5 Summary and Conclusions

5.1 Summary

A team of structural engineers representing the Pacific Earthquake Engineering Research (PEER) Center visited the area affected by the August 17, 1999, Izmit earthquake in late August and early September 1999. The M_w 7.4 earthquake occurred on the North Anatolian fault in northwestern Turkey at 3:02 a.m. local time. The hypocenter of the earthquake was located near Izmit, 90 km east of Istanbul. Official figures placed the loss of life at 17,225, with more than 44,000 injured. Approximately 77,300 homes and businesses were destroyed and 245,000 were damaged. The total direct loss was estimated to be more than US$ 6 billion.

The PEER reconnaissance team traveled to Turkey to study damaged and undamaged buildings, bridges, industrial facilities, and infrastructure. Two key objectives of the reconnaissance effort were (1) to improve the understanding of the *performance* of the built environment and (2) to identify gaps in the PEER research agenda, which is developing knowledge and design tools for performance-based earthquake engineering. Documenting collapsed structures was not a high priority of the reconnaissance team, and no such documentation is provided in this report.

This report begins with an introduction to building seismic design and construction practice in the region impacted by the earthquake, and follows with a description of the performance of damaged and undamaged structures. The review of design and construction practice (Chapter 2) confirmed that the construction of reinforced concrete buildings without special details for ductile response (by far the most prevalent form of construction in the epicentral region) was permitted up to the time of the earthquake.

The performance of reinforced concrete frame and wall buildings is presented in Chapter 3. Typical construction practice did not make use of special details for ductile component behavior because (a) the use of special details was not mandated by the codes of practice or local authorities and (b) buildings without the special details were easier to construct. Construction quality varied widely and ranged from excellent to poor. The quality of residential construction was typically moderate to poor. The performance of components of moment-frame buildings (beams, columns, joints) and wall buildings is described. Much of the observed poor performance was directly related to the use of (a) nonductile reinforcement details and (b) inappropriate framing sizes (e.g., strong beams and weak columns). Another key contributor to poor building performance was widespread ground failure or liquefaction that likely protected some buildings from severe earthquake shaking but which resulted in gross building settlement or overturning. A detailed discussion on the performance of four buildings is presented in Section 3.5. Components of three of the four buildings were either severely damaged or destroyed but none of these buildings collapsed. The effect of component failure on system response is studied in this section, and issues related to preventing collapse of gravity-load-resisting frames are explored.

Chapter 4 presents information on the performance of industrial facilities. Because many of these facilities were designed in the 1960s and 1970s using U.S. or European codes of practice, and given that the construction quality in these structures was typically good to excellent, the performance of these older facilities during the August 17 earthquake could be considered to be representative of that of industrial facilities of a similar age in the United States and Europe. Of particular relevance to facility operators in the United States was the performance of the Tüpras refinery and the life-threatening problems faced by the refinery staff immediately following the earthquake. One important lesson from the Tüpras experience is that earthquake preparedness is key to rapid response and timely recovery.

5.2 Conclusions and Recommendations

A short list of conclusions and recommendations related to design and construction practice in Turkey is enumerated below.

1. Nonductile detailing should not be allowed in moderate and severe seismic zones, regardless of the lateral forces used for design.

2. A factor that accounts for the proximity of a building site to a fault (i.e., a near-field factor) should be included in the design force equation.

3. Construction on ground prone to liquefaction should be avoided.

4. Building frames that have been designed for gravity loads alone, and without a clear load path for lateral loads, should be treated as a high priority for retrofitting.

5. Continuous shear walls on stiff and strong foundations are an effective means of retrofitting nonductile reinforced concrete buildings. Existing independent column foundations should be tied together with grade beams in retrofit construction.

6. In new and retrofit reinforced concrete construction, smooth reinforcing bars should not be used other than for stirrups and ties.

7. Careful attention should be paid to concrete mix design, quality control, and placement.

The work and observations of the reconnaissance team raise many questions related to the performance of reinforced concrete buildings and the implementation of performance-based earthquake engineering in the United States and abroad. Some of the important questions are

1. Why do apparently similar buildings subjected to apparently similar earthquake shaking perform very differently? What are the determining features that differentiate their behaviors?

2. What are the causes of collapse in gravity-load-resisting frames? Can we better capture the effect of component failure on system response? Can we develop gravity-load-framing systems that are less prone to collapse?

3. Can we better characterize the effect of ground failure on earthquake ground motion? Can cost-effective methods for ground improvement be developed for new and retrofit construction?

4. Why did some buildings within meters of the fault, or in some cases straddling it, survive with little to no damage, while others of apparently similar construction but further from the fault collapse? Is earthquake shaking very close to the line of rupture less severe than that a short distance from it?