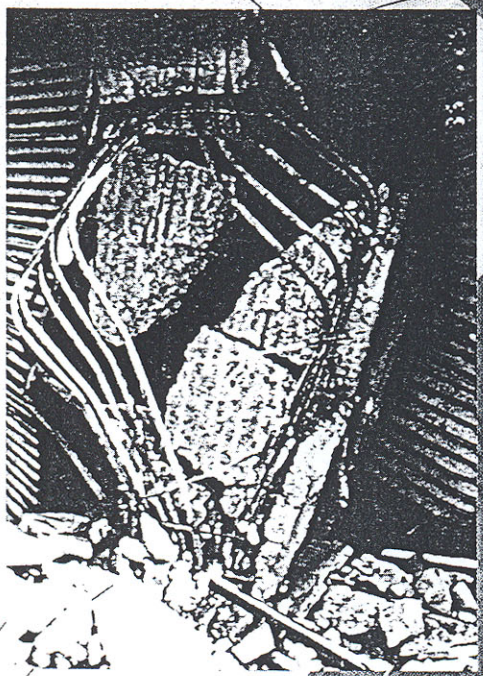
Advances in Earthquake Engineering

# Earthquake Resistant Engineering Structures



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# Earthquake Resistant Engineering Structures II

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Published by

**WIT Press**
Ashurst Lodge, Ashurst, Southampton SO40 7AA, UK
Tel: 44 (0)238 029 3223; Fax: 44 (0)238 029 2853
Email: witpress@witpress.com
http://www.witpress.com

For USA, Canada and Mexico

**Computational Mechanics Inc**
25 Bridge Street, Billerica, MA 01821, USA
Tel: 978 667 5841; Fax: 978 667 7582
Email: cmina@ix.netcom.com

**British Library Cataloguing-in-Publication Data**

A Catalogue record for this book is available
from the British Library

ISBN: 1 85312 689 6

ISSN: 1361-617X



Printed and bound in Great Britain by The MFK Group

*Advances in Earthquake Engineering, Earthquake Resistant Engineering Structures, Wit Press 1999, vol.4, p.785-798.*

# Adana Earthquake: Peculiar damage distribution and seismotectonic characteristics

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## Abstract

The earthquake of Adana (Southern Turkey) took place on 27 June 1998. Its epicenter lays close to the city and its magnitude was $M_s$=6.2, sufficient to cause a large number of deaths and extensive damage to human constructions. This motion resulted by a left lateral strike-slip faulting along the NE-trending East Anatolian fault system and other fault zones, parallel to it, in the west. The earthquake focal mechanism solution is in agreement with this tectonic setting. In Adana, mainly older constructions bore the brunt of damage, though newer; multi-story buildings did not escape unharmed. In Ceyhan, extensive damage was spread, even to new constructions, while multi-story buildings were largely destroyed. In Ceyhan, specific types of failure were observed; they were due to construction type, building shape and azimuthal position of building relative to the epicentre. The general image of the area, was comprised by damages due not only to age of constructions, quality of construction and building materials, and insufficient earthquake design, but also to location and type of earthquake faulting, epicentral distance and azimuthal location of buildings with respect to the epicentre.

## Introduction

On the 27$^{th}$ of June 1998, an earthquake of magnitude $M_s$=6.2 struck the broader area of Adana (South Turkey) at 13:55:49 (GMT). The main earthquake was followed by numerous aftershocks with the strongest one occurring on the 4$^{th}$ of July 1998 at 02:15:44 with a magnitude M=5.1. The epicentre of the earthquake was located in the SSE suburbs of Adana based on the existing data (Lat: 36.95, Lon: 35.91) while the epicentre of the strongest aftershock was a few kilometres southwest of the city (Lat:

36.89, Lon: 35.17). The depth of the main shock was 10-14 km while the focal depth of the aftershock was somewhat higher (Figure 1).

It should be mentioned that there is a slight difference between the international and the Turkish official organisations, regarding the precise location of the epicentre of the main earthquake and of the aftershock, as well as the focal depths of the two events. (USGS, Marmara Research Center in Gebze, Earthquake Research Center in Ankara, etc).

The main earthquake caused extensive damages to the structured environment in the province of Adana. According to official records, 150 people were killed while more than 3000 were injured. The strongest aftershock did not cause casualties, however, more than 1000 people were injured and many structures suffered additional damages.

This paper aims to present some interesting observations for special cases of damages, investigate the geographic distribution and the types of damages relative to the controlling factors. The regional seismotectonic regimes as well as the geological-geotechnical conditions are also given in order to provide background information about the area.

## Geological - Neotectonic framework

The broader area of Adana is characterised by a complicated neotectonic setting, where the main characteristic process is the advance of the Arabic plate that wedges the Eurasian plate as the African plate undergoes compression. The motion of the Arabic microplate (Kasapoglu[1]), which includes geographic parts of Syria, Arabia, Israel, Jordan etc, leads to the development of fault zones towards the west collision boundaries with a sinistral strike-slip movement of the blocks (Figure 1A). The motion of the plate takes place through the dominating East Anatolian fault zone, which runs in a NNE-SSW direction along the eastern Mediterranean shoreline and crosscuts Turkey.

On both sides of this zone and corresponding to the aforementioned zone, there are smaller parallel or subparallel neotectonic structures like the Karatas-Yumurtalik fault zone which is representative in the meizoseismal area. This zone, which is located to the east of Adana, has a NE-SW direction with sinistral strike-slip block movement (Barka[2]). The zone includes a couple of faults that shape the shoreline in this area and according to records they were activated on the 20$^{th}$ of March 1945 yielding an earthquake of magnitude $M_s$=6.0 (Saroglu[3]).

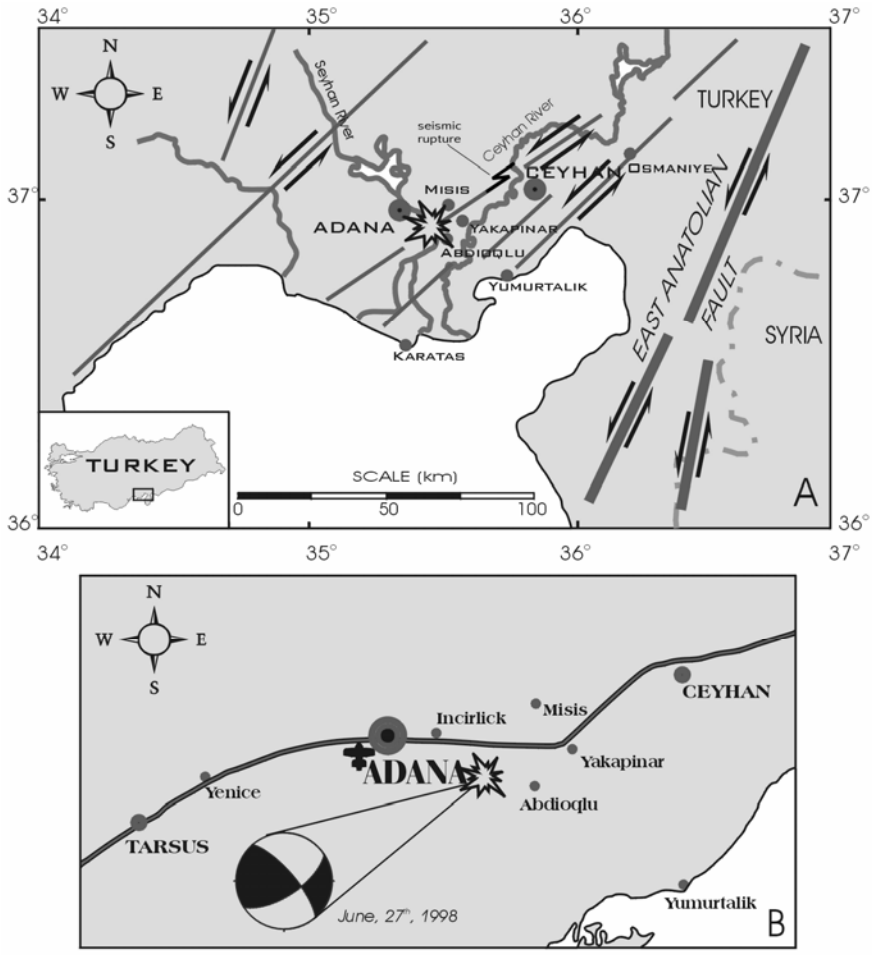


Figure 1. Geotectonic map of the wider meizoseismal area with the location of the epicentre (A) and the focal mechanism (B).

Similar zones of same direction with same kinematic characteristics are encountered to the northwest. This indicates that the whole region is controlled by the tectonic setting imposed by the advance of the Arabic plate towards the Eurasian plate (Perincek[4]).

The earthquake of June 27, 1998, resulted from the aforementioned processes as indicated by the presence of seismic ruptures in the epicentral area with similar geometric and kinematic characteristics (NE-

SW direction and sinistral strike-slip movement). In addition, the focal mechanism solution showed that the earthquake originated from a fault of NE-SW direction and sinistral strike-slip movement (Figure 1B).

The geological formations in the meizoseismal area are:

! Recent formations of Holocene-Pleistocene age which comprise the delta southward of Adana created by Ceyhan and Seyhan rivers, with a thickness up to some tens of meters.

! Recent fluvial deposits and terraces of the same rivers on both sides of the present river-beds with limited outcrops, with a thickness of up to some tens of meters.

! Pleistocene formations consisting of travertine limestones and redsilicate formations, which form a relatively level-gentle relief at the delta apex between the cities of Adana, Mersin and Ceyhan (Figure 2).

! Alpine formations in the coastal area southeast of Adana between Karatas, Yumurtalik and Osmanigi, represented mainly by Mesozoic carbonate formations, ophiolites as well as clastic Tertiary formations. These formations occur in oblong outcrops of a NE-SW direction and are crosscut by faults of the Karatas-Osmanigi zone.

Figure 2. Aspect of the travertine limestones that outcrop at the area between Adana and Ceyhan.

## Geography of damages

The damages in the meizoseismal area were developed with varying intensity among the different types of structures comprising the structured environment of the cities and residential units. The meizoseismal area is characterised by the presence of large urban areas like Adana, Ceyhan and Tarsus, as well as smaller residential units like Yakapinar, Yumurtalik, Abdioglu, Misis etc, where the residential lattice and the structured environment are completely different. The presentation of the damages is generally given for each residential unit in order to provide a first overview of the geographic distribution and of the types of damages (Figure 3).

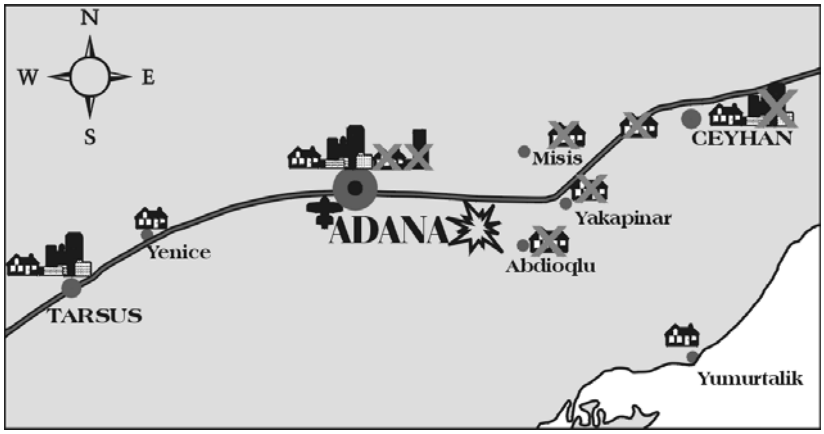


Figure 3. Compendious map of the damage distribution (X) and the type of it (tall buildings, old residential structures), after the main shock.

### City of Adana

The city of Adana has a population that exceeds 2,000,000 and includes a wide variety of structures. Specifically, in the northern suburbs as well as towards the centre of the city, most of the structures are modern multi-story buildings with armed concrete and earthquake-design standards, in contradiction to the historic centre that includes old buildings with few stories but with no modern or earthquake-design standards (Celebi[5]).

Towards the outskirts of the city and mainly to the south, there is a gradual prevalence of old structures with few stories and minimal or no earthquake-design standards.

In the city of Adana, some collapses of multi-story buildings occurred. These buildings were constructed a few decades ago without any modern earthquake-design standards and poor quality materials were used. Damages in modern and recently constructed buildings were extremely limited. Additionally, damages occurred in a significant percentage of old structures with few stories and no reinforcement, which had undergone unsuccessful modifications and in general were of low quality in terms of construction and materials. The damages had been observed mainly at the eastern and southern sectors of the city. Conclusively, in the city of Adana, damages and collapses occurred in characteristic cases of problematic buildings with anticipated results to a great extent. The general picture was not a typical one of an area close to the epicentre with extensive damages.

**Ceyhan**

The city of Ceyhan is located approximately 50 km to the northeast from the city of Adana with a population of about 80,000 people. The city includes new and old districts with buildings of corresponding age but with earthquake-design standards. The old parts of the city and the historic centre are characterised by old type buildings, with masonry or brick construction with some type of reinforcement. Furthermore, there are multi-story buildings, some decades old, without modern earthquake-design standards and of low quality construction and materials. The areas close to the city limits and especially the eastern ones are characterised by newly constructed multi-story buildings with 6-8 stories and modern earthquake-design standards, which comprise the modern districts of the city.

In the city of Ceyhan, only a small percentage of damages occurred in small old type structures, while the majority of these structures remained essentially undamaged. On the contrary, a significant number of multi-story buildings collapsed. They were of older age and located in the centre and the outskirts. Additionally, more than 30 modern buildings of 6-8 stories with earthquake-design standards collapsed or suffered significant damages (Figure 4).

According to the Ministry of Reconstruction and Resettlement, only a single strong-motion main shock record was obtained in the area. This record from Ceyhan had peak accelerations of 0.22g (NS), 0.28g (EW)

and 0.086g (UP). The records show several dominant frequencies (periods) at approximately 0.7, 1, and 1.5 Hz (1.4, 1 and 0.67 sec) (Celebi[5]). These resonating frequencies are within the site frequencies that can be expected from alluvial media with depths ranging from 25-50 m. It is possible that double resonance was one of the main causes of collapses or severe damage in the mid-rise buildings in Ceyhan. Soil-structure interaction of the rather stiff buildings may have contributed to the lengthening of the buildings' periods to coincide with the dominant periods of the site. The response spectra demonstrate that the horizontal components of the motion had several dominant peaks within a 0.2-0.7 second band.

Figure 4. Aspect of the damages on modern constructions at the eastern sector of Ceyhan.

**Tarsus**

Tarsus is located about 35 km WSW of Adana and poles apart from Ceyhan considering Adana as a centre and almost the epicentre of the earthquake. The city has a population of approximately 60,000 and is characterised by a variety of structures. In particular, one-story or two-story buildings with or without earthquake-proof planning are dominant as well as multi-story structures with earthquake-design standards.

In the city of Tarsus, the observed damages were significantly less compared to Adana and of course Ceyhan. Indicative of this situation is the fact that no collapses occurred despite the prevalence of the same type of buildings, which collapsed in the cities of Adana and Ceyhan. Any minor damages were extremely limited and it should be mentioned that

even older multi-story buildings, which had undergone remarkable interventions and expansions, suffered minor damages.

**Yakapinar - Abdioqlu**

The villages of Yakapinar and Abdioqlu are located midway between Adana and Ceyhan with an approximate population of 5,000 people. They are a residential units that includes older one-story or two-story masonry or brick structures with or without, in some cases, earthquake-design standards and reinforcement mainly by means of concrete pillars or intermediate plates of armed concrete. Relatively modern one-story or two-story buildings existed and suffered significant damages as well. The structures were built on the Pleistocene travertine limestones (Figure 2).

In the village of Yakapinar, almost all structures suffered significant damages and many of them collapsed. It is estimated that about 50% of the structures collapsed totally or partially.

**Misis**

The village of Misis is also located midway between Adana and Ceyhan to the north of the old road connecting the two cities. The foundations of the village are laid in travertine limestone as well as in locally overlying Pleistocene redsilicate formations. The village usually includes one-story and two-story structures with or without basic earthquake-design standards. Only a small percentage of the buildings had an armed concrete framework.

The damages in the village of Misis were very extensive. The village was the typical picture of an earthquake-hit epicentral area. More than 70% of the structures collapsed while structures reinforced with armed concrete suffered significant damages. Only a small percentage of the buildings was not damaged (Figure 5).

**Other residential units**

In the broader meizoseismal region the damages were minimal except for some residential units in the outskirts of the village of Misis. Beyond the Tarsus-Adana-Ceyhan axis, which runs ENE-WSW, towards the north and south in the areas Karatas, Tusla, Yumurtalik, Dogankert, Aigea, etc, the damages were extremely limited and were hardly detected even in low quality old structures.

Figure 5. Collapse of older residential structures at the village Misis.

## Special cases of failures

Impressive special cases of damages were observed in the city of Ceyhan as well as in the broader meizoseismal area. Especially in the city of Ceyhan, selective collapses of structures were observed while rakes or collapses of the top parts of minarets took place in selective directions.

In the eastern part of Ceyhan, multi-story residential buildings have been constructed, which have a different orientation, although identical regarding the ground plans and the construction in general. In particular, two perpendicular orientations can be identified in the oblong ground plan: one running NE-SW and the second running NW-SE. The main characteristic of the aforementioned buildings is that almost all pillars had an oblong direction perpendicular to the oblong direction of the greater dimension of the ground plan, namely NW-SE and NE-SW respectively (Figure 6).

The collapses occurred in the above structures, which had the oblong direction parallel to the NE-SW direction, which is the direction towards the epicenter. Evidently, the oblong pillars (NW-SE) were of a direction

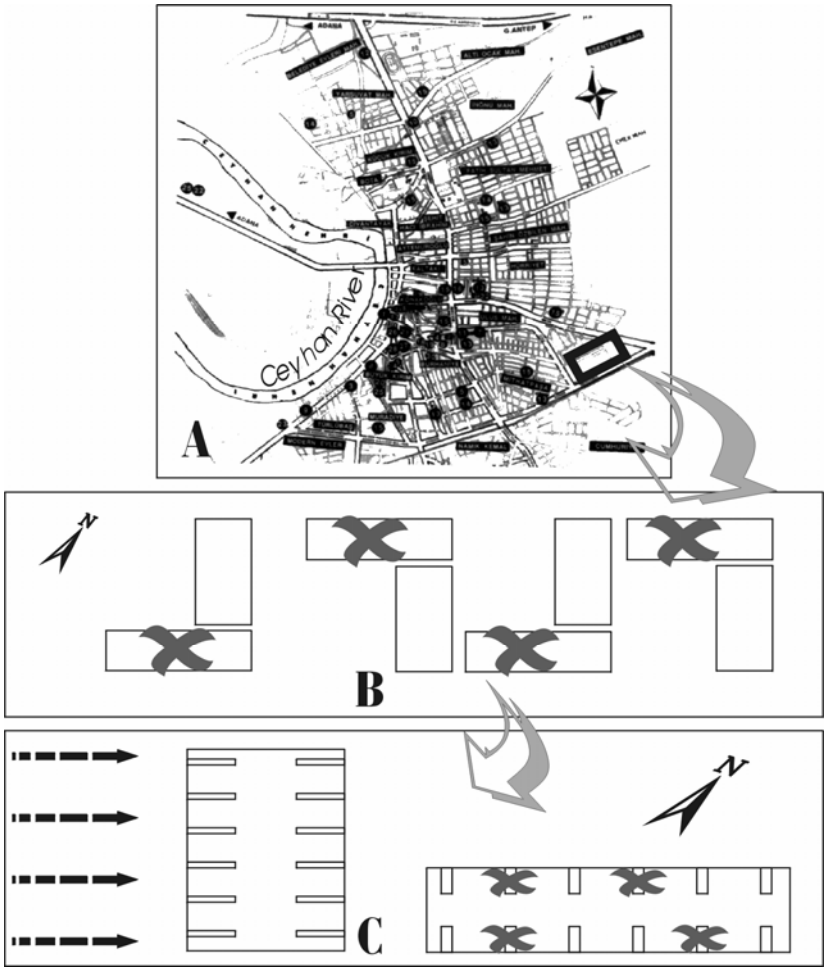


Figure 6. Map of Ceyhan town centre (A) and the exact place of the collapsed multi-story structures having NE-SW orientation (B). As shown at the schematic representation of the failures at the pillars (C) the collapse happened due to the perpendicular direction of the seismic waves.

perpendicular to the direction of propagation of the seismic waves and consequently of a lower resistance to loading. On the contrary, no collapses occurred in those of the specific structures, which had the oblong direction of the pillars (NE-SW) parallel to the direction of propagation of the seismic motion. The deformation suffered by the

structure shown in Figure 7 from west to east is very characteristic, with collapse, compression, deformation etc of structural elements.

Except for the selective distribution of damages in the city of Ceyhan, the deformations and collapses of the top parts of the minarets were very interesting, too. The transpositions, rakes and collapses of the top parts of the minarets, which took place in the broader region, were recorded, as can be seen in Figure 8. It is concluded that the phenomena were focused in the broader area of the Tarsus-Adana-Ceyhan axis and the vectors of the movements indicate the approximate location of the epicentre.

Figure 7. Aspects of a modern muti-story construction of NE-SW orientation, which collapsed totally.

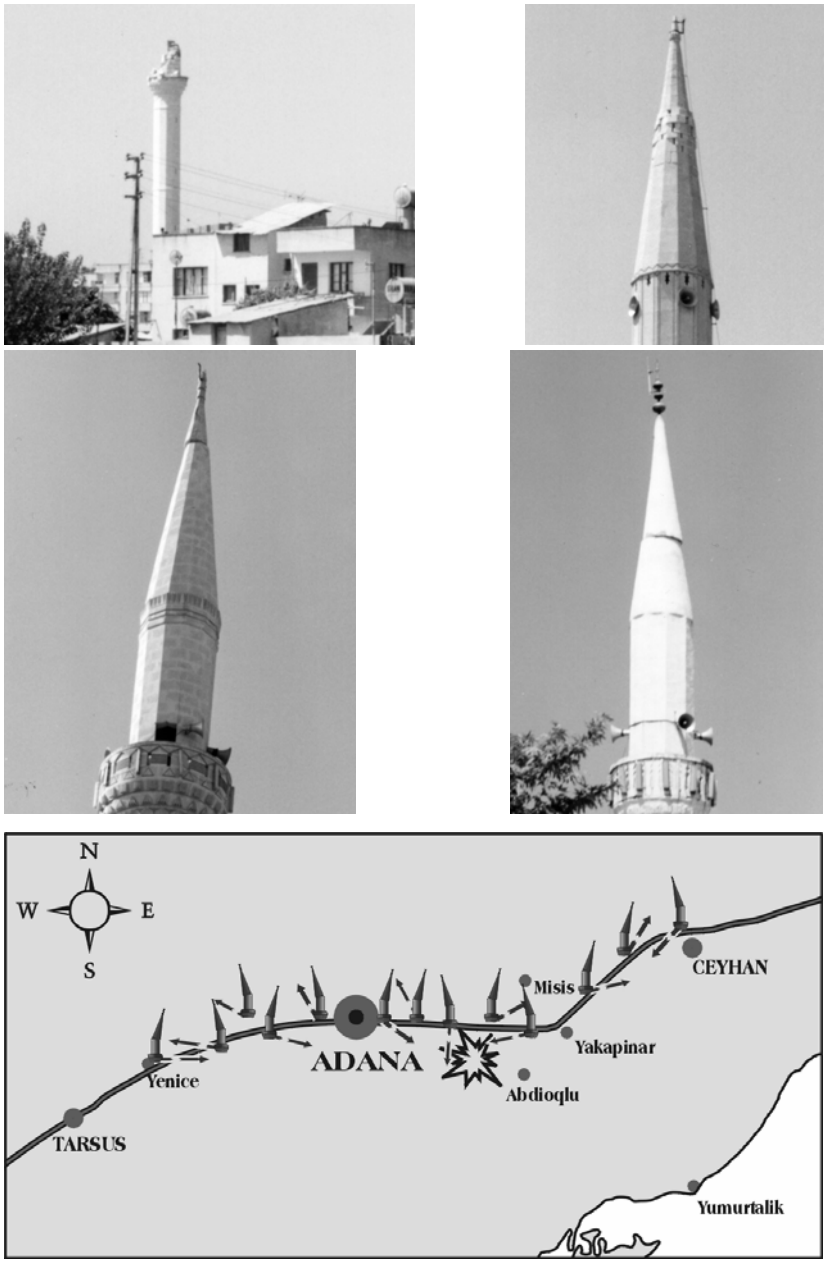


Figure 8. Aspect of minarets' collapse and their geographic distribution along with the direction of the collapse.

## Conclusions - Discussion

The earthquake of June 27th 1998, with a magnitude of $M_s$=6.2, a focal depth of approximately 10 km and the city of Adana as epicentre, is the result of the intense regional geodynamic processes with the wedging of the Eurasian plate by the Arabic plate being the dominant one. Based on the existing field data and the instrument recordings, it is concluded that the earthquake resulted from the reactivation of sinistral strike-slip faults which facilitate the advance of the Arabic plate to the north.

The earthquake caused significant damages to the broader region of the Adana province. The damages displayed notable differentiation among residential units with respect to the intensity of the damages as well as to a selective development in the various types of structures, despite the fact that the geological structure and the geological conditions are essentially the same throughout the area.

Specifically, considerable damages and some collapses occurred in both small and multi-story structures in the city of Adana, which are located a few kilometres from the epicentre. In the case of Adana, those damages in the specific buildings were anticipated due to defective construction, low quality materials and bad maintenance. In the city of Ceyhan, 50 km NE of Adana, numerous collapses were observed in multi-story buildings (6-8 stories). Many of those buildings suffered special types of damages owing to favouring orientation and size, while smaller structures remained intact. On the contrary in the city of Tarsus, 40 km WSW of Adana and poles apart from Ceyhan relative to the epicentre, no substantial damages were observed.

Damages were also observed in the villages between Adana and Ceyhan, where the destruction in old and modern one-story and two-story buildings was enormous. Eventually, special types of failures were observed in the top parts of minarets in the axial area Tarsus-Adana-Ceyhan.

Based on the above macroseismic data, some interpretations can be given regarding the aforementioned observations. The limited damages in Adana comparing to Ceyhan can be mainly attributed to the prevalence of the vertical component of the seismic motion, in spite of the frequency content of the proximal motion. Thus, only few older multi-story structures collapsed or sustained significant damages, while only few small low quality buildings of older age collapsed or suffered damages.

In the villages, located within a few kilometres from Adana, there was a complete destruction at all types of small buildings. This is

possibly due to resonance of the higher frequency seismic waves along with the small period of the structures.

Finally, in the city of Ceyhan, the numerous collapses of tall buildings, even with modern planning, are due to the frequency of the ground motion from distant excitation combined with the characteristics of the multi-story buildings, their orientation peculiarities in construction, ground characteristics etc. At the city of Tarsus, only minimal damages occurred, although the distance between Adana and Tarsus, is the same as the distance between Adana and Ceyhan and the poles apart position of Tarsus and Ceyhan. This fact can be explained by seismic wave directing, due to migration of the seismic focus, to the NE along the faults of the same direction that were activated (Lekkas[6]**,** Lekkas[7]). However, in any case the greatest damages, regardless of the type of buildings, are localised in a narrow elongated zone of ENE-WSW direction that extends from the southern suburbs of Adana to Ceyhan. This zone coincides with the fault zone that caused the seismic activity.

# References


[1] KASAPOGLU, E. & TOKSOZ, M.N., Tectonic consequences of the collision of the Arabian and Eurasian plates: Finite element models. Tectonophysics, 100, 71-95, 1983.

[2] BARKA, A. & KADINSKY-CADE, K., Strike-slip fault geometry in Turkey and its influence on earthquake activity. Tectonics, 7, 663-684, 1988.

[3] SAROGLU, F., EMRE, O. & KUSCU, I., Active fault map of Turkey, Scale 1:1.000.000. MTA, Ankara, 1992.

[4] PERINCEK, D., GUNAY, Y. & KOZLU, H., New observations on strike-slip faults in east and south-east Anatolia. Proceeding of 7th Biannual Petroleum Congress of Turkey, 89-103, 1987.

[5] CELEBI, M., The Adana-Ceyhan earthquake of June 27, 1998. EERI Special Earthquake Report, EERI, Newsletter, 32/9, September 1998.

[6] LEKKAS, E. & KRANIS, H., The Doppler-Fiseau effect on the damage distribution during the Kobe earthquake (Japan). Advances in Earthquake Engineering, Earthquake Resistant Engineering Structures, Computational Mechanics Publications, 2, 57-66, 1997.

[7] LEKKAS, E., Dinar earthquake (Turkey, October 1st 1995) correlation of the recent seismicity data and the neotectonic setting in SW Turkey. Bull. Geol. Soc. Greece, XXXII/1, 199-207, 1998.