The 1999 Kocaeli and Düzce-Turkey Earthquakes

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ABSTRACT: Two major earthquakes exceeding magnitude 7 occurred with in three months in Turkey in 1999, which ruptured a 200 km segment of the North Anatolian Fault. Since the broken fault traversed the densely populated and industrialized east Marmara region, damage was enourmously high. Death toll exceeded 17,000 and estimated financial losses reached 10 billion USD. Building structures and precast concrete facilities that do not possess sufficient seismic resistance played the most important role on the large losses of life and property. Wide spread liquefactions caused bearing capacity losses and consequent foundation failures in Adapazarı, and extensive subsidences at the shores of Gölcük at the Gulf of İzmit, and Lake Sapanca. Although transportation facilities generally performed well, fault displacement caused severe damage in a bridge and a freeway viaduct. Hightened odds for a large magnitude earthquake in the Marmara Sea after the 1999 events created severe public unrest in Istanbul, mainly due to the existing building stock in the city with inadequate seismic safety. This is considered as a major problem in Turkey for the near future.

1 INTRODUCTION

17 August 1999 Kocaeli and 12 November 1999 Düzce earthquakes are the largest natural disasters of the 20th century in Turkey after the 1939 Erzincan earthquake. The official death toll is 17,322 in the Kocaeli earthquake and 950 in the Düzce earthquake. During these two earthquakes, Gölcük, Değirmendere, Derince, Adapazarı, Gölyaka, Düzce and Kaynaşlı cities were almost completely destroyed. A total of 330,000 residences were damaged, where the shares of light, moderate and severely damaged or collapsed units are 118,000, 112,000 and 100,000, respectively. Total economical losses are estimated at 10 billion USD, leading to a 6% shrinking of the Turkish economy in 1999. The impact of the 1999 earthquakes in Turkey are evaluated with an engineering perspective in this paper, and the causes leading to the observed effects are discussed.

2 SEISMOLOGICAL ASPECTS

Turkey experienced two major earthquakes in 1999, which occurred 86 days apart on the North Anatolian Fault system. Two consequent earthquakes with magnitudes over 7 in the same region is very seldom in the world seismic history. Large earthquakes in the last 60 years displayed a migration phenomena from east to west on the North Anatolian Fault, starting with the magnitude 8.1 Erzincan earthquake in 1939 that killed 40,000 people (Barka 1996, Toksöz et al., 1979). The last two in the series on the west were the 1957 Bolu Abant (M 7.1) and 1967 Mudurnu Valley (M 6.8) earthquakes which ruptured the southern branch of the North Anatolian Fault on the west. The northern branch is completely ruptured in 1999.

On 17 August 1999, Mw 7.4 Kocaeli earthquake had broken the 140 km long western part of the 1200 km long North Anatolian Fault in a multiple rupture process (Toksöz et al. 1999, Yagi and Kikuchi, 1999). Its epicenter is located at 40.76°N and 29.97°E, the depth is at 16 km. A multiple
strike-slip rupture process occurred in a propagating fashion along three consecutive segments of
the fault (Figure 1). It is revealed in Figure 1 that the first rupture initiated at Gölcük has an oblique
directivity toward Yalova, which caused substantial damage in the city although fault rupture did
not extend that far. Similarly, the third segment on the east ruptured unilaterally toward east, and
developed significant directivity effects at Gölyaka and Düzce towns. An overall MSK intensity
distribution of the Kocaeli earthquake in shown in Figure 2. This figure indicates narrow elliptical
isoseismal intensity distribution, typical of strike-slip faults, and displays the features of segmental
rupture with directivity effects at the ends of segments. Adapazarı region was further subjected to
severe liquefaction and consequent ground failures as well as site amplifications which increased
damage intensity enormously.

Three months after the 17 August event, Mw 7.2 Düzce earthquake ruptured another 40 km segment
of the same fault which was broken during the Kocaeli earthquake, toward further east. The second
rupture zone started from the termination of the 17 August rupture. A bi-lateral, symmetrical,
predominantly strike-slip rupture occurred, with the epicenter located at 40.76°N and 31.15°E, and
the focal depth at 12 km. The epicenter of the Düzce earthquake was 6 km south of Düzce, where
the fault rupture propagated mainly in the upward direction toward Düzce along the highly stressed
region under the city. Düzce, a city with a population of 78,000 has almost been devastated as a
result of two consecutive earthquakes, both producing high intensity ground motions as evidenced
by the strong motions recorded in the city. Kaynaşlı and Bolu were also affected significantly from
the Düzce earthquake.

3 STRONG GROUND MOTIONS

A total of 32 station recorded strong motions with engineering significance during the Kocaeli and
Düzce earthquakes, where 7 of these stations are in the near field of the fault. These are the only
near field ground motions recorded in Europe during an earthquake with magnitude over 7. The
main properties of the near field strong motions are given in Table 1. Here, FD is the nearest
distance to the fault, and t_{ef} is the duration of the strong part, which is the time window between
5% and 95% of the square acceleration integrated over time. It is observed that the Kocaeli
earthquake produced long durations, but low PGA's in the near field expected from magnitude 7.4,
except the Düzce station. This is possibly an effect of multiple rupture process. However PGV's are
usually high. It is unfortunate that no strong motion records are available from Gölcük, Yalova and
alluvial part of Adapazarı where damage was overwhelming.

The acceleration spectra of the east-west components are shown in Figure 3 in comparison with
the elastic design spectra specified in the Turkish Seismic Design Code (1997). It is observed that
the code level hazard is not usually exceeded in these stations. Therefore the experienced damage
during the earthquake may be easily attributed to the unconformity of the buildings to seismic code
requirements, which is a serious problem for most of the existing structures. Elnashai (1999)
applied Yarımca and Düzce records to a test structure, resembling similar buildings in Europe,
analytically. This structure was subjected to severe ground motions recorded in Europe on the
shaking table and withstood them with acceptable damage. He showed that the test structure is not
able to survive under the two ground motions from the Kocaeli earthquake. Table 1 indicates that
the near field ground motions from the Düzce earthquake have considerably higher intensities than
the Kocaeli ground motions although their durations are short.

The recorded strong motions and observed damage distributions at the corresponding sites during
the Kocaeli and Düzce earthquakes suggested that rupture directivity and soil amplification effects
have increased damage concentration significantly (Anderson et al., 2000)
Figure 1. Fault geometry and rupture process in the Kocaeli earthquake

Figure 2. Intensity distribution (MSK) of the Kocaeli earthquake
Table 1. Properties of Near Field Strong Motions from Kocaeli and Düzce Earthquake

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Station</th>
<th>Soil Type</th>
<th>FD(km)</th>
<th>Component</th>
<th>PGA (cm/s²)</th>
<th>PGV (cm/s)</th>
<th>t_eff (s)</th>
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<tr>
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<td>Gebze</td>
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</table>

Figure 3. Comparison of the acceleration response spectra of east-west components of the near field accelerograms recorded during the Kocaeli earthquake with the Code design spectra. Z1, Z2 and Z3 are the rock, stiff soil and soft soils, respectively.
4 GEOTECHNICAL ASPECTS

Kocaeli earthquake caused substantial geotechnical hazards in different forms: liquefaction, bearing capacity loss, subsidence and lateral spread. In addition to such direct effects of ground deformations, site response amplification was mainly responsible for the remarkable increase of damage over young alluvial soil layers.

Spectacular ground deformations occurred in Adapazarı due to liquefaction of unconsolidated river deposits on the northern part of the city. Geotechnical investigations conducted in this region indicates seasonal variation of water table between the surface and 3-4 meters, whereas the soil layers in the top 15 meters consist of loose and medium stiff sandy layers containing different amounts of low plasticity clay and silt, and gravel. Assessment of liquefaction potential with the available geotechnical data and methods consistently give high liquefaction susceptibility of soils in Adapazarı (Bakır et al., 2000). During the earthquake, neither the only two buildings on pile foundations nor any of the 1-2 story buildings located on these soils were affected from liquefaction. However 3-6 story buildings having shallow mat foundations displayed substantial amounts of base settlements and rotations as rigid blocks (Figure 4). There were no structural damages in these buildings, even window glasses were unbroken. This is a clear indication that liquefied layers completely isolated the buildings from ground vibrations, however liquefaction did induce bearing capacity failures in soils underneath the heavier building blocks.

Other forms of liquefaction induced ground failures are due to subsidence of gentle slopes along the Gulf of Izmit and Sapanca Lake. Many buildings on natural or artificial fills adjacent to the shores shifted toward sea, and the shoreline was flooded with the sea waves resulting from the volume change during subsidence (Figure 5).

Besides direct effects of ground failures, site response played an important role on the amplification of ground motions on soft soil sites. The ground motions recorded at Düzce and Yarımca on soft sites have significantly higher intensities than the rock motions recorded at İzmit and Sakarya stations, as compared in Table 1 and Figure 3. Sakarya station is on a hill side in Adapazarı where damage was low, however structural damage was enormous at the city center located mostly on alluvial river deposits, especially in the zones of unliquefied soils. Although there is no mainshock record available at the soil site, aftershock records were obtained from portable instruments deployed in the area. A comparison of horizontal response spectra on stiff and soft sites in Adapazarı during a large aftershock is given in Figure 6. The ratios of spectral accelerations on soft and rock sites vary between 2 and 5 in the short and medium period ranges, indicating that the buildings on soft sites were influenced significantly more than those on stiff sites.

Figure 4. Liquefaction induced foundation failures at Adapazarı
5 STRUCTURAL DAMAGES

The enormous amount of life and property losses during the Kocaeli and Düzce earthquakes were mainly caused by the collapsed or heavily damaged multistory reinforced concrete buildings as shown in Figure 7. Structural damages were mostly due to the repetition of well known mistakes of the past in the design and construction of reinforced concrete buildings. Although most of them were relatively new, less than 10 years of age, none of them satisfy the minimum seismic safety requirements described by the codes. Structural framing of damaged buildings were generally irregular, detailing was poor, shear walls were not employed even in buildings taller than five stories. The amount of damage was drastically less in properly designed and built structures. A remarkable correlation exists between the number of stories and the amount of damage in buildings as shown in Figure 8. In short buildings, gravity forces are equally important as seismic forces and
the structural members which are designed to sustain the self weight of the building also provide considerable resistance against lateral forces, although this is not directly intended in their construction. However, when the number of stories exceeds 3 or 4, seismic forces prevail structural response. The most critical buildings against seismic hazard are 5 to 8 story reinforced concrete buildings. They do not benefit from the inherent excess lateral load capacity of shorter buildings, their vibration periods match with the dominant frequencies of earthquake ground motions leading to increased seismic demands, but they are usually constructed by local contractors using conventional methods and provide the cheapest unit floor area for the consumer. Taller buildings always receive higher quality engineering services in design, and they are constructed by more
qualified contractor companies. Eight to fourteen story apartment blocks in the İzmit housing
development region sustained only minor damages during the Kocaeli earthquake.

Another notable damage feature of the Kocaeli earthquake was structural failures directly caused
by the fault displacement, as shown in Figure 9. The geographic location of the North Anatolian
Fault is well known according to geologists. Regardless of this information, cities, industrial plants
and even a naval base was built right on the fault. There is no rational engineering solution for
structures on a probable fault. Avoiding such locations is clearly the only reasonable approach.

Prefabricated precast concrete industrial facilities performed very poorly during the 1999
earthquakes. Despite their high material and construction quality, these systems do not possess an
integral framing system against lateral loads. Simple connections between girders and columns do
not provide a framing action and diaphragm rigidity. Moreover, 6 meter tall, 50 cm by 50 cm
cantilever columns spaced at 15 meters do not have the lateral load capacity required to resist the
lateral actions imposed on them.

Seismic design codes in Turkey are compatible with the codes in other seismic countries of the
world. They are updated as seismic design criteria and practice undergoes changes with the
progress of knowledge. Major weaknesses are in the enforcement of seismic codes and regulation,
and in the establishment of an effective design and construction supervision system. Technical
deficiencies in earthquake engineering practice cannot be prevented unless the legal weaknesses are
resolved.

Figure 9. Fault rupture running through building blocks in Gölcük

6 BRIDGES AND VIADUCTS

The highway and railway bridges and freeway viaducts usually performed satisfactorily except
three bridge structures located in the close vicinity of the ruptured faults.

During the Kocaeli earthquake, an overpass of the Trans European Motorway in Arifiye collapsed
due to insufficient seating length on the piers (Figure 10). The provided seating length of 50 cm
had been insufficient for the skew bridge. Sakarya viaduct is a 400 meter long, 10 span structure
crossing the Sakarya river. This viaduct was damaged because of the malfunction of shear keys.
Consequently, expansion joints and deck supports were also damaged. Sakarya viaduct was
repaired and opened to traffic after the earthquake.
During the Düzce earthquake, the ruptured fault crossed the Bolu viaduct at the eastern termination of the fault. The Bolu viaduct was completed weeks before the November 12 earthquake. It is a 2.5 km long structure composed of a pair of independent parallel decks, each of 17.5 meter width for two traffic directions. It consists of sixty 40 meter spans simply supported by single piers with maximum height of 49 meters. The viaduct was designed for the code acceleration response spectrum shown in Figure 3, however relative transverse displacement of piers due to fault displacement was not accounted for properly. In fact, a relative displacement of adjacent piers by 1.50 meters as measured at the fault crossing shown in Figure 11 is very difficult to accommodate. Seismic dampers were mounted between pier caps and the end diaphragms of the decks to supply passive energy dissipation, however they were completely destroyed during the earthquake. The 500 Million USD viaduct sustained significant damage at the deck structure during the November 12 earthquake. It requires significant and costly repairs, possibly replacement of the deck. This unique case is a clear indication that crossing an active fault with a long viaduct may not be a sound engineering decision.

Figure 10. Collapse of a viaduct overpass in Arifiye during the Kocaeli earthquake.

Figure 11. Fault rupture running across the Bolu viaduct during the Düzce earthquake.
7 CONCLUSIONS

Turkey experienced a fast population growth at urban settlements during the last four decades as a result of internal social dynamics, which was accompanied by heavy construction activity in urbanized districts. Although the fast growing urban settlements were mostly in the seismic prone regions, seismic hazard sensitive urban planning and seismic resistant construction was not the highest priority during this transition phase. The country is now in the process of renewing its legal structure in order to mitigate the effects of inevitable future seismic hazards. In this respect, regional city plans are being updated by reconsidering the geological, geotechnical and seismic characteristics of the urban zones, and a construction control law is passed in order to enforce seismic codes and building regulations. The existing building stock however remains as a major problem since its seismic upgrading requires expenses beyond the financial capacities of the building owners.

REFERENCES


