



## **THE ADANA EARTHQUAKE (TURKEY) - SEISMOTECTONIC FRAMEWORK - GEODYNAMIC PHENOMENA - IMPACT ON THE STRUCTURED ENVIRONMENT**

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### **SUMMARY**

The earthquake of Adana in Southern Turkey occurred on 27 June 1998 and caused extensive damage to the building environment. Approximately 150 people were killed and thousands were injured. Instrumental data give that the shock measured 6.2 ( $M_s$ ) and was due to the reactivation of a sinistral strike-slip fault. The reported focal mechanism solution is in general accordance with the regional geotectonic setting, and was also confirmed by our observations on surficial seismic ruptures. Numerous ground fractures were located in and around Yakapinar. These were caused either by the seismic motion itself and/or were due to ground failure. Liquefaction and soil settlement were also observed in the same area, in the outcrops of the fluvial deposits of Ceyhan River, between Yakapinar and Abdioglu. Of prime interest is the damage caused by the earthquake to the inhabited areas within the meizoseismal area, and in particular in Adana, Ceyhan and smaller villages and settlements as Abdioglu, Yakapikaz, Misis, and so forth. The building environment is diverse, including various construction types. There were the older stone and brick masonry houses, together with modern ones; the former are usually small and highly vulnerable to earthquakes, while the latter have been built to meet certain earthquake-design standards. Every construction type suffered certain forms of damage, according to the quality of construction materials used, its age and the overall quality of construction.

### **INTRODUCTION**

On the 27<sup>th</sup> of June 1998 at 13:55:49 (G.M.T), an earthquake of magnitude  $M_s=6.2$  and focal depth of about 10km occurred in southern Turkey with its epicentre close to the city of Adana (Lat: 36.95, Lon: 35.31). The earthquake was widely felt in the broader area of Turkey, Syria, Cyprus and Israel. According to the official statements, the earthquake resulted in 150 casualties, 3000 injured and tremendous destruction. The epicentre was located in the broader region to the east of the city of Adana and the main shock was followed by a great number of aftershocks. The greatest aftershock occurred on the 4<sup>th</sup> of July with a magnitude of  $M_s=5.1$ , having the same focal depth with the main earthquake and epicentre in the same area (Lat: 36.89, Lon: 35.17). The aftershock caused panic and almost 1000 people were injured (Figure 1). Following are some background information on the regional seismotectonic framework as well as observations regarding the occurrence of geodynamic phenomena and their impact on the structured environment. These observations were obtained from fieldwork that took place immediately after the occurrence of the main seismic event.

### **THE SEISMOTECTONIC FRAMEWORK**

The broader region of Turkey is characterised by high seismicity that has resulted repeated destruction of various cities [Ergin et al., 1967], [Ambraseys and Adams, 1992], [Bektur, 1996]. The earthquakes of Ladik (1943), Erzincan (1939, 1992) and Dinar (1995) are the most recent characteristic examples of tectonic deformation that

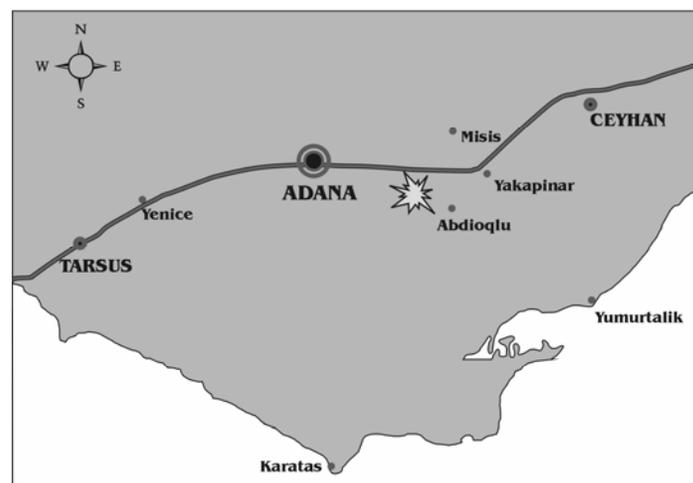
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displays special characteristics [Lekkas, 1998]. Neotectonic structures are dominant in distinct parts of the broader Turkish region as a result of the overall regional deformation due to the movement of the Eurasian, Arabic and African lithospheric plates.

Thus in the northern part, there is a dominant structure of a general E-W direction represented mainly by the Northern Anatolian fault which is characterised by strike slip movement and has repeatedly yielded big earthquakes such as those of Erzincan (1939, 1992). Normal faults with small horizontal displacement are dominant in central Turkey and have yielded earthquakes such as in the case of Dinar (1995) which is the most representative example.

In the specific broader area of Adana and of the Turkish-Syrian border, the dominant structures are similar to those encountered in the eastern Mediterranean coasts and are represented by sinistral strike slip faults through which the Eurasian plate is wedged by the Arabic plate. These faults, which comprise a first grade neotectonic macro-structure [Perincek et al., 1987], [Kasapoglu and Toksoz, 1983], have repeatedly yielded earthquakes such as those of 1514 and 1945 which destroyed cities and villages in the area of Ceyhan [Barka and Kadinsky-Cabe, 1988], [Saroglu et al., 1992], [Ambraseys and Finkel, 1995].



**Figure 1: Geographic map of the area.**

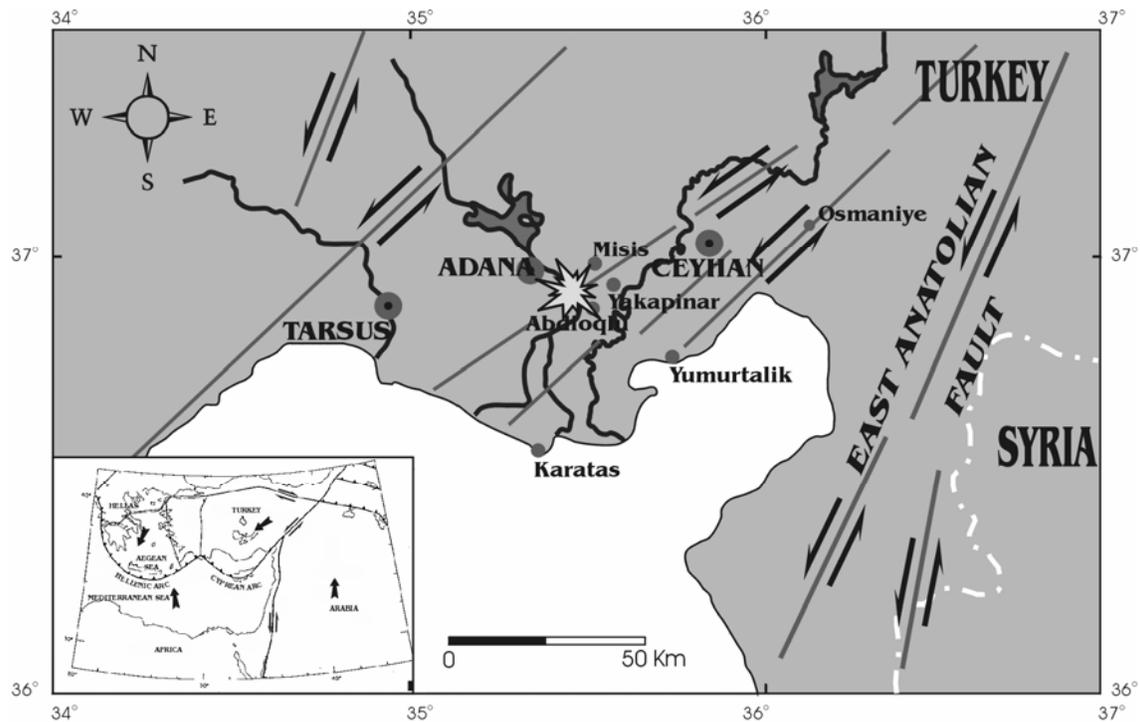
### **THE GEOLOGICAL FRAMEWORK**

The broader region of Adana, where the seismic activity was developed, is characterised by significant morphological variety due to the presence of on-going neotectonic processes. Specifically, the city of Adana is located at the apex of a gentle relief delta, formed by the deposits of the Seyhan and Ceyhan rivers which drain a broad area of southern Turkey. A mountainous terrain with elevations exceeding 1.500m is located at the N-NW of Adana and is the end of the central Turkey highlands. In addition, morphological uplifts are encountered from Karatas to the area of Osmaniye in the southeastern part of the delta and along the coastal zone owing to the presence of the homonymous fault zone which is mainly characterised by sinistral strike slip displacement. (Figure 2).

The earthquake-struck area is characterised by smooth relief except for some significant uplift in the southeastern part Karatas-Yumurtalik-Ceyhan. Specifically, the low flat part consists of deltaic deposits of the Seyhan and Ceyhan rivers (clays, silts, sands, conglomerates, etc.) while the part to the NE is comprised by Pliocene-Pleistocene-Holocene formations like travertine limestones, red-coloured siliclastic formations, alluvial formations etc. The aforementioned unconformably overlie on Alpine basement formations, mainly limestones, ophiolites and flysch, which outcrop in the area of the morphological uplifts at Karatas-Yumurtalik-Ceyhan.

Tectonic fault structures are hard to identify in the broader area due to the nature of the post-alpine formations and of the relief. The most significant structure identified, is the Karatas-Osmaniye fault zone which cross-cuts Alpine formations and includes 3-4 parallel faults and displays sinistral strike slip displacement. This zone is the result of the general regional deformation expressed mainly by geotectonic structures of sinistral displacement.

According to existing data, this zone was activated on the 20<sup>th</sup> of March 1945 yielding a destructive earthquake of Ms=6.0 [Saroglu et al., 1992].



**Figure 2: Neotectonic sketch map of the Adana region.**

### **CORRELATION OF INSTRUMENT DATA WITH FIELD OBSERVATIONS**

According to instrument recordings on a worldwide basis as well as on a country network level (USGS-ERCA, etc.) and based on the analysis of the focal mechanism solution, it was concluded that the earthquake was generated by a sinistral strike slip fault of a general NE-SW direction.

Seismic ruptures with sinistral displacement of NE-SW direction were identified after fieldwork observations. It should be noted that the general distribution of the epicentres of the recorded aftershocks displays the same arrangement with the seismic ruptures. The seismic ruptures, which extended for a length of approximately 300m between Incirlik and Yakapınar, in many locations, exhibited an en-echelon arrangement with practically no vertical displacement. This fact corroborates the sinistral displacement (Figure 3). Additionally, numerous ground ruptures were observed in the area, which are not related with the rupture caused by the fault plane but resulted from the behaviour of the ground formations during the earthquake.



**Figure 3: Part of a seismic rupture caused by sinistral strike slip movement.**

## CONCOMITANT GEODYNAMIC PHENOMENA

In the broader shaken area, concomitant geodynamic phenomena were observed which are mainly represented by ground ruptures and soil liquefactions. The ground ruptures were observed in the area of Adana-Ceyhan but their greatest and most impressive development was in the vicinity of the villages Yakapinar and Abdioglu. The soil ruptures displayed various directions while their length ranged from a few meters to many tens of meters and they often exhibited a vertical movement component and rarely an horizontal one. They formed on recent fluvial deposits and old flood-plain terraces of Ceyhan River where in some cases they displayed an impressive vertical displacement of more than 1m. The research conducted proved that these ruptures are not seismic ruptures for three main reasons:

- The great dispersion of their directions although there was a poorly established preferred orientation of NNE-SSW and NW-SE.
- The concurrent presence of liquefaction phenomena in many locations.
- The proximity of the ground ruptures with existing riverbanks or old flood-plain terraces where the ruptures developed with a parallel orientation.

Besides ruptures, extensive liquefactions were observed in many locations, formed mainly on recent and old deposits of the Ceyhan River. The liquefactions were located on both banks of the river where the unconfined aquifer was close to the surface and in the areas south of the village Yakapinar. Limited liquefactions occurred 8km north of the Ceyhan River in the villages Kucuk, Mangit and Katamerar. In the first area sand boils also occurred through holes with a diameter of up to 1m concurrently with ground ruptures. In many cases the liquefactions were accompanied by or caused settlements, which were extensive in the banks of Ceyhan River and the nearby areas. In some cases the observed settlements exceeded 3m.

## THE EARTHQUAKE IMPACT ON THE STRUCTURED ENVIRONMENT

The Adana earthquake ( $M_s=6.2$ ) caused significant damage on the structures of the broader area. A wide variety of damages in every type of structure were observed in the big cities of the shaken area as well as in smaller urban units.

The main types of structures identified are:

- Old one-story and rarely two-story adobe structures which are encountered in the smaller urban units and the historic centre of Adana.
- Two-story adobe structures with some type of reinforcement like mortar.
- Two-story or three-story structures of unreinforced concrete or with minimal reinforcement.
- Two-story or multi-story structures of reinforced concrete without earthquake-design standards.
- Multi-story buildings of reinforced concrete and earthquake-design standards.
- Mixed constructions with combinations of the previous construction methods.
- Special structures like mosques etc.
- Industrial complexes with special construction methods like steel pillar support and metal roofs.

The most substantial damages occurred in buildings of the first four categories mainly in villages where at least 30%-80% of the structures suffered significant damage. Furthermore, significant damages occurred in multi-story buildings of reinforced concrete and without earthquake-design standards or with the quality of the materials significantly degraded. Such damages that led to total collapse occurred in the area of Adana and in the area of Ceyhan (Figure 4).



**Figure 4: Total collapse of multi-story building at the city of Ceyhan.**

Significant damages were also observed in the historic monuments of the area and mostly in mosques and minarets (Figure 5). These damages showed a selective development in the upper parts of the minarets [Lekkas and Vassilakis, 1999]. Additionally in the vicinity of the villages Yakapinar-Abdioglu, some industrial buildings with metal framework suffered significant damages.



**Figure 5: Partially collapsed mosque in the city of Ceyhan.**

It is interesting that there is a correlation between the type of building and the type of damage suffered. The extent of the damage however, is also related to the construction quality, the quality of the materials, the age of the structure, the maintenance but also to the geographic location and the azimuth position with respect to the epicentre. Some of the reasons that caused the damages are similar to those determined in other earthquake cases in Turkey like the earthquake of Dinar [Carydis et al., 1995]. Such reasons are: (i) soft first story, (ii) inadequate detailing and reinforcements of column-beam connections and columns, (iii) design of strong beam/weak columns rather than strong column/weak beams and (iv) succession of flexible and rigid parts in big buildings (Figure 6).



**Figure 6: Partially collapsed building, due to the succession of flexible and rigid structural elements.**

Finally based on the research of damage development, it was concluded that the area of damage development is strictly constrained from Adana to Ceyhan in a NE-SW direction. This is the direct result of the type of earthquake, of the direction of the fault that yielded the seismic event and of the seismotectonic framework in general.

## CONCLUSIONS

The Adana earthquake is a geodynamic event that resulted from the intense geodynamic processes taking place in southern Turkey that are characterised by the advance of the Arabic plate towards the north and the consequent wedging of the Eurasian plate. Based on field observations, seismic ruptures and the analysis of the focal mechanism solution, the sinistral strike slip character of the earthquake-generating fault is typical of the regional neotectonic deformation which has also produced other seismic events with the 1945 earthquake being the most recent one.

In some cases the Adana earthquake caused concomitant concurrent geodynamic phenomena in sensitive areas which are represented by ground ruptures and soil liquefactions near the epicentre. These phenomena took place wherever the geological conditions favoured the development of such phenomena i.e. the recent fluvial deposits of the Ceyhan River and the elevated water table on both banks.

The impact of the earthquake on the structured environment was particularly great and every type of building is associated with specific type of damage. The intensity of the damages observed for every type of building is directly related to the quality of the construction, the quality of the materials and the azimuth position relatively to the epicentre whereas the intensity of the damages was irrelevant to the distance of the epicentre.

Finally, based on the specific earthquake and other recent earthquakes in Turkey, it was concluded that every seismic event exhibits characteristics directly related to the type of the regional neotectonic deformation that causes the seismic activity. Furthermore, other parameters like the small focal depth and the proximity of big urban areas with a variety of structure types increase the vulnerability and pose a direct threat.

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## ABSTRACT

The earthquake of Adana in Southern Turkey occurred on 27 June 1998 and caused extensive damage to the building environment. Approximately 150 people were killed and thousands were injured. Instrumental data give that the shock measured 6.2 ( $M_s$ ) and was due to the reactivation of a sinistral strike-slip fault located southeast of Adana. The reported focal mechanism solution is in general accordance with the regional geotectonic setting, which is a consequence of the northward movement of the Arabian plate relative to the Eurasian, and was also confirmed by our observations on surficial seismic ruptures.

Numerous ground fractures were located in and around Yakapinar. These were caused either by the seismic motion itself and/or were due to ground failure. Liquefaction and soil settlement were also observed in the same area, in the outcrops of the fluvial deposits of Ceyhan River, between Yakapinar and Abdioglu, east of Adana. Of prime interest is the damage caused by the earthquake to the inhabited areas within the meizoseismal area, and in particular in Adana, Ceyhan and smaller villages and settlements as Abdioglu, Yakapikaz, Misis, and so forth.

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Based on the specific earthquake and other recent earthquakes in Turkey, it was concluded that every seismic event exhibits characteristics directly related to the type of the regional neotectonic deformation that causes the seismic activity. Furthermore, other parameters like the small focal depth and the proximity of big urban areas with a variety of structure types increase the vulnerability and pose a direct threat.