NOTES ON THE 1999
KOCAELI-GOLCUK AND DUZCE-BOLU
EARTHQUAKES IN TURKEY

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Introduction

At the time of this writing, three months after the 18 Aug. 1999 Kocaeli-Golcuk earthquake in northwest Turkey, the available data on the impact of the earthquake are still in a state of flux. The reported casualty count from the Kocaeli event has been slowly approaching 20,000 with almost twice as many reported injured. Over 100,000 residential units are reported to have been lost. The following major event of 12 November 1999 (the Duzce-Bolu earthquake, M_w=7.2) claimed over 700 lives. Approximately 5000 were reported injured. Statistics of structural and environmental damage have not yet been compiled for the Duzce-Bolu event.

The Kocaeli fault trace, estimated to be over 150 km long (Fig. 1), tracks the most important industrial region in Turkey, a region that is responsible for approximately one-sixth of the "value added" for the entire country. The overall direct economic impact is currently set at $16 billion.

The visible fault trace for the Duzce earthquake of 12 November has been identified to extend E-W approximately 40 km at the east end of the Kocaeli rupture (Fig. 1). The town of Duzce, with a population of 80,000 was subjected to very strong ground motion twice within three months.

The moment magnitude, M_w, of the Kocaeli event was set at 7.4 by the USGS and its hypocenter was located at a depth of approximately 17 km. Considering that the rupture ran through a densely populated region, the location of the epicenter (near Golcuk) is not a critical factor for reconciling damage with magnitude. Perhaps the best quantitative indicator of the damage potential is a qualitative and fictionalized one. Imagine a corridor from Milwaukee to South Chicago. Assume that heavy and

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light industry has developed along that corridor within a span of less than 25 years. Industrial development has been matched by residential development to attract over 2 million people to live along the strip. Both developments have been assembled with as much or as little planning as can be exercised over that short a period for so much construction. Now put a vertical cut through this N-S corridor and move the western part abruptly some 4 m. south and 2 m. down. The cut goes right through some of the concentrations of the building inventory, the vibrations set up by friction between the faces of the fault jar the entire region, and some of the land west of the cut subsides and is inundated by the lake. To boot, this devastating jolt is followed by another strong one within a few months.

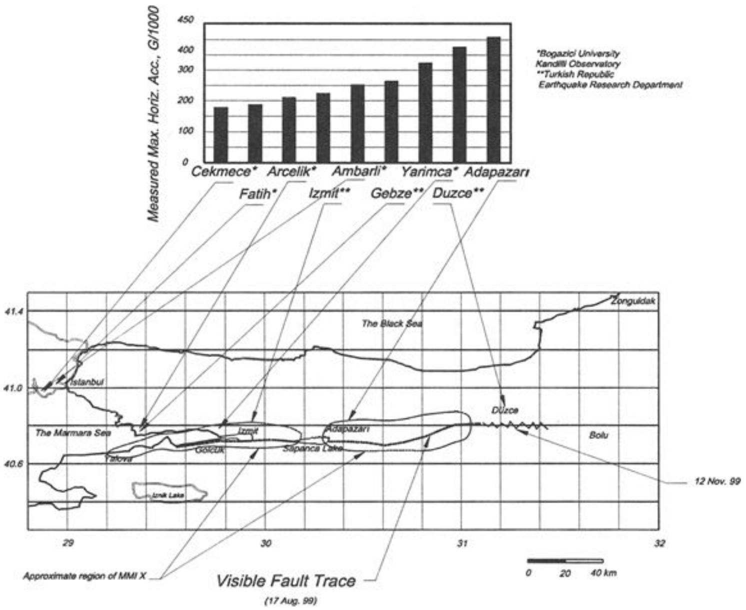

Figure 1 Map of Region Affected by the Kocaeli-Golcuk (17 August 1999) and the Duzce-Bolu (12 November 1999) Earthquakes

It will be a long time before all aspects of what happened as a result of the Kocaeli 1999 and Duzce 1999 earthquakes get documented and we obtain a proper perspective of what should be learned from this event. The following text has been written to provide glimpses of a few aspects of the disaster.

At the moment the two events appear not only to have inflicted heavy damage but also impacted severely our conventional wisdom about earthquake occurrence and effects. The Kocaeli earthquake was not unexpected in location and magnitude. But the timing of the Duzce event was not. The intensity and nature of the few strong ground motion recordings obtained during the Kocaeli earthquake raised questions about our projections of near-fault shaking associated with large magnitude events. The intensity of the motions measured during the Duzce earthquake appears to have tested strongly the relationships between observed damage and instrumental measurement. There are also serious questions that need to be answered about the sequence of ground failures in Adapazari during the 17 August event. Was the liquefaction affected by the continual aftershocks, albeit of lower magnitude, that supplied fresh energy to the soils for approximately six minutes?

The Ground Motion

A total of 35 strong-motion instruments were triggered by the earthquake (Table 1). Locations and maximum readings of the nine instruments that yielded peak horizontal acceleration measurements in excess of 0.15G are indicated in Fig. 1.

Along the approximately 200-km length (E-W) of the strongly affected region, there were only six instruments. In the Golcuk-Yalova strip (Fig. 1), there was none. It is possible that the actual maximum ground acceleration could have exceeded 0.4G and yet not have been documented. The right lateral slip along the portions of the fault trace between Golcuk and Sapanca exceeded 4 m and may have reached 5 m. The hypocenter of the event was placed almost immediately below Golcuk at a depth of 17 km.

The few strong motions recorded during the 17 August and 12 November events deserve intensive study and may alter the way we think about strong motion intensity and distribution related to large-magnitude earthquakes. There is no reason to expect that their characteristics will coincide with those of earlier records or their projections. Nor is it reasonable to accept that the few instrumental records obtained capture the universal characteristics of the earthquake. It is still of interest to examine them in the light of expectations based on convention.

Figure 2 contains an example from the Kocaeli earthquake (17 August): the records obtained by DAD* at Duzce. This was not the most demanding record obtained by DAD but it has become of primary interest because of what happened in Duzce later on 12 November. Because it was obtained using an analog instrument (SMA-1), the record obtained on 12 November has not yet been released. For an example of the 12 November ground motion, the Bolu record will have to do (Fig. 2). The location for the city of Bolu is indicated in Fig. 1. It was approximately 40 km distant from the end of the fault trace observed after the 12 November event.

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The strong motion captured in both the Duzce and Bolu records was of relatively short duration, approximately 15 sec. The peak values are listed in Table 1. As the strong-motion data are studied in greater detail, it is possible that the reported peaks will be adjusted.

Linear response spectra calculated for the horizontal components are shown in Fig. 3 and 4. The Duzce (17 August) spectra are ordinary. The Bolu spectra show an unusual sensitivity to direction. It is also surprising to find the amplification of acceleration response so low for the E-W direction. The magnitude of the linear displacement response is not unusual for either record, given the peak acceleration readings.

As reported by Dr. Gulkan of Middle East Technical University, Ankara, the five-story building containing the instrument that recorded the motion did not appear to sustain the damage that would be associated with a 0.8 G peak horizontal acceleration on the basis of conventional knowledge. Indeed, the calculated response spectrum simply would imply serious damage. The observed phenomenon questions the very foundations of the intellectual chain that extends from the source, through the path, to ground motion and building response.

Problems Related to Fault Trace and Ground Failure

The structural failures observed after the 17 August earthquake were, in general, complex results of ground failure and structural shaking. In some instances, they could be classified categorically to be caused primarily by the foundation or by structural inadequacy. Because the results of ground failures were dramatic, it is difficult to deny the temptation of mentioning a few even though the discussion must remain superficial.

Near Golcuk, the observed right lateral throw and its effects were clearly visible (Fig. 5). It traversed a heavily populated region and caused direct damage (independently of shaking) as illustrated in Fig. 6 through 8. The direct effect of the ground distortion is clearly demonstrated by the foundations of the communication tower in Fig. 8. Subsidence on one side of the fault trace resulted in pulling out of one of the foundations blocks.

The landslides during the Kocaeli event were not as dramatic as in the Duzce 12 November event but they did lead to serious losses especially near the shoreline (Fig. 9 and 10).

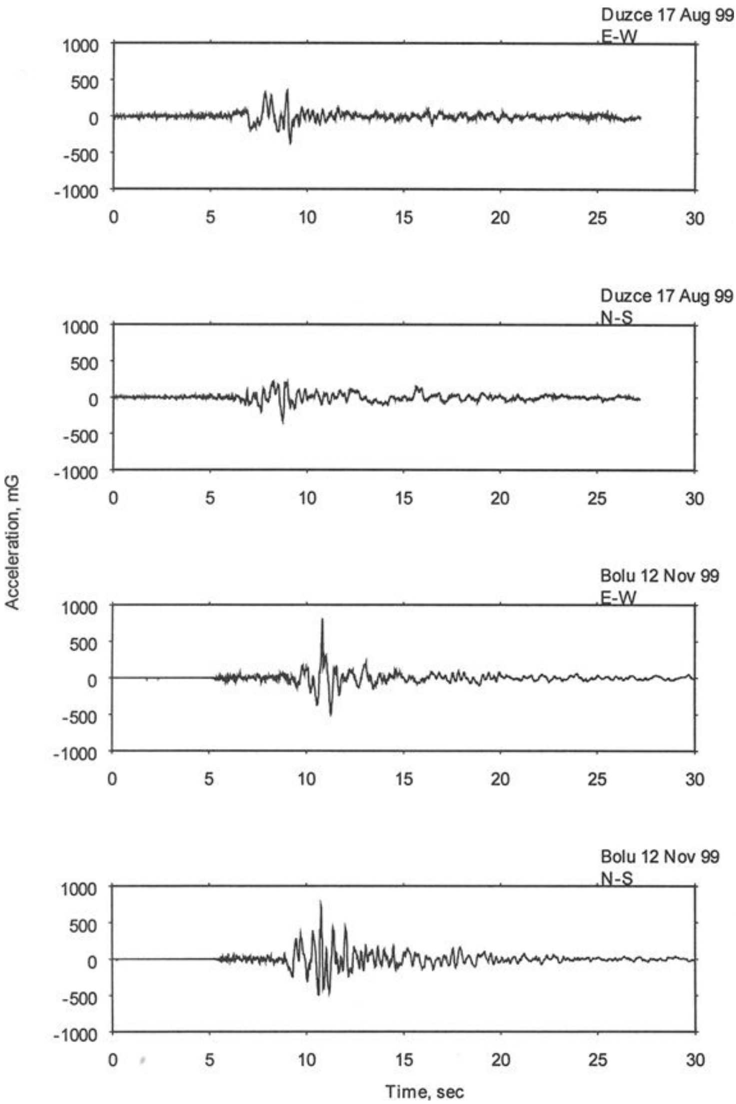

Figure 2 Strong Ground Motion Measured in Duzce and Bolu by The Earthquake Research Dept., Ministry of Settlement and Disaster Affairs, Ankara

TABLE 1. Measured Ground-Motion Maxima (Earthquakes of 17 August and 12 November 1999)

Source	Date	Time GMT	Longitudinal MG	Transverse mG	Vertical mG	S-P sec	Location	Direction
DAD	17.08.1999	0:05:14	0.8	1.2	0.4	N/A	Tokat	L=South
DAD	17.08.1999	0:05:04	50	59.7	23.2	N/A	Kutahya	L=South
DAD	17.08.1999	0:04:54	2	3	1.5	N/A	Ceyhan	-
DAD	17.08.1999	0:03:26	5.9	5.2	3.3	46	Aydin	L=South
DAD	17.08.1999	0:02:56	1	2	1	N/A	Konya	-
DAD	17.08.1999	0:02:47	5.9	11.7	3.7	N/A	Denizli	L=South
DAD	17.08.1999	0:02:41	9.9	10.8	3.3	42	Bornova	L=South
DAD	17.08.1999	0:02:39	11.7	8.9	4.4	43.87	Tosya	L=South
DAD	17.08.1999	0:02:36	24.6	28.6	7.9	38	Canakkale	L=South
DAD	17.08.1999	0:02:25	8.9	7.2	3.4	30.53	Usak	L=South
DAD	17.08.1999	0:02:19	17.8	18.2	7.6	26.24	Balikesir	L=South
DAD	17.08.1999	0:02:05	13.5	15	5	27.9	Afyon	L=North
DAD	17.08.1999	0:01:58	12.5	6.5	4.5	40.43	Manisa	L=North
DAD	17.08.1999	0:01:56	54.3	45.8	25.7	13	Bursa	L=South
DAD	17.08.1999	0:01:54	60.7	42.7	36.2	12.36	Istanbul	L=South
DAD	17.08.1999	0:01:51	N/A	407	259	N/A	Sakarya	L=South
DAD	17.08.1999	0:01:48	32.2	33.5	10.2	24.15	Tekirdag	L=South
DAD	17.08.1999	0:01:39	29.4	33.6	14.5	N/A	Sarkoy	-
DAD	17.08.1999	0:01:39	91.8	123.3	82.3	N/A	Iznik	L=South
DAD	17.08.1999	0:01:39	91.4	101.4	57	N/A	Eregli	-
DAD	17.08.1999	0:01:39	118	89.6	49.8	N/A	Cekmece	L=North
DAD	17.08.1999	0:01:39	171.2	224.9	146.4	N/A	Izmit	L=South
DAD	17.08.1999	0:01:39	264.8	141.5	198.5	N/A	Gebze	L=North
DAD	17.08.1999	0:01:39	373.7	314.8	479.9	N/A	Duzce	L=West
DAD	17.08.1999	0:01:39	117.8	137.7	129.9	N/A	Goynuk	L=East
KO	17.08.1999	3:01:52	211	134	83		Arcelik	L=North
KO	17.08.1999	3:02:03	252	186	80		Ambarli	L=North
KO	17.08.1999	3:02:06	101	100	48		Botas	L=East
KO	17.08.1999	3:07:01	101	100	48		Bursa	L=North
KO	17.08.1999	3:01:48	177	132	58		CKN	L=North
KO	17.08.1999	3:11:45	90	84	55		Yesilkoy	L=North
KO	17.08.1999	3:01:18	189	162	132		Fatih	L=North
KO	17.08.1999	3:03:04	56	110	143		Heybeli Ada	L=North
KO	17.08.1999	3:01:54	41	36	27		Yap K	L=North
KO	17.08.1999	3:01:39	230	322	241		Yarimca PetKim	L=East
DAD	12.11.1999	16.59.30	1.5	2.0	1.0	-	Manisa	L=North
DAD	12.11.2000	16.59.06	3.9	3.3	1.1	-	Canakkale	L=South
DAD	12.11.2001	16.58.59	5.7	6.1	1.8	-	Tekirdag	L=South
DAD	12.11.2002	16.58.21	3.1	3.1	1.4	42.5	Usak	L=South
DAD	12.11.2003	16.58.17	2.7	2.4	1.7	40.4	Balikesir	L=South
DAD	12.11.2004	16.58.03	7.9	7.6	4.1	30.5	Tosya	L=South
DAD	12.11.2005	16.58.01	8.0	10.0	3.5	28.1	Afyon	L=North
DAD	12.11.2006	16.57.55	17.1	20.6	9.4	23.5	Kutahya	L=South
DAD	12.11.2007	16.57.54	9.3	8.0	4.8	25.6	Bursa	L=South
DAD	12.11.2008	16.57.53	9.0	5.2	8.2	21.7	Istanbul	L=South
DAD	12.11.2009	16.57.34	17.3	24.7	11.5	9.4	Sakarya	L=South
DAD	12.11.2010	16.57.22	739.5	805.8	200.1	4.2	Bolu	L=North

Notes DAD: Ministry of Settlement and Disaster Affairs, Earthquake Research Dept., Ankara

KO: Kandilli Observatory, Bogazici Univ. S-P : Time between primary and secondary wave arrivals

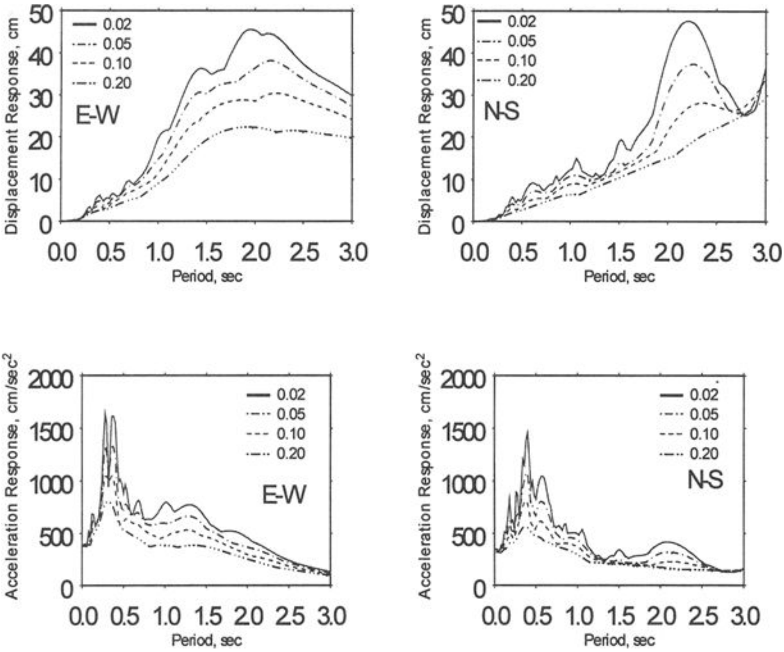

Figure 3 Displacement and Acceleration Response Spectra for Damping Factors of 1, 5, 10, and 20% for the Strong Motion Records Measured at Duzce (17 August 1999)

Liquefaction in Adapazari, where the water table was within 1 m of the surface and the blow count was less than three in some locations, was endemic. An example is shown in Fig. 11. According to records released by DAD, the maximum horizontal acceleration in Adapazari may have exceeded 0.4G during the main shock. The main shock was followed by a series of smaller shocks almost every minute for the next six minutes.

Structural Failures

Despite the devastation, the main questions about structural behavior relate more to why buildings survived than to why they failed. The damage inventory included all the usual suspects but in greater breadth and depth than observed in previous earthquakes. The "typical" residential/office buildings in the region had five

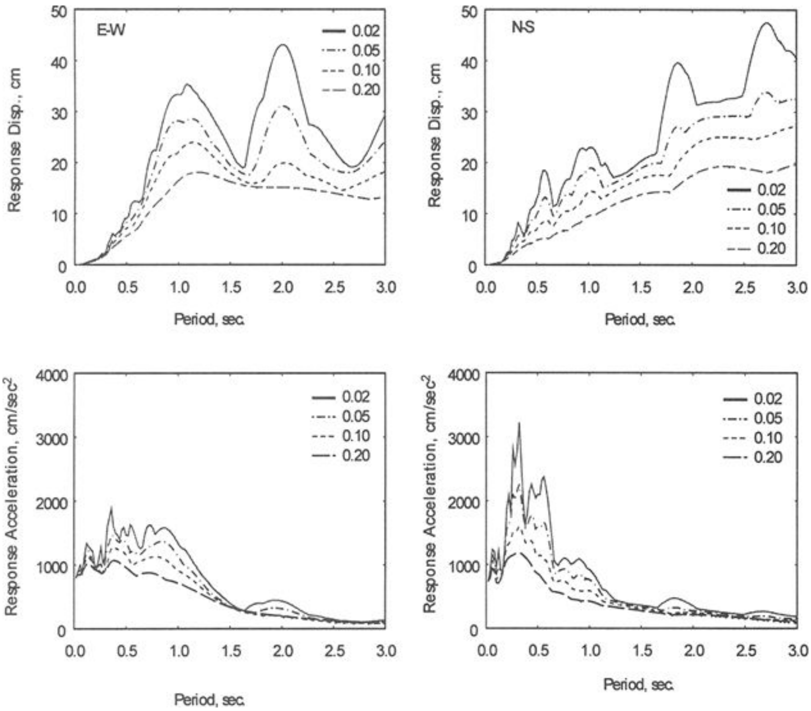

Figure 4 Displacement and Acceleration Response Spectra for Damping Factors of 2, 5, 10 and 20% for the Strong Motion Records Measured at Bolu (12 November 1999)

3-m stories, floor spans of 4 to 5 m, column dimensions of 0.3 x 0.6 m, and girder depths of 0.5 m (See Table 2). The initial building periods, ranging from 0.5 to 1.0 sec., were well within the fury of the ground motion.

The dominant of symbol of structural damage in the region from Yalova to Duzce was the first-story column torn away from the wrecked building (Fig. 13, 14). The reason for the tear was simply the lack of transverse reinforcement. Typically, the shear failure occurred at the top extremity of the reinforced concrete column (the location of the failure possibly influenced by the rotational flexibility of the footing).

Examples of shear failures resulting from interaction of columns with other elements are shown in Fig. 15 and 16.

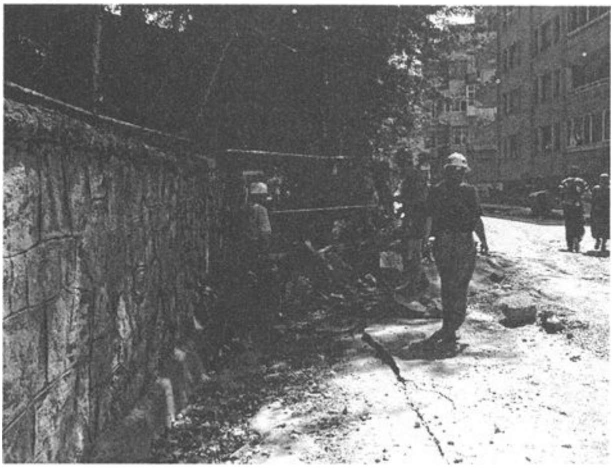

Figure 5 Wall Offset in Golcuk

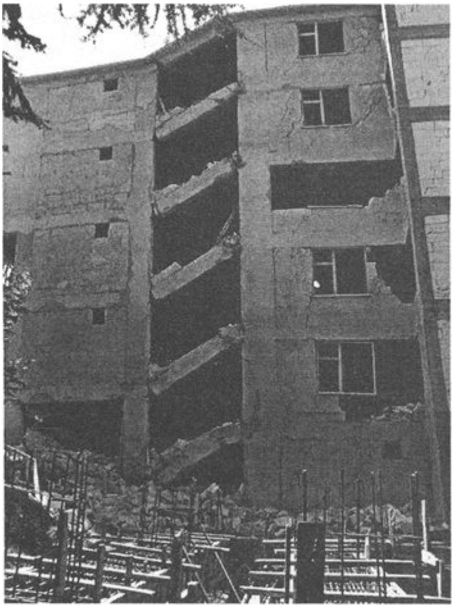

Figure 6 Effect of Ground Movement on Structure

Figure 7 Fault Trace Cuts through Building (Golcuk)

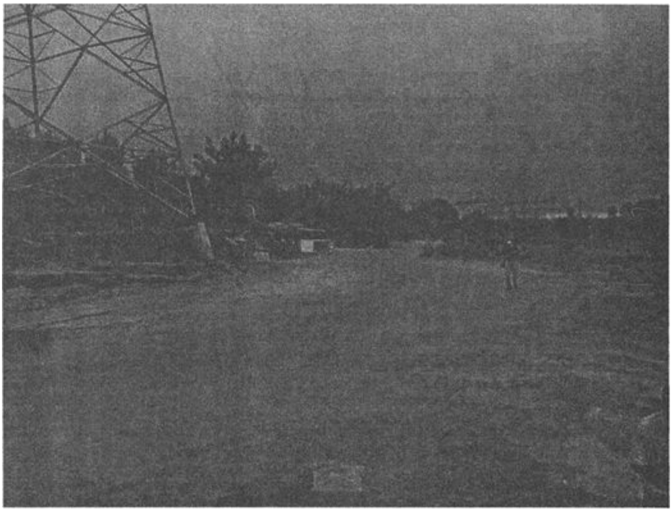

Figure 8 Vertical Movement of Ground at Fault Trace Exposes Tower Foundation Block