Learning from Earthquakes

Preliminary Observations on the Sultandagi, Turkey, Earthquake of February 3, 2002

This report was contributed by the reconnaissance team from the Department of Earthquake Engineering at the Kandilli Observatory and Earthquake Research Institute of Bogazici University, Istanbul, Turkey. The team was in the field the morning of the day after the earthquake, and the field survey continued for two days. The team was comprised of Professor Mustafa Erdik; Research Assistants K. Sesetyan, M. B. Demircioglu, U. Celep, and Y. Biro; and Assistant Professor E. Uckan. The publication and distribution of this report are funded by the National Science Foundation as part of EERI's LFE Program, under Grant #CMS 0131895.

Introduction

An earthquake of magnitude Md = 6.0 (Mw = 6.3) struck on February 3, 2002, at 9:11 a.m. local time, causing damage and casualties in the town of Afyon (population 183,351) and its neighbors (Sultandagi, Cay, Bolvadin, Cobanlar, Suhut, and Aksehir). The macroseismic epicenter was located near the Sultandagi province. The earthquake is associated with the Sultandagi fault zone. Three major aftershocks with magnitudes between 5 and 6 followed the main event. One of those (Mw = 6.0, at 11:26 a.m. local time) might be considered as another main shock. The peak horizontal accelerations recorded were 0.11g at Afyon, approximately 55 km from the epicenter. Casualties totaled 42 dead and 325 injured.

Tectonics

The main tectonic features of the central and western Anatolian regions are illustrated in Figure 1. Extensive investigations have shown that numerous graben systems have been forming in the E-W and WNW-ESE directions due to the N-S substantial extension in western Anatolia (Ketin 1968; Dewey and Sengor 1979; Jackson and McKenzie 1984). The Gokova, Buyuk Menderes, Kucuk Menderes, Gediz, Bakircay, Kutahya, Eskisehir, and Simav grabens constitute the main tectonic structure of the region, together with the Fethiye-Burdur, Tuzla, and Bergama-Foca fault zones that are trending in the NE-SW direction. A number of major normal faulting events have occurred along these faults; for example, the 1899 Buyuk Menderes, 1928 Torbali, 1955 Balat, 1969 Alasehir, 1969 Menderes, 1969 Simav, 1970 Gediz, and 1995 Dinar earthquakes. NW to SE striking normal fault systems (such as the Pamukkale, Dinar, and Yatagan-Mugla faults) occur mostly in the southwestern Aegean.

The February 3, 2002, earthquake was centered in the Sultandagi fault zone (see Figure 2), which is a NW-SE trending fault separating the Sultandagi rise and the Aksehir-Afyon graben. According to Boray et al. (1985), Saroglu et al. (1987), and Barka et al. (1995), it is a thrust fault. However, Kocyigit et al. (2000) name the fault as the "Aksehir fault" and define it as a normal fault with oblique offset. The rapid moment tensor solutions taken from the USGS support the latter claim.

Seismicity

Although the Burdur-Dinar (Apameia) region, about 100 km southwest of the earthquake epicenter, has been repeatedly affected by large historical earthquakes, the site of the Sultandagi earthquake has been relatively free of historical earthquakes. This may be the result of the very low strain rates. Records over the last century indicate that

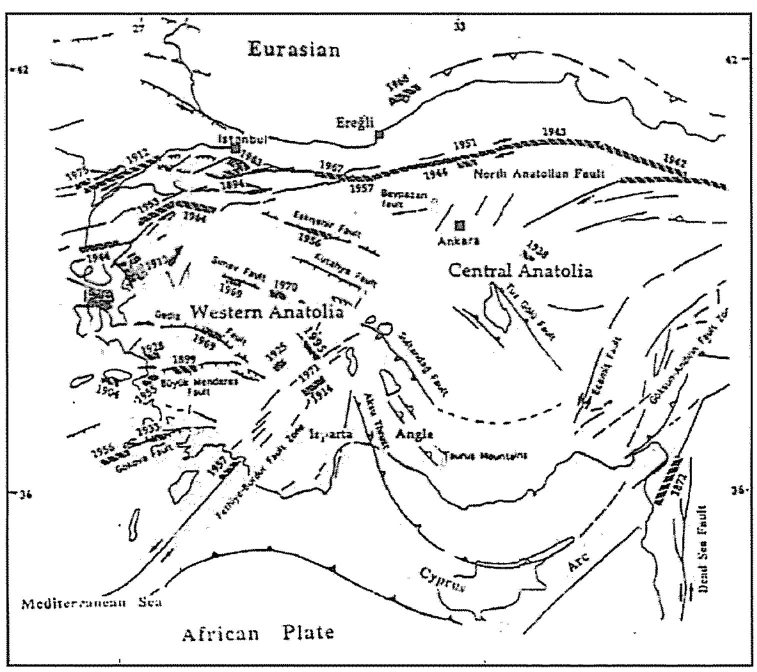

***Figure 1** - Tectonic features of the central Anatolian and Aegean regions.*

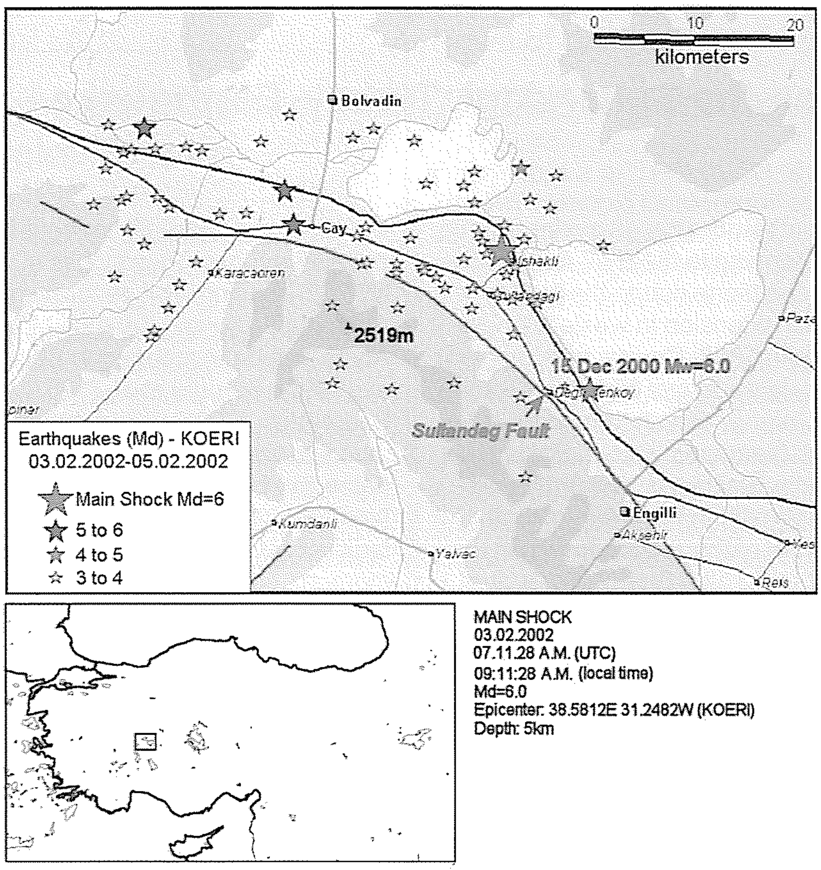

Figure 2 *- The main shock and the aftershock distribution.*

on October 3, 1914, the Burdur earthquake (37.50N, 32.50E) (M = 7, intensity IX) killed about 4,000 people and destroyed about 17,000 houses. That earthquake was associated with a 23-km fault rupture along the southeast coast of Burdur Lake. Another earthquake (Ms = 6, intensity VIII) occurred on August 7, 1925, at Afyon-Dinar, causing damage in the region lying between Hamidiye and Denizli. On May 12, 1971, an earthquake (Ms = 6.2, intensity IX) struck the town of Burdur, destroying 1,487 houses and killing 57 people. Another earthquake of magnitude Ms = 6.1 struck Dinar on October 1, 1995. The earthquake killed 90 people, injured 260, and caused extensive damage to 30% of the buildings in the city (population 35,000). The fault ruptures associated with those earthquakes are illustrated in Figure 1.

The Sultandagi fault was recently activated by the December 15, 2000, (Mw = 6.0) Bolvadin earthquake, which occurred in the southeastern part of the fault zone. The earthquake caused six casualties, 82 injuries, and damage in Bolvadin, Aksehir, and Ilgin provinces. The epicenter of this earthquake is also shown on Figure 2. The Sultandagi earthquake is located in the first-degree earthquake hazard zone on the hazard map associated with the 1998 Turkish earthquake-resistant design regulations.

Soil Conditions

The affected cities of Cay, Yakasinek, and Sultandagi are located on alluvial fans to the north of the Sultandagi mountains. The soil conditions represent gradation from stiff soil sites to alluvial deposits from south to north, as morphology changes from mountain slopes to fan deposits. The village of Eber is located essentially on holocene marshlike deposits.

Seismology

The main shock and the distribution of aftershocks recorded at Kandilli Observatory and Earthquake Research Institute are given in Figure 2. The epicenter, magnitude, and the available rapid moment tensor solutions as given by USGS of the main shock, and the three major aftershocks, are noted in Table 1 below.

The physical parameters of the earthquake are somewhat similar to those of the October 1, 1995 Mw = 6.0 Dinar earthquake (Durukal et al. 1998). Both earthquakes had normal fault mechanisms, but the seismic moment of the Sultandagi earthquake was about twice that of the Dinar earthquake (2.9*10^18 Nm compared to 1.3*10^18 Nm).

Preliminary reports indicate a fault scarp of about 30 km for Sultandagi. The Dinar earthquake caused a fresh fault scarp with about 30 cm vertical and 5 cm right lateral fault offset.

The maximum PGA recorded in the 1995 quake was 0.33g at Dinar City. Peak ground accelerations caused by the 2002 Mw = 6.3 and Mw = 6.0 events are given in Figure 3.

Table 1 - List of the major events

Date	Time (UTM)	USGS	KOERI	D USGS	Md	Mw
03.02.2002	07:11	38.521N 31.156E	38.5812N 31.2482E	10	6.0	6.3
03.02.2002	09:26	38.646N 30.819E	38.6855N 30.8350E	10	5.3	6.0
03.02.2002	11:39	38.53N 30.96E	38.6317N 30.9973E	10	5.1	
03.02.2002	11:54	38.56N 31.03E	38.6013N 31.0077E	10	5.0	

Table 2 - Damage distribution

Location	Heavy damage and collapse		Medium damage		Low damage	
	Res.	Comm.	Res.	Comm.	Res.	Comm.
Bolvadin	471	35	436	254	3,134	408
Cay	1,226	245	136	14	1,660	29
Cobanlar	446	5	375	35	981	37
Iscehisar	45	1	3	-	55	1
Merkez	1,116	37	143	7	1597	26
Sincanli	35	1	2	1	52	2
Suhut	-	-	-	-	99	-
Sultandagi	712	15	302	22	1,427	48
Total	4,051	339	1,397	333	9,005	551

Res. = Residential; Comm. = Commercial

Table 3 - Casualty distribution

Location	Dead	Injured
Aksehir	1	7
Bolvadin	2	200
Cay	23	67
Cobanlar	-	21
Merkez	2	-
Sincanli	1	-
Sultandagi	13	30
Total	42	325

Damage

The distribution of casualities and damaged buildings are given in Tables 2 and 3.

The damaged towns are illustrated in Figure 4.

Intensities were estimated with the help of the tabulated damage and field observations as follows: VII in Cay and 20 km to its southeast, and VI in an 80-km oblong area centered on Cay.

Performance of Structures

Heavy damage and total collapse were particularly concentrated in a narrow region in Cay. Older single-story buildings in the region are commonly himis structures (buildings composed of timber frames and braces with adobe infills), whereas newer ones are unreinforced masonry and reinforced concrete structures with two or three stories.

Himis Buildings: Most of the injuries and casualties in the region are associated with the total collapse of himis buildings. They were widely preferred in rural areas three or four decades ago and were traditionally built by their residents without engineering considerations. Thick perimeter walls and heavy roofs are common features of himis buildings, providing heat insulation. The observed performance indicates the poor strength and brittle behavior of the walls, and the considerable mass of the buildings. Observations suggest that due to the lack of rigid diaphragm action, most of the walls responded individually to the ground motion. Moreover, observation of collapsed buildings indicates that as a consequence of weak connections between the perimeter walls and orthogonal partition walls, separation occurred there, and most of the thick perimeter walls collapsed in the out-of-plane direction. Figure 5 shows a collapsed himis building in Eber.

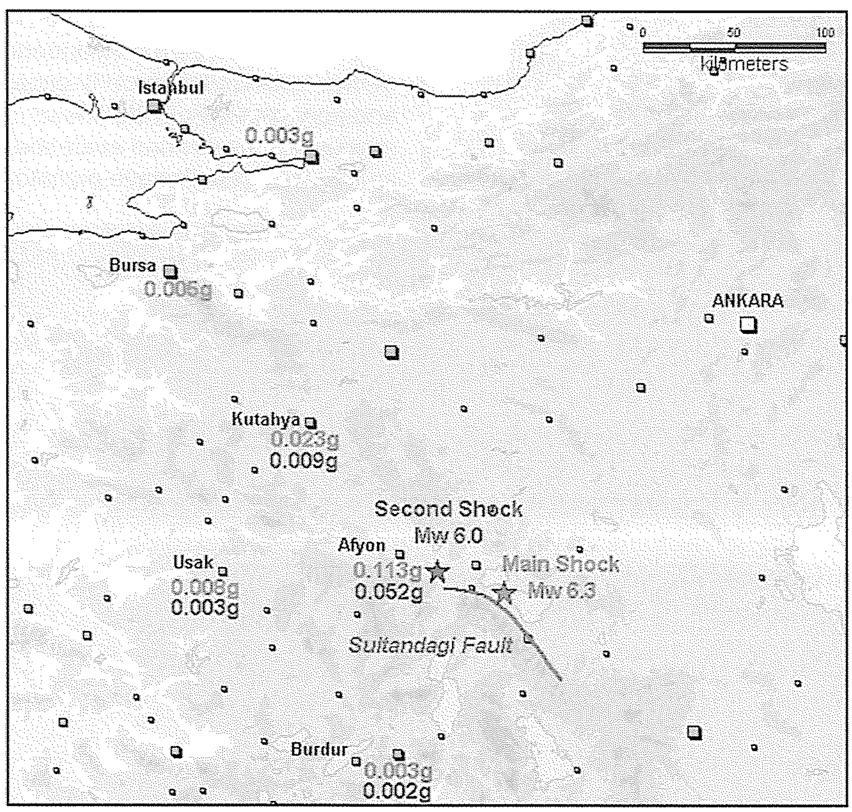

***Figure 3** - Peak ground accelerations recorded from the Mw = 6.3 event (indicated in gray) and from the Mw = 6.0 event (indicated in black).*

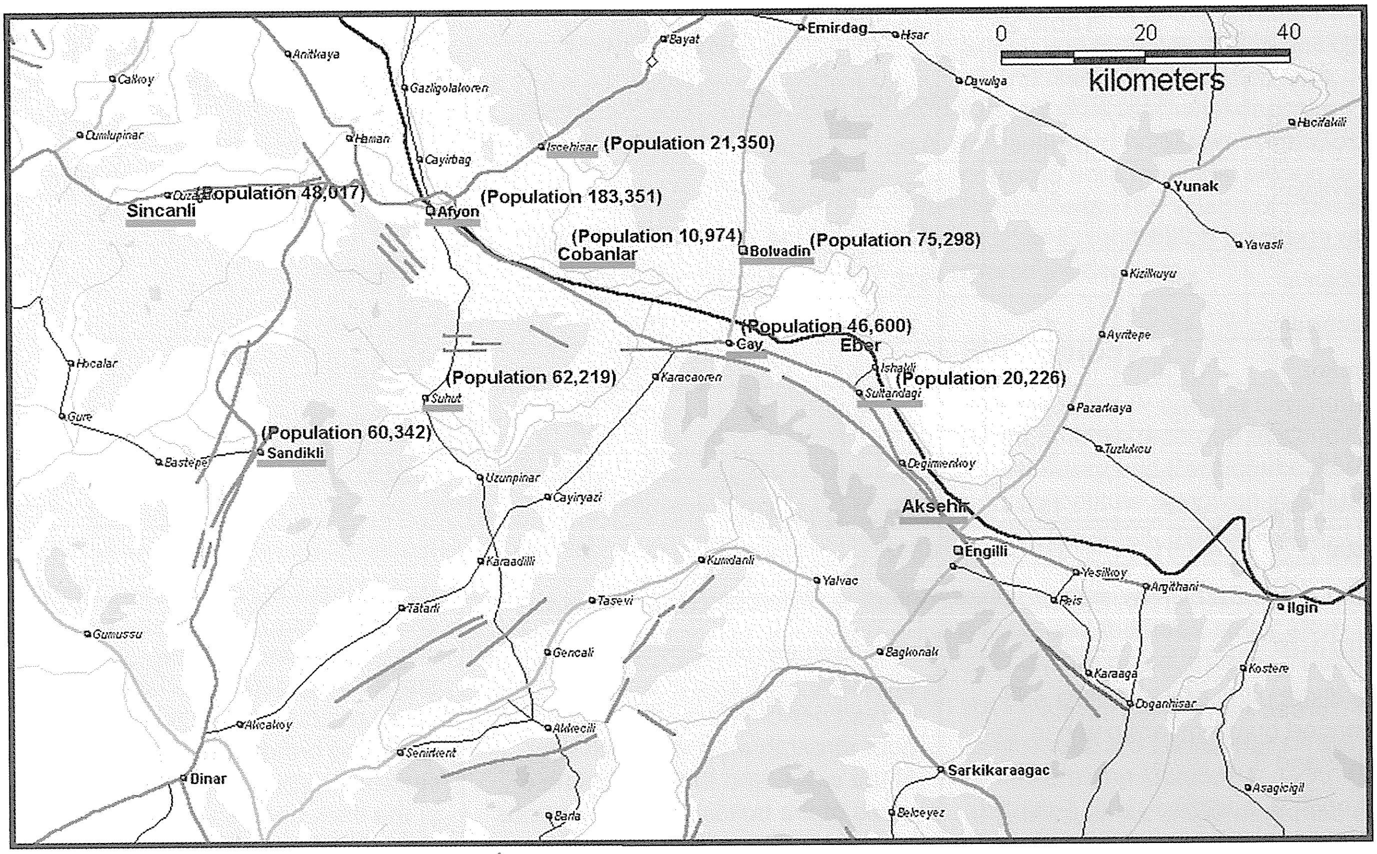

Figure 4 - Damage distribution.

Unreinforced Masonry Buildings: In Turkey, unreinforced masonry has always been chosen over reinforced masonry despite its seismic vulnerability. However, Turkish seismic codes have attempted to reduce the disadvantages by limiting the number of stories (e.g., a maximum of two stories for seismic zone 1, and three stories for seismic zone 2), with conservative detailing and force reduction factors. Eventually, it is hoped that most of the new buildings in the region will satisfy the story limitation rules for seismic zone 1; however, new masonry buildings with three or four stories have been observed.

Observed heavy damage and collapse of unreinforced masonry buildings are associated with the use of hollow clay tiles instead of solid brick units. Hollow clay tiles are widely used as infill panels in reinforced concrete buildings, but are not allowed for masonry structures as load-bearing members. First-story collapse (Figure 6) is the common failure mode for structures built with hollow clay tiles as a consequence of their very limited ductility capacity and poor strength. Wide shear cracks in the walls and evidence of crushing (Figure 7) have commonly been observed in heavily damaged hollow clay tile buildings. Some of the buildings with fewer than three stories survived the earthquake with minor damage even though they were built with hollow clay tiles.

Figure 5 - Collapsed himis building in Eber.

Figure 6 *- Collapsed masonry building built with hollow clay tiles.*

Reinforced Concrete Buildings: Most of the heavy damage and collapse of reinforced concrete buildings was limited to a narrow region in Cay. Peak ground acceleration (PGA) in Cay, which is approximately 10 km away from the epicenter, was estimated to be approximately 0.20-0.25g. About 30% of the buildings in the Cay commercial blocks collapsed, while those remaining were heavily damaged (Figure 8).

The commercial blocks were designed and completed in the 90s. Each block was composed of five spans in the longitudinal direction and four spans in the transverse direction. Observations suggest that plain round bars (fy = 220 MPa, 40 ksi) and deformed bars (fy = 420 MPa, 60 ksi) were used as reinforcement. Bond failure of the column bars was observed to be the major cause of the collapse: the column bars were not bent in 90° hooks in the beam-column joints, and splices at column bases were inadequately lapped. This resulted in slip of the column bars from the joints and from the foundations before a sound plastic mechanism could develop in the potential plastic hinge zones. Some of the columns collapsed in the direction opposite to that of the collapsed slab. Some remained vertical, even though the supporting slab collapsed (Figures 9 and 10). Blocks that did not collapse show evidence of wide flexural cracks concentrated at the beam-column joint faces and splitting cracks in the beam-column joints, indicating some level of bar slip.

There are instances of column core concrete crushing as a consequence of inadequate transverse reinforcement failure. Transverse reinforcement spacing of 200 mm is common in most of the columns; most of the transverse reinforcement with 90° hooks opened during the earthquake due to their poor anchorage features, particularly after cover concrete spalling (Figure 11). Exterior beam-column joint failures were also observed in some blocks. Details of the joints suggest that outer column bars buckled and joint cores crushed to some extent due to the lack of joint transverse reinforcement (Figure 12).

One of three identical eight-story apartment buildings in Cay, close to the commercial blocks, totally collapsed (Figure 13). Observations suggest that loss of column bar anchorage at the foundation level, and probably at the story levels (Figure 14), caused the collapse. Columns showed no evidence of distributed flexural or shear cracks, suggesting the possibility that column bars slipped before the attainment of flexural capacity. Another building lost its first two stories, which collapsed due to inadequate transverse reinforcement details. There are many instances of crushed concrete due to excessive transverse expansion of the core concrete and shear cracks in the weak

Figure 7 *- Heavily damaged 4-story masonry building in Cay.*

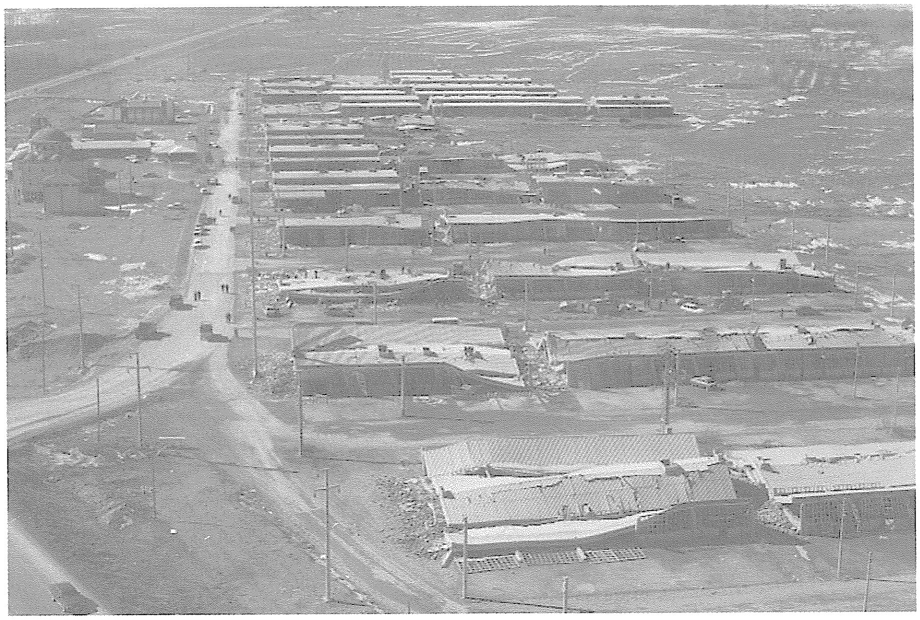

Figure 8 *- Cay Commercial Blocks.*

direction of the columns.

The mosque in the commercial blocks also suffered considerable damage (Figure 8 — upper left). This soft-story building is reinforced with plain round bars (fy = 220 MPa, 40 ksi). Full-depth single flexural cracks, 3-4 mm wide, at beams concentrated at column faces suggest some level of beam bar slip (Figure 15). Observed damage indicates that the building responded dominantly in the oblique direction, causing biaxial bending in columns. Most of the bars buckled and cover concrete spalled at column corners. None of the columns exhibited shear-flexure cracks distributed over a constant length; however, one of the columns adjacent to infill walls in the first story failed in shear (Figure 16). It was observed that corner beam-column joints exhib-

Figure 9 *- Column and slab collapsing in opposite directions.*

Figure 10 *- Collapsed slab due to bond failure of the column bars.*

ited beam bar slip, longitudinal column bar buckling, and some level of diagonal tension cracking (Figure 17).

It was difficult to determine the behavior of members at the upper stories; however, the outer face of the building did not indicate any evidence of significant outer column damage.

Fortunately, the collapses caused no fatalities since it was an off-day for the workers, and the eight-story buildings were unoccupied at the time of the earthquake.

Buildings in Eber and Sultandagi performed well due either to the adequacy of all aspects of their design and construction, or to a level of ground motion not strong enough to test them.

Figure 11 *- Spacing of transverse reinforcement visible in a column.*

References

Barka, A., R. Reilinger, F. Saraoglu and F. Sengor, A.M.C. (1995), *Proceedings of the International Earth Science Colloquium on the Aegean Region*, 1, 3-18.

Boray, A., F. Saroglu and O. Emre (1985), *Jeoloji Muhendisligi*, 23, 9-20.

Dewey, J. F. and A. M. C. Sengör (1979), "Aegean and surrounding regions: Complex multiplate and continuum tectonics in a convergent zone," *Geological Soc. of Am. Bull.*, Vol. 90, pp. 84-92.

Durukal, E., M. Erdik, J. Avci, Ö. Yüzügüllü, Y. Alpay, B. Avar, C. Zülfikar, T. Biro and A. Me (1998), "Analysis of the strong-motion data of the 1995 Dinar, Turkey earthquake," *Soil Dynamics and Earthquake Engineering* 17, pp 99.557-578.

Kandilli Observatory and Earthquake Research Institute, Bogazici University, Istanbul, Turkey: *www.koeri.boun.edu.tr.*

Ketin, I. (1968), "Relations between general tectonic features and the main earthquake regions of Turkey," *Bull. of Mineral. Research and Expl. Inst.*, 72, pp. 1-28, Ankara.

Kocyigit; A., E. Unay and G. Sarac (2000), *GSA Special Publ.*, pp 173,405-421.

Figure 12 *- Exterior beam-column joint damage.*

Jackson, J. and D. McKenzie (1984), "Active tectonics of the Alpine-Himalayan belt between western Turkey and Pakistan," *Geophys. J. R. Astr. Soc.*, 77, pp. 185-264.

Saroglu, F., O. Emre and A. Boray (1987), *MTA Report,* No. 8174.

Figure 13 *- Collapsed and damaged 8-story apartment buildings.*

Figure 14 -
Bond failure at column base.

Figure 15 -
Full depth beam flexural crack.

***Figure 16 -** Observed column shear failure.*

***Figure 17** - Damage at a beam-column joint.*