IX. These values have to be compared with the observed distribution of damage shown in Tab. 3. The results of Fig. 36 are reformatted in Tab. 3 to be directly comparable to Tab. 2. A macroseismic intensity of XIII with a trend toward intensity IX on the EMS-98 scale was found for the evaluated district of Ceyhan. This result agrees well with the preliminary estimation of IX for the maximum intensity in rural areas west of Ceyhan by (Raschke 1998).

Damage Grade	Grade 1	Grade 2	Grade 3	Grade \geq 4	
Intensity VIII		15–55%	1–15%	-	
Intensity IX		-	15–55%	1–15%	

Table 2: Required damage grade distributions of buildings of Vulnerability Class C for EMS-98 intensities VIII and IX

Damage Grade	Grade 1	Grade 2	Grade 3	Grade \geq 4	All
Number of buildings	20	30	12	3	65
Percentages	31%	46%	18%	5%	100%

Table 3: Observed damage grade distribution of 65 buildings in the Cumhuriyet Mahallesi district of Ceyhan

5.4 Typical Residential Building

A typical residential building in the Cumhuriyet Mahallesi district of Ceyhan is a regular eight-story building constructed as cast-in-place reinforced concrete frames with masonry infill walls and with occasional irregularities at the ground floor.

5.4.1 Structural Configuration

A plan view of the typical building is given in Fig. 37. The main characteristics of its structural configuration are:

- Reinforced concrete frame, cast-in-place. The columns are at a distance of 3.5 to 4.0 m. The beams are integrated in the joist slab.
- Combined footing on one side and on the other side a cellar story, which rises 0.5 to 1.0 m above the ground level.
- Unreinforced masonry infills placed in the already constructed concrete frame. A gap is left between the upper edge of the infill and the slab. The walls are one stone (0.18 m) thick. Frequently, the bricks were placed with the perforation in the horizontal direction.
- Openings in the first story (as built or later removed infills) causing irregular stiffness and strength distribution in plan and elevation.

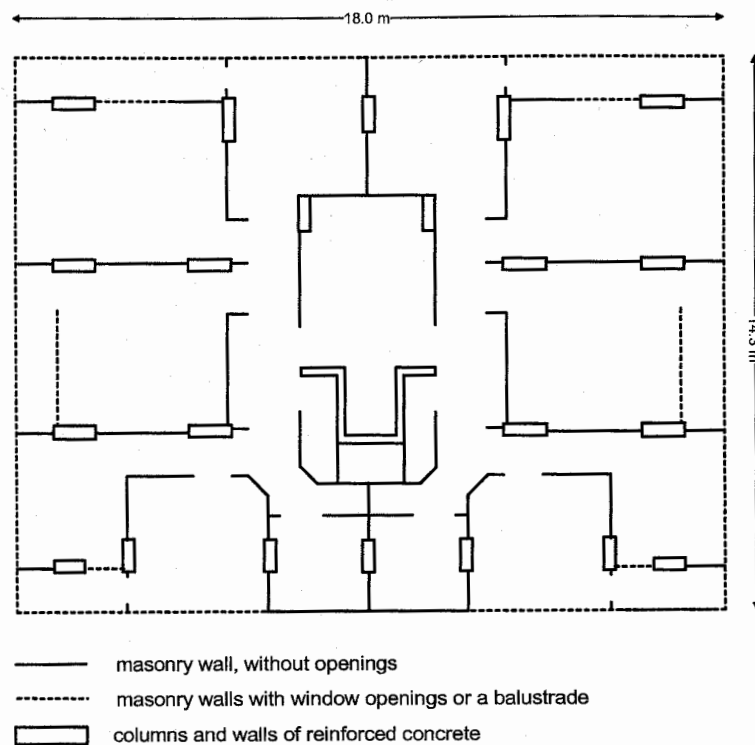


Fig. 37 Plan section through an upper story of a typical residential building; in the first story, the masonry infill walls were often replaced by openings

- Columns with wall-like rectangular cross section 0.80 m to 1.10 m long and 0.30 m wide, oriented in the principal building directions (see Fig. 37). Vertical reinforcement bars were \varnothing 14 mm with $s = 150$ mm, corresponding to a reinforcement ratio of about 0.6%. The confining reinforcement consisted of \varnothing 8 mm stirrups spaced at 330 mm (0.1%).
- The lift cage is constructed of reinforced concrete.
- Joist slab floors made of hollow concrete stones with a cast-in-place topping and beams of the same height as the slab. The beams were 0.30 to 0.35 m high and about 1.20 m wide running between columns.
- Material quality:
 Concrete: Schmidt-Hammer measurements yielded values between $f_{cwm} = 20 \text{ N/mm}^2$ and $f_{cwm} = 25 \text{ N/mm}^2$ for the concrete resistance.
 Reinforcement steel of two qualities: the lower quality, usually plain bars, with a yield strength of $f_y = 220 \text{ N/mm}^2$ and the higher quality, deformed bars with a yield strength of $f_y = 420 \text{ N/mm}^2$ (according to Prof. P. Gülkan, Middle East Technical University, Ankara).

5.4.2 Eigenfrequencies

A possible range of the fundamental eigenfrequency was computed for the described eight-story residential building (Tab. 3). The modulus of elasticity of the concrete was determined by Schmidt-Hammer measurements. For the lower bound of the fundamental frequency, the stiffness of the reinforced concrete section was reduced by a factor of three to account for cracking. The masonry infill walls were neglected and a certain foundation subsoil compliance was considered in the frequency calculation. Based on the results for the eight-story building, the fundamental eigenfrequencies were

extrapolated for buildings with other numbers of stories by empirical formula (Tab. 3).

Number of stories	Eigenfrequency of the fundamental mode [Hz]
3 -4	1.2 – 2.1
5	0.9 – 1.3
6	0.7 - 1.1
8	0.5 – 0.8
10	0.4 – 0.7

Table 4: Range of fundamental eigenfrequency in Hertz for typical reinforced concrete frame building in function of the number of stories

5.4.3 Damage Pattern

The typical damage pattern can be explained by the specific construction type of the residential buildings. Under gravity loading, the reinforced concrete frame takes all the forces and the masonry infills are not stressed. Assuming a regular stiffness and mass distribution over the height of the building, the horizontal earthquake forces are distributed as shown in Fig. 38 on the left. The resulting shear forces are highest in the first story (Fig. 38, in the middle). As a consequence, the largest horizontal story deformations occur there, too. Due to the horizontal column deformations, the stiff masonry infills are quickly loaded to their ultimate capacity and fail in a brittle manner. The more flexible and ductile reinforced concrete frames have a larger deformation capacity and remain intact longer. Due to the progressing damage of the masonry infill walls in the first story, the building softens in this story resulting in a base isolation effect. As a consequence, the upper stories will be somewhat isolated from the ground excitation and exposed to reduced horizontal accelerations and reduced shear forces. Less damage could be expected in the upper stories compared to the first story.

The building is not only stressed by shear forces but also by bending moments (Fig. 38 on the right). The deformations due to the bending moment are smaller than the shear deformations and are essentially carried by the concrete frames.

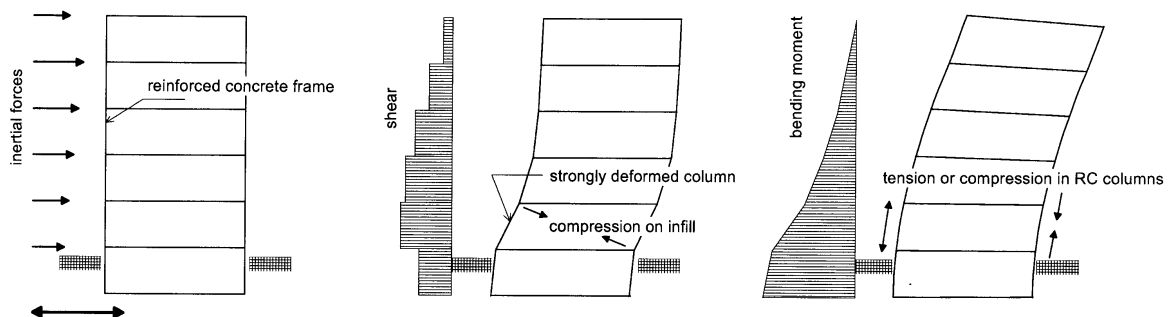


Fig. 38 Behavior of reinforced concrete frame buildings under seismic action: horizontal earthquake forces (left); resulting shear forces and corresponding deformations (middle); resulting global bending moments and corresponding deformations (right)

5.5 Turkish Seismic Code

The first official code for earthquake resistant design in Turkey, entitled *Specifications for Structures to be Built in Disaster Areas*, was published in 1975 (ERD 1975). Adana and Ceyhan were located in seismic zone 3, the second highest of five hazard zones (0 to 4), with a seismic zone coefficient $C_o = 0.08$. The earthquake resistant design is based on a set of equivalent lateral static forces applied at the various floor levels of the building (Durgunoglu 1994). For the example eight-story building, the total equivalent static force V had to be computed as follows : $V = C_o * K * S * I * W$, where W is the building weight in kN including a portion of the live load, and the product $C = C_o * K * S * I$ is called seismic coefficient, where K is the structural coefficient, I the structural importance coefficient and S the spectral coefficient. A value of $C = 0.09$ was found for the seismic coefficient of the example building. Most of the existing modern reinforced concrete buildings in the Adana and Ceyhan areas were built after 1975. It is unknown if the 1975 seismic code was systematically used in the design of these buildings.

In 1996, a new seismic code was introduced in Turkey (ERD 1996). The seismic hazard map of the Adana province is shown in Fig. 39. The cities of Adana and Ceyhan are now situated in seismic zone II (zone I is the highest zone). According to the new code, the seismic coefficient for the example building is $C = 0.19$ (IAEE 1996). In this example, the seismic design forces have more than doubled compared to the earlier 1975 code. For other buildings a similar increase of seismic design forces would be obtained. During the last two decades, a pronounced upward trend of the level of seismic forces could be observed in building codes all over the world.

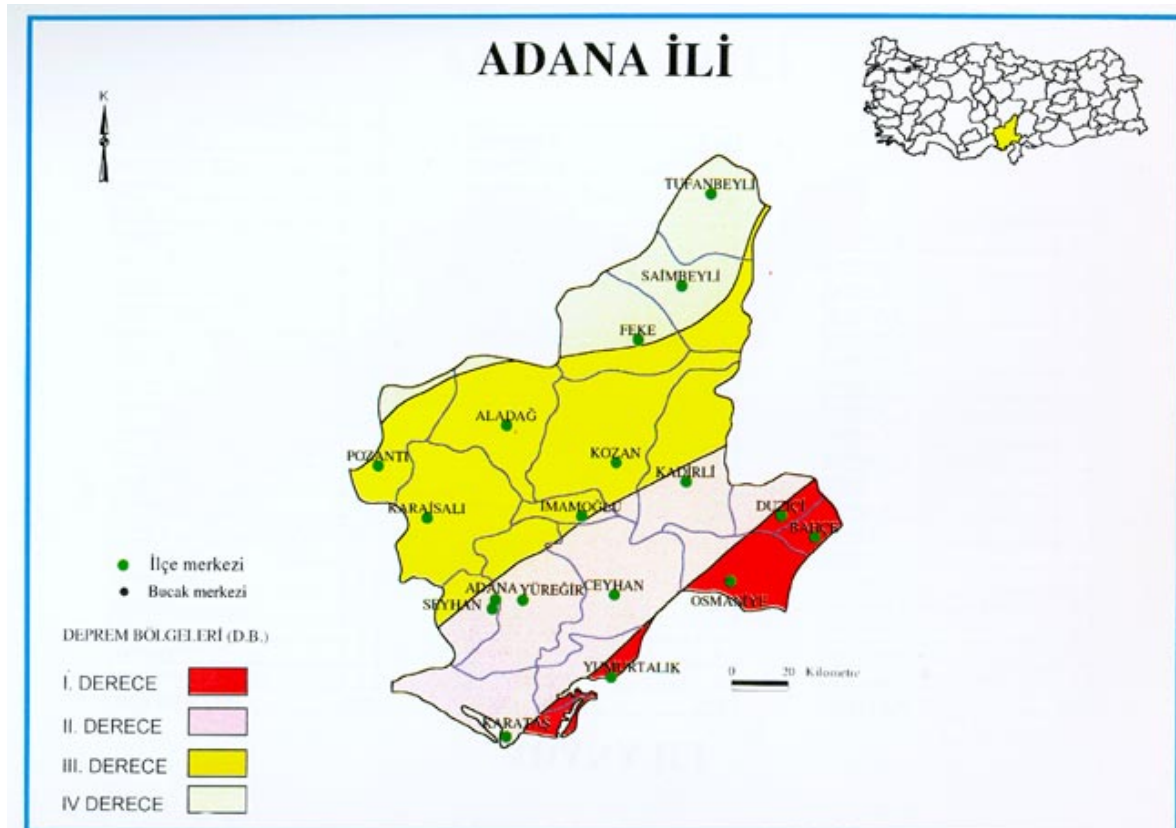


Fig. 39 Seismic Zones in the Adana-Ceyhan region showing Adana and Ceyhan in seismic zone II (Gencoglu 1996)

6 Conclusions

Well designed buildings survived the earthquake without noticeable damage right next to severely damaged buildings. One positive example of undamaged buildings is the new technical school in Ceyhan (Fig. 21). Although, a modern seismic building code is available, it is questionable whether this code was correctly applied in all cases. The vulnerability of modern industrialized society and, as a consequence, the seismic risk are constantly growing with the development of new settlements and industrial sites. In parallel, the loss of production is taking a larger and larger share of the total financial consequences in the aftermath of an earthquake. These considerations should be given more significance in the seismic design criteria.

Based on the experiences from many past earthquakes, reinforced concrete frames with unreinforced masonry infills must be judged as an inappropriate structural system for buildings located in seismic areas as evidenced by the heavy damage suffered by this type of building construction. When repairing these buildings, their seismic performance should be improved not just restored to the previous unsatisfactory state (Fig. 23). Pin-connected structures made from prefabricated elements present a particular risk due to the lack of continuity between individual elements. For an adequate seismic resistance the joints have to be carefully designed, respecting a minimum support length of the corbels or realizing a complete continuity of the joints to avoid a collapse like a house of cards.

The assessment of the damage pattern within a selected area (Cumhuriyet Mahallesi district of Ceyhan) revealed that the buildings with five to six stories were particularly affected by the earthquake. This observation may be explained by a pronounced site effect (i.e., resonance between buildings and underlying subsoil). The fundamental frequency of the five- to six-story buildings was calculated and corresponded closely to the fundamental frequency of the subsoil as measured by the Nakamura method, a relatively simple procedure. The concurrence of the fundamental frequencies of the five- to six-story buildings and of the subsoil resulted in significant amplification of the building excitation from resonance.

This mission showed the important influence of local soil conditions on building damage. To successfully mitigate the seismic risk in the future, these effects have to be considered more carefully in seismic design. A close cooperation between engineering seismologist and earthquake engineers is indispensable for this purpose.

7 Recommendations

7.1 General Recommendations

The seismic building code should be more strictly respected. Building permits should only be issued if the seismic design was correctly performed. More attention should be paid to quality assurance in construction.

The seismic zoning of the building code should be improved by complete microzoning of all densely populated areas and for all industrial areas. First priority should be given to the microzoning of new planned settlements. Special construction regulations such as height limitations should be enacted depending on the results of the microzoning.

A few multi-story buildings should be instrumented with strong motion recorders placed on different floor levels. It is important to gain better insight into the actual dynamic behavior of typical structures during earthquakes.

It is important to reduce the vulnerability of existing structures. All existing buildings should gradually be upgraded to the level of seismic protection of the new building code considering microzoning. It is recommended to retrofit essential facilities and particularly vulnerable buildings, such as buildings with soft stories or irregular layout, in first priority.

It is recommended to reinforce masonry walls in multi-story buildings with steel or fibre reinforcements.

7.2 Seismological Recommendations

Unfortunately, the recording of aftershocks was not very successful due to the low seismic activity during the short monitoring time. A longer operational time of strong motion instruments should be planned for future missions.

The ambient noise measurements by the Nakamura method provided important informations about local site effects. A resonance frequency of 0.7 Hz appeared quite often at the investigated sites in the Adana region, which can probably be attributed to the fundamental resonance of the whole sedimentary basin. It is recommended to systematically extend the site effect study to the Adana basin. The advisable procedures for the different sites are as follows:

Ceyhan

The site effect investigation was limited to the south-east part of Ceyhan, where homogeneous soil conditions characterized by a resonance frequency of 0.7-0.8 Hz were found. It is recommended to extend the site effect study to other parts of Ceyhan and to quantify the expected ground motion amplification by numerical modeling. Considering the important construction activity in this area and the relatively homogeneous soil conditions, these investigations will have a particularly low cost/benefit ratio.

Adana Haci Sabanci Industrial Park

Soil conditions vary strongly from site to site. Particularly pronounced site effects have been observed at sites on soft sediments. Nearly no amplification was measured at neighboring sites on travertine. As a consequence, earthquake ground motions are expected to vary considerably from site to site. It is

recommended to perform a detailed site effect study of the Industrial Park with measuring points every 200 to 300 m. Site specific design response spectra could then be determined for every position of industrial plants. The location of new factories, particularly facilities presenting an important damage potential, should be selected considering the site effect study.

Adana

The preliminary two measurements gave resonance frequencies at 0.7 Hz and between 4 to 8 Hz. More measurements are needed to determine the importance of site effects. Possibly, the same low frequency domains as in Ceyhan are strongly amplified in some districts of Adana threatening the higher multi-story buildings. Considering the high population density in Adana, it is very important to conduct a more detailed site effect study.

Kaldirim

A resonance frequency of 2 Hz was measured close to Kaldirim in the south of Adana, a rural area with a relatively low population density. Site studies in this area are of low priority.

8 References

- Çelebi M. (1998) The Adana-Ceyhan Earthquake of June 27, 1998. Learning from Earthquakes, EERI Special Earthquake Report, Earthquake Engineering Research Institute Newsletter, September 1998, Vol. 32, No. 9, Oakland, California.
- DMC (1998): Disaster Management Implementation and Research Center, Middle East Technical University. The Ceyhan-Misis Earthquake of 27 June 1998: A Preliminary Engineering Reconnaissance Report, <http://www.metu.edu.tr/home/wwwdmc/ceyhan-ing.html>, Ankara.
- Durgunoglu T. (1994): International Handbook of Earthquake Engineering, Codes, Programs and Examples, M. Paz (ed.). Turkey. Chapman & Hall, New York.
- ERD (1975): Ministry of Public Works and Settlement, Earthquake Research Department. Specifications for Structures to be built in Disaster Areas, Ankara.
- ERD (1996): Ministry of Public Works and Settlement, Earthquake Research Department. Specifications for Structures to be Built in Disaster Areas, Part III – Earthquake Disaster Prevention, Ankara.
- ERD (1996): Ministry of Public Works and Settlement, General Directorate of Disaster Affairs, Earthquake Research Department, Strong Ground Motion Working Group, <http://angora.deprem.gov.tr/recentquakes.htm>, Ankara.
- Gencoglu S., Özmen B., Güler H. (1996): Yerlesim Birimleri Ve Deprem. Türkiye Deprem Vakfı, Ankara.
- Grünthal G., Musson R.M.W., Schwarz J., Stucchi M. (1993): European Macroseismic Scale 1992 (EMS-92, updated MSK-scale). Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 7, Conseil de l'Europe, Luxembourg.
- Grünthal G., Musson R.M.W., Schwarz J., Stucchi M. (1998): European Macroseismic Scale 1998 (EMS-98). Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 15, Conseil de l'Europe, Luxembourg.
- IAEE (1996): International Association for Earthquake Engineering (IAEE), Regulations for Seismic Design, a World List – 1996, Tokyo.
- Nakamura Y. (1989): A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report, Vol. 30, No.1, RTRI, Japan.
- Raschke M., Wuttke F., Wenk T. (1998): Das Adana-Ceyhan Erdbeben vom 27. Juni 1998. Erdbebeningenieurwesen und Baudynamik, D-A-CH-Mitteilungsblatt, Band 18 Nr. 2, Deutsche Gesellschaft für Erdbebeningenieurwesen und Baudynamik, Berlin.
- Wenk T., Lacave C., Peter K. (1998): Séisme de Adana-Ceyhan, Turquie, 27 juin 1998. Ingénieurs et architectes suisse, Vol. 124, No. 21, Société des éditions des associations techniques universitaires, Lausanne.