# REVELATIONS FROM A SINGLE STRONG-MOTION RECORD RETRIEVED DURING THE 27 JUNE 1998 ADANA (TURKEY) EARTHQUAKE

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**Abstract**

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During the June 27, 1998 Adana (Turkey) earthquake, only one strong-motion record was retrieved in the region where the most damage occurred. This single record from the station in Ceyhan, approximately 15 km from the epicenter of that earthquake, exhibits characteristics that are related to the dominant frequencies of the ground and structures.

The purpose of this paper is to explain the causes of the damage as inferred from both field observations and the characteristics of a single strong-motion record retrieved from the immediate epicental area. In the town of Ceyhan there was considerable but selective damage to significant number of mid-rise (7-12 stories high) buildings. The strong-motion record exhibits dominant frequencies that are typically similar for the mid-rise building structures. This is further supported by spectral ratios derived using Nakamura's method [1] that facilitates computation of a spectral ratio from a single tri-axial record as the ratio of amplitude spectrum of horizontal component to that of the vertical component [R=H(f)/V(f)]. The correlation between the damage and the characteristics exhibited from the single strong-motion record is remarkable.

Although seismically deficient construction practices played a significant role in the extent of damage to the mid-rise buildings, it is clear that site resonance also contributed to the detrimental fate of most of the mid-rise buildings. Therefore, even a single record can be useful to explain the effect of site resonance on building response and performance. Such information can be very useful for developing zonation criteria in similar alluvial valleys.

Keywords: earthquake, damage, strong-motion, spectrum, site-response, resonance, frequency, period, Turkey, Adana, Ceyhan

## INTRODUCTION

The Adana-Ceyhan earthquake of Magnitude 6.2 occurred on June 28, 1998 at 16:56 PM local time (15:56 UTC). The National Earthquake Information Center in Golden, Colorado identified the epicentral coordinates of the earthquake as latitude: 36.9 degrees North (Latitude) and 35.3 degrees East (Longitude). Seismological stations in souther Turkey reported the local magnitude of the earthquake as $M_L = 5.9$, the coordinates as 35.85 N and 35.55 E. The depth of the earthquake is given as 13 km. and 22 km by two different sources (MAM[1] and DAE[2]).

A general map of the region, historically known as Cilicia, depicting the epicenter and major towns is provided in Figure 1. The earthquake epicenter is approximately 50 km to the east of Tarsus (birthplace of St. Paul of Tarsus and the meeting place of Antonius and Cleopatra. During the Roman times, Antonius met Cleopatra at Tarsus Port. Present day Tarsus is approximately 20 km inland from the seashore). The earthquake caused approximately 150 deaths and injuries to several thousand people. On July 4, 1998 at 5:05 AM local time, the largest aftershock of magnitude 5.1 occurred. Approximately 1060 people were injured during this aftershock – most were injured as a result of jumping from windows. The areas severely shaken by the earthquake covered approximately 150 km radius but the serious structural damage was within a 30 km radius of the epicenter. It was reported that the earthquake was felt as far south as Cyprus, Syria, Israel and Jordan.

The scope of the paper covers typical damages in Ceyhan and related strong motion records. Damages to lifelines and ground failures due to earthquake are not discussed. Detailed damage survey descriptions was reported by Çelebi [2].

## GEOLOGY AND SEISMICITY

The geology of the Adana-Ceyhan (Cukurova) Basin is dominated by a Quarternary alluvial valley covered by clay and surrounded on the north by the Taurus Mountains. The depth of the agro-clay surface varies from location to location (1-6 meters). In Adana, for example, the depth is reported to be approximately 1-3 meters. In the valley, below the clay surface, the layers are in general loose gravelly or dense hard alluvium mixed with pockets of sand and clayey-sand. The northern part of Adana, more or less divided by the recently built Cukurova Toll Expressway, is hard conglomerate. To the west of the epicentral region, there are two small mountains (elevation 763m). Ceyhan River meanders to the east of these mountains. The Misis-Ceyhan Fault follows the general N60E direction of the two mountains (Barka and Akyuz [3]). Below this, the young alluvial layers consist of gravel, sand and clay. Underground water can be located at 1-3 m. depth in young layers and at 6-8 m. in older layers.

The left-lateral fault that caused the earthquake is called the Misis/Ceyhan Fault (Barka and Akyuz [3]).The region is known to be seismically active. However, because of the short length of the faults in the region, large earthquakes (M>7) are not historically known or expected. The historical data base however refers to several earthquakes with M<7 that have caused damage in the area.

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[1] MAM- Marmara Arastirma Enstitusu (Marmara Research Center operated by Turkish Science Foundation, Gebze, Turkey : web page : from http://www.nemrut.mam.gov.tr)

[2] DAE-Deprem Arastirma Enstitusu – Earthquake Research Center, Ministry of Construction and Resettlement, Ankara, Turkey)

Adana and Ceyhan are in the 2nd Seismic Zone according to the Seismic Zoning Map of Turkey (Map, 1996). There are 5 zones with Zone 1 and Zone 2 assigned seismic coefficients of 0.4 and 0.3, respectively according to the new Seismic Design Code of Turkey (1997) [4]. The current Seismic Zoning Map (1996) identifies the region, in general, to be in the 2nd zone [5].

## BUILDING INVENTORY AND DAMAGE

Typical construction in the area is reinforced concrete framed building with (cinder block or hollow-brick) infill walls. Often, the slabs are also of cinder-block type. In the area, there are significant number of older, timber-reinforced adobe, stone or brick masonry buildings. These are mainly in the older part of Adana or in the surrounding villages. Many of the industrial plants that are significant to the economy of the area are of prestressed and precast concrete construction. Damage to these structures varied as did the damage to rtheir contents. Steel construction is practically non-existent.

Both in Adana and Ceyhan, where a significant number of buildings were damaged, most buildings performed well. The majority of mid-rise and taller buildings(5-15 stories) in Adana performed well. Presence of well designed and significant percentage of shear walls (and/or infill walls) must have contributed to the satisfactory performance of most buildings during this earthquake. In many cases, the infill walls may have improved the performance of the reinforced concrete framed buildings with added reserve strength and stiffness.

On the other hand, Ceyhan suffered the most damage and loss of lives. Most of the damage and loss of lives occurred in only a few of the 7-10 story buildings located in two subdivisions. Collapse of two buildings in one of these subdivisions was the cause of 57 deaths in total.

The types of structural damages in Adana, Ceyhan and other smaller settlements are, as expected, similar to the damages suffered during previous earthquakes in Turkey, and regional countries (Bulgaria, Greece, Romania, Iran and Italy). The causes of damage can be attributed to one, or combination of the following: (a) soft first story, now an internationally known defect in design when not properly designed for, (b) inadequate detailing and reinforcements of column-beam connections and columns [insufficient or lack of shear reinforcement, anchorages, inadequate spacing of ties, inadequate bonding of round bars used instead of deformed bars], (c) design of strong beam/weak columns rather that strong-column/weak beams, (d) creation of short-columns due to infill walls or off-sets in design, (e) unreinforced or inadequately reinforced concrete and/or brick masonry piers or coupling beams, (f) age of older and deteriorated buildings with little lateral load resistance, (g) poor quality of construction materials used [concrete, steel, mortar, brick, cinder block, river washed stone-masonry], (h) site effects, double-resonance and soil-structure interaction of the 5-10 story buildings on alluvial media with single story basements and no-piles. This issue is currently being investigated further by the author.

The fact that most of the new mid-rise and tall buildings in Adana (5-15 stories) performed better than those in Ceyhan may be attributed to those characteristics of ground motions in Adana being different than those in Ceyhan. Depth to bedrock (thickness of soil layers) at Adana is reported to be less than at Ceyhan which may account for a weaker site response resulting in less damage to structures noted there. A strong-motion record was not obtained in Adana; however, judging on the basis of local geology, the peak accelerations were probably smaller in that area.

## STRONG MOTION RECORDS

Although several strong-motion records were obtained from the sparsely deployed strong-motion accelerographs in the region, the most important record was retrieved from the station in Ceyhan (Figure 1) in the immediate epicentral region. This record from Ceyhan, where the largest number of deaths and damage occurred, had peak accelerations of 0.22 g (NS), 0.27 g (EW) and 0.087 g (UP). Figure 2 shows the components of the records and their response spectra. The response spectra clearly demonstrates that the horizontal components of motion have several dominant peaks within 0.2-0.7 second band. These peaks are very significant in describing the damages to the structures in Ceyhan.

Figure 3a shows the Fourier amplitude spectra of the Ceyhan record. Each horizontal component of the Ceyhan record show several dominant frequencies (periods) at approximately 0.7, 1 and 1.5 Hz (1.4, 1 and .67 s).

Figure 3b shows transfer function calculated using Nakamura's method [1]. In absence of reference rock sites in close proximity to those soft and/or alluvial sites (as in Ceyhan) to calculate spectral ratios, this method facilitates calculation of the transfer function using the realtionship $R= A(f)_{horizontal}/ A(f)_{vertical}$. As seen in the figure, both the amplitude spectra and the transfer function shows the resonating peaks within the frequency band 1-1.5 Hz.

To further demonstrate the effect of ground motions on the performance of structures in Ceyhan, we proceed to calculate site transfer function using Haskell's method [6, 7]. The available geotechnical logs are from within Ceyhan (Aktar [8]). The logs available are about 140 meters in depth. A single layer as well as two layers of depth are considered in Figure 3c. As in Figure 3a and b, also from this figure, it is seen that site resonance can take place around 1.5 Hz (0.67 seconds). It is therefore possible that one of the main causes of collapses or severe damages inflicted on the mid-rise (7-10 story buildings) in Ceyhan is due to double resonance.

Figure 4 shows the NS and EW acceleration and the normalized cumulative energy variation with time. Particularly for the NS component, it is seen that between 6.7 – 10.0 time frame, approximately 65 % of the shaking energy takes place within about four, relatively harmonic excursions. The rate of increase in energy is decreasing after about 10 seconds. However, the strong shaking within this time frame must have been quite damaging to those structures with 0.5-0.7 second fundamental periods. Figure 5 shows the NS component and its Fourier amplitude spectra calculated using the total record and the band between 6.7-10 seconds. The signal within that time-band exhibits the same peaks and significant percent of the amplitude (>50%) as that from the total time band.

A study of 65 buildings in a well defined subdivision of Ceyhan (Figure 6) was performed by Wenk, Lacave, and Peter [9] who classified the buildings according to degree of damage as defined by European Macroseismic Scale (Grunthel and others, [10,11]). Their conclusions, summarized in Figure 6, also indicates that the most severely damaged (or collapsed) buildings were 5-7 stories with estimated frequencies of 1.5-2 Hz. This study confirms the effect of the resonating motions in Ceyhan at ~1.5 Hz. The foundations of the buildings in Ceyhan were shallow (continuous footing on the surface or with little or no embedment). The buildings with infill walls being relatively rigid and on alluvial site conditions were at ideal setting for soil-structure interaction. Thus, the fundamental frequencies of these rather stiff buildings may have lengthened with soil-structure interaction and coincided with the dominant periods of the site.

## CONCLUSIONS

This paper shows that in addition to structural deficiences, site effects can be a very important factor in the performance and damageability of structures. A single strong-motion record is used to depict the resonating frequencies of the site. This is further confirmed by transfer functions calculated using geotechnical information. A damage survey study performed by Wenk and others (1998) is referenced to show that there is a correlation between the site frequencies and the frequencies of structures that were damaged. Such results must be used in developing criteria for zonation of structural systems in seismic areas site characteristics that can be determined by empirical or theoretical methods.


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## Vitae


Dr. Mehmet Çelebi is the senior Research Civil Engineer with the Earthquake Hazards Team of United States Geological Survey in Menlo Park, California. His main assignment is as Project Chief for structural instrumentation to record seismic responses. In this capacity he develops plans for structural instrumentation and conducts related research from recorded responses of structures. In his earlier career, Dr. Çelebi served as Professor of Civil Engineering at San Francisco State University and as Engineering Specialist with Bechtel Power Corporation. He received his undergraduate degree from the Middle East Technical University in Ankara Turkey in 1964 and thought at the same university as Assistant and Associate Professor between 1969-1977.

**FIGURE CAPTIONS**

Figure 1. Map showing the general earthquake region, the epicenter and relative positions of major towns.

Figure 2. Strong-motion records from the Ceyhan Station (on the ground floor of a three-story building) and corresponding response spectra.

Figure 3. (a) Amplitude spectra of recorded motion in Ceyhan, (b) transfer function using Nakamura's method, and (c) transfer function using Haskell's method.

Figure 4. Horizontal components of Ceyhan main-shock and time variation of normalized cumulative energy.

Figure 5. North-South component of the Ceyhan main-shock record and amplitude spectra.

Figure 6. A subdivision of Ceyhan and damage distribution (from Wenk and others, 1998).

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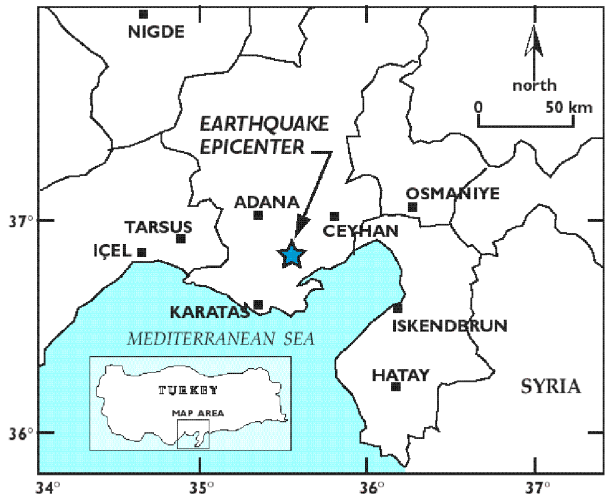
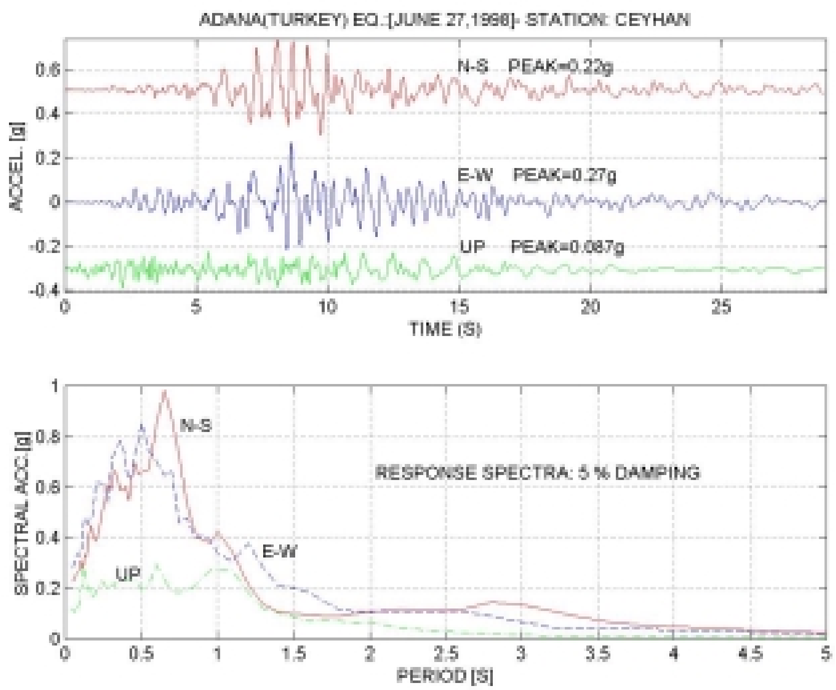



Figure 1. Map showing the general earthquake region, the epicenter and relative positions of major towns.

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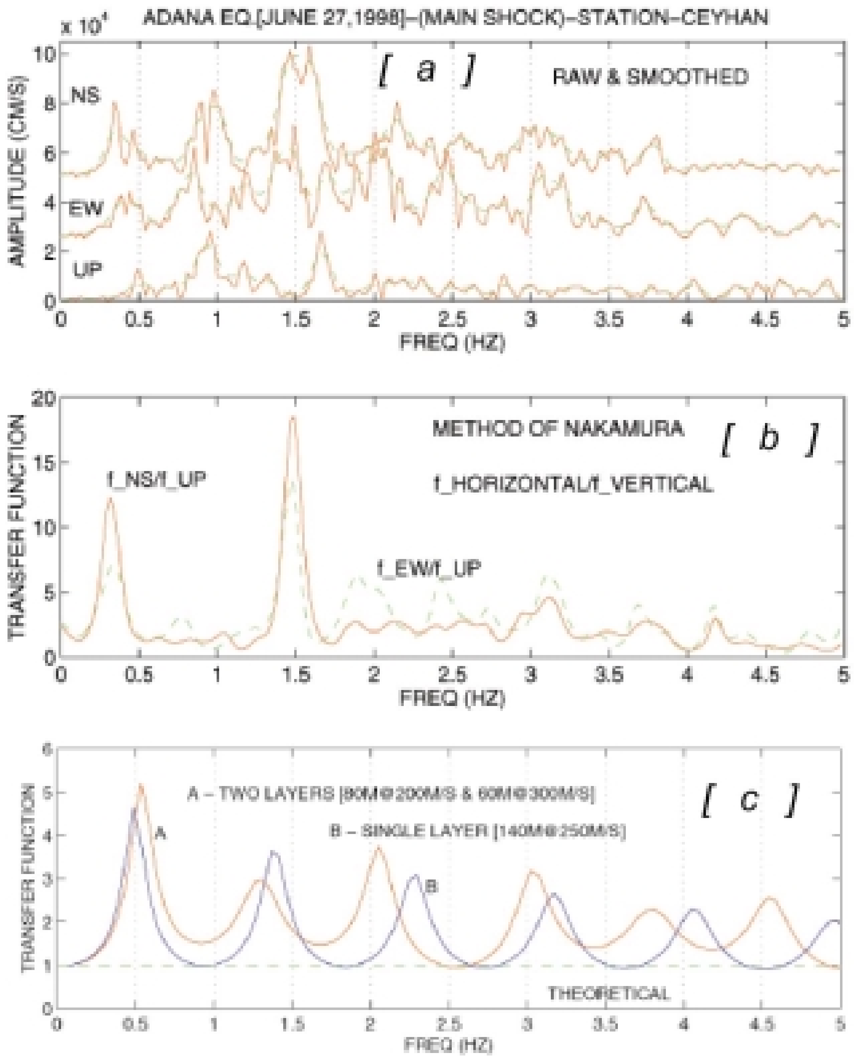


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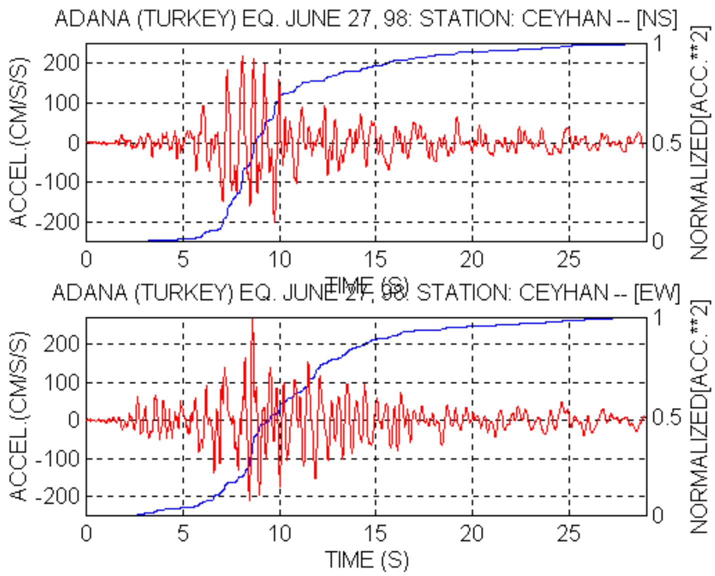


Figure 4. Horizontal components of Ceyhan main-shock and time variation of normalized cumulative energy.

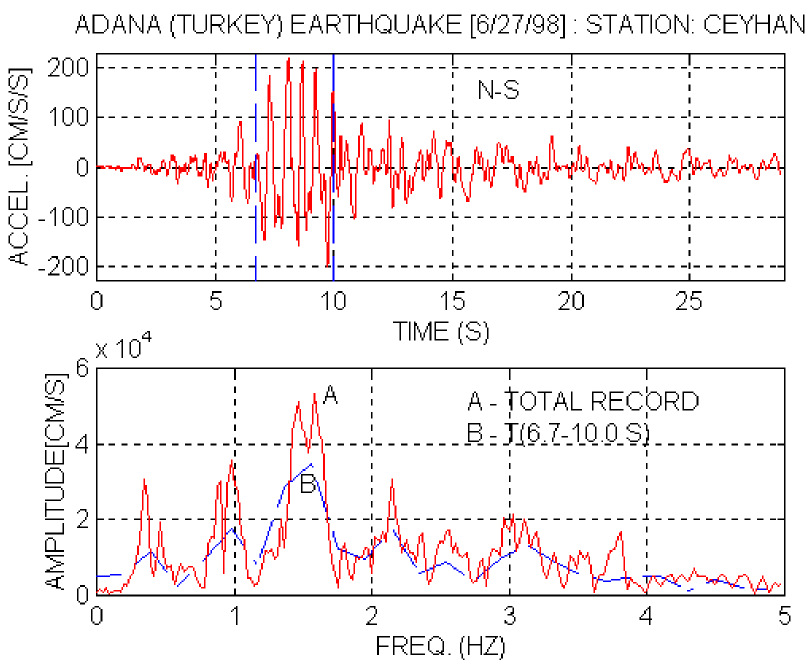


Figure 5. North-South component of the Ceyhan main-shock record and amplitude spectra.

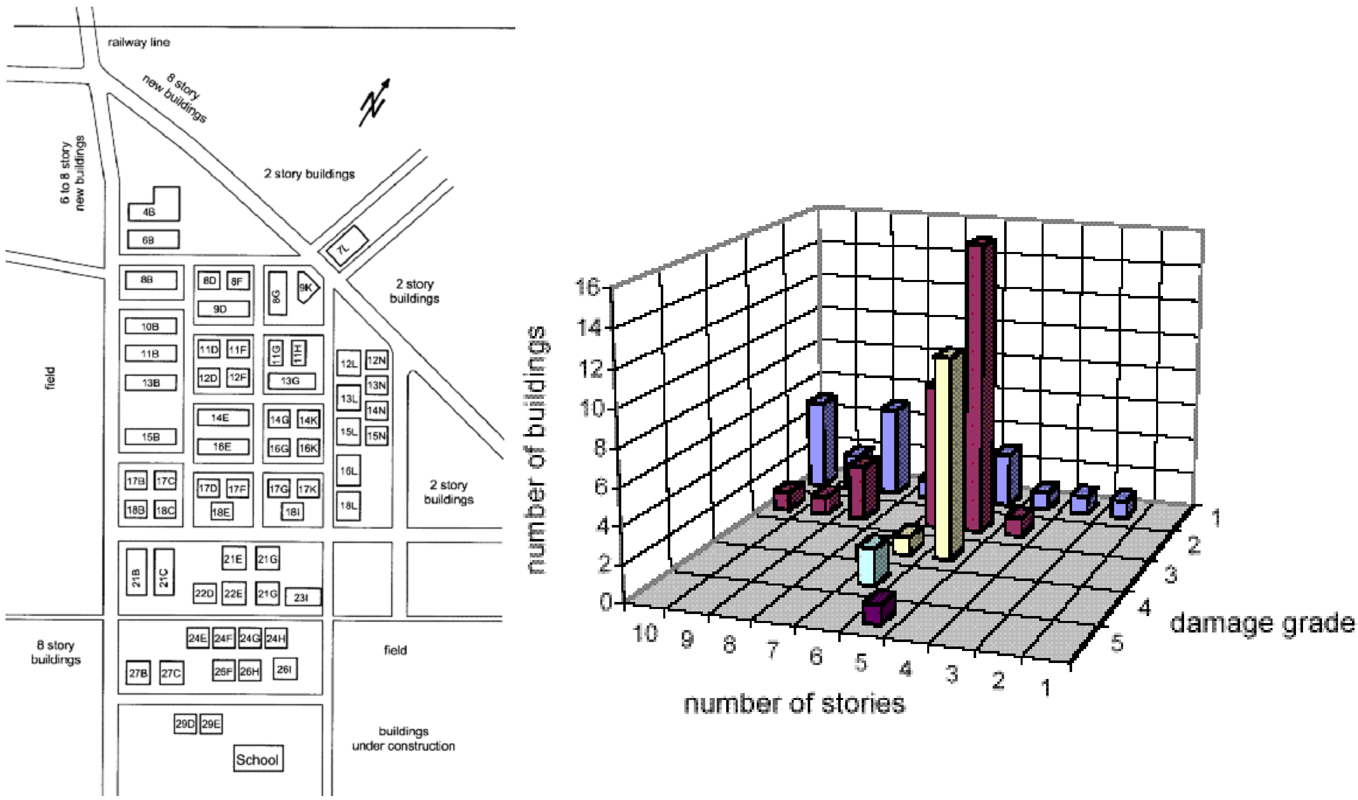


Figure 6. A subdivision of Ceyhan and damage distribution (from Wenk and others, 1998).