Chapter 19

Damage to and Vulnerability of Industry in the 1999 Kocaeli, Turkey, Earthquake

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Over the past 10 years, Turkey has been hit by several moderate to large earthquakes that caused significant loss of life and property. These took place in: Erzincan, 1992; Dinar, 1995; Adana-Ceyhan, 1998; and Kocaeli and Duzce, 1999. Adana-Ceyhan and Kocaeli are the most industrialized regions in Turkey, and the earthquakes of 1998 and 1999 resulted in extensive losses to industry in these regions.

On August 17, 1999 a magnitude MW 7.4 (MW is moment magnitude) earthquake struck Turkey's northwestern Kocaeli and Sakarya provinces, a densely populated region in the industrial heartland. The earthquake nucleated at a depth of about 15 kilometers, some 10 kilometers east of the town of Gölcük. The earthquake was associated with a 120-kilometer rupture involving four distinct fault segments on the northernmost strand of the western extension of the 1300-kilometer-long North Anatolian fault system. Predominantly right-lateral strike-slip offsets were in the range of three to four meters over a significant length of the fault. Another segment at the eastern end of the fault break ruptured on November 12, producing the MW 7.2 Duzce earthquake. The August 17, 1999 (MW 7.4) Kocaeli and November 12, 1999 (MW 7.2) Duzce earthquakes resulted when a wedge of continental crust known as the Anatolian Block was squeezed between the Arabian and Eurasian plates. This motion was accommodated by two major strike-slip faults: the North and East Anatolian faults.

The 1999 Kocaeli and Duzce earthquakes caused considerable damage to residential and commercial buildings, public facilities, and infrastructure, and caused significant casualties in an area 20 kilometers by 200 kilometers. The number of condemned buildings after the earthquakes totaled 23,400. Some 16,400 of these, encompassing 93,000 housing units and 15,000 small business units, collapsed or were heavily damaged. Another 220,000 housing units and 21,000 small business units experienced lesser degrees of damage. Widespread building collapse in the two earthquakes resulted in a substantial number of casualties. Deaths numbering 18,373 were recorded, and 48,901 people were hospitalized for injuries; 40 percent of them will be left permanently disabled.

The two major earthquakes that took place in 1999, namely the MW 7.4 Kocaeli, Turkey and the MW 7.6 Chi-Chi, Taiwan (China), earthquakes, caused comparable economic and insured losses. In the Kocaeli earthquake, the economic losses were estimated to have been $10–40 billion, while insured losses were estimated at $550–750 million. The Chi-Chi earthquake resulted in economic losses of $8–14 billion and insured losses of $500–$850 million (Johnson 2000). It is worth noting, however, that there is an order of magnitude difference in the human losses in these earthquakes. The Kocaeli earthquake resulted in more than 18,000 deaths and nearly 50,000 injuries, while in Taiwan there were 2,405 deaths and 10,718 injuries.

The Kocaeli earthquake is considered the largest event to have damaged an industrialized area since the 1906 San Francisco and 1923 Tokyo earthquakes. In the earthquake, 70 percent of total insured losses related to direct damage and 30 percent was due to business interruption. Estimations in U.S. dollars (all dollar amounts in this paper are U.S. dollars) by the insurance industry of total insured losses were in the order of $1.5–$3.5 billion (RMS 1999) as compared to the $550–$750 million estimated to have been paid by the industry (Johnson 2000).

The epicenter of the 1999 Kocaeli earthquake was the main site of Turkey's heavy industry. Major industries located there include: automobile manufacturing;

petrochemicals; motor and railway vehicle manufacture and repair; basic metal works; production and weaving of synthetic fibers and yarns; paint and lacquer production; tire manufacturing; paper mills; steel pipe production; pharmaceuticals; sugar processing; cement production; power plants; and tourism.

The region affected by the earthquake is geographically extensive, economically dynamic, and the industrial heartland of Turkey. The four districts most severely affected (Kocaeli, Sakarya, Bolu, and Yalova) contribute more than 7 percent of the country's GDP and 14 percent of industrial value-added. Per capita income is almost double the national average. With only 4 percent of the nation's population, the region contributes more than 16 percent of budget revenues. The districts immediately surrounding the area (Bursa, Eskisehir, and Istanbul) were indirectly affected because of their close economic linkages, since industries and small businesses supply services and material inputs to each other's production processes. The greater region now realizes that it shares a seismic risk and faces magnified uncertainty for the future. Taking all seven cities together, the wider earthquake region accounts for 35 percent of national GDP and nearly half of the nation's industrial output. Building losses reportedly amounted to $5 billion. Damage to lifelines is estimated to be some $1 billion. Industrial facilities and small business losses are $2 billion and $1 billion, respectively. If we assume that indirect socioeconomic losses will be as much as direct physical losses, the total loss figure is in the vicinity of $16 billion (about 7 percent of Turkey's GDP). Most industrial losses were covered by insurance.

Private and public sector estimates of damage to industry as a whole range from $1.1 to $4.5 billion. The value-added loss in manufacturing is estimated at $600 to 700 million. The State Planning Industry estimated that value-added losses stemming from damage to industry were $700 million. The losses may have resulted in a 1.6 percent decline in the growth of the production sector in Turkey. Other sources put this loss figure as high as $2 billion. According to the Kocaeli Chamber of Industry, 214 enterprises (about 19 percent of all enterprises in the province) reported significant damage totaling $2.5 billion in capital losses. Many major facilities faced extensive business interruptions; however, the biggest loss was that of qualified manpower. Most industrial losses were covered by insurance. Payments of claims were reported to have totaled $600 to $800 million. The State Planning Organization estimates a loss of $880 million just for the 19 state-owned enterprises located in the region (mainly in Tupras, Tuvasas, Igsas, Petkim, Seka, and Asil Celik). The State Planning Organization also estimates that the loss of business in these industries may have amounted to $632 million. The tourism industry (based in Yalova) was virtually destroyed and has yet to pick up even three years after the earthquake. A fundamental regional restructuring in the tourism industry may be needed.

Rahnama and Morrow (2000) note that older, heavy industrial facilities, especially those with taller structures, that partially to totally collapsed, were more affected by the earthquake than newer facilities. It was observed that any type and quality of anchorage improved the performance of machines and equipment, except very sensitive equipment such as assembly line sensors in the automotive industry and rotary kilns in cement plants. Losses associated with business interruption were more severe for these types of facilities. For light industrial facilities, building damage turned out to be the primary reason for direct and indirect losses. As was the case in the 1998 Adana-Ceyhan earthquake, the poor performance of precast concrete structures was observed. For refineries and other chemical processing facilities, nonbuilding structures turned out to be the most vulnerable, with tanks being the most susceptible to earthquake and fire damage. It was observed that damage to industrial facilities was more severe and extensive than that seen in earthquakes with similar peak ground acceleration levels. This observation was attributed to the duration and long-period ground motion of the earthquake (MCEER 2000). Most industrial facilities damaged by this earthquake were within 10 kilometers of the fault rupture and in intensity zone IX.

In general, the earthquake damage at industrial facilities in Turkey was not significantly different than that observed in other earthquakes worldwide. Large storage tanks, pipelines, transmission lines, and precision machinery are generally susceptible to damage from earthquakes. Due to the high relative value of contents, their vulnerability and dependence on structural performance are key in assessing loss potential, especially for heavy manufacturing facilities. Port and harbor facilities are

particularly susceptible to sub-marine landslides or ground settlement due to liquefaction that may occur during earthquakes. In addition, all processes that involve a substantial risk of explosion, such as those in the petrochemical industry and processes involving molten metal, should be examined carefully.

Earthquake vulnerability is the measure of damage a building or structure is likely to experience when subjected to ground shaking of a specified intensity. The dynamic response of a structure to ground shaking is a complex behavior that is dependent upon a number of inter-related parameters that are often difficult, if not impossible, to predict precisely. These include: the exact character of the ground shaking that the building will experience; the extent to which the structure will be excited by and respond to the ground shaking; the strength of the materials in the structure; the quality of construction and condition of individual structural elements; the interaction of the structural and nonstructural elements of the industrial facility; the weight of contents in the facility at the time of the earthquake; and other factors. Most of these factors can be estimated, but never precisely known. As a result, it is typically necessary to define vulnerability functions for buildings within levels of confidence.

In addition to physical vulnerabilities, the socioeconomic vulnerabilities of industrial facilities need to be assessed in terms of casualties, social disruption, and economic losses. Casualties in earthquakes arise mostly from structural collapse and other collateral hazards. Lethality per collapsed building can be estimated by a combination of factors representing the number of people per building, occupancy at the time of the earthquake, occupants trapped by collapse, mortality at collapse, and mortality post-collapse. Lethality for collateral hazards is difficult to generalize and may require facility-specific assessments.

It is generally known that losses due to collateral hazards and indirect economic losses constitute a major portion of total earthquake losses in industrial systems. Indirect economic losses arise from shutting down damaged facilities and include: production and sales lost by firms in damaged buildings; production and sales lost by firms unable to get supplies from other damaged facilities; production and sales lost by firms due to damaged lifelines; lost tax revenue; and increased unemployment compensation. Partial quantification of these indirect economic losses can be found in ATC-25 (1991).

An industrial facility consists of many integrated components and processes. As such, operation of a facility depends upon the performance of its critical components. The greatest risk from an earthquake is that to life safety. Building code requirements in most counties, including Turkey, are written with the objective of protecting lives. A building is allowed to be damaged, but it should not collapse and people should be able to evacuate even under extreme conditions. However, in large earthquakes, industrial buildings and related machinery and equipment damaged may be costly to repair and there may be additional damage from fire and chemical spills. Since most revenue generated by industrial facilities is related to the products and services they provide rather than the physical assets of the company, any significant interruption in the production of these goods and services will have an adverse effect on business. The risk of business interruption is a critical economic reason for controlling earthquake and post-earthquake damage. As such, the design (or seismic retrofit) of industrial facilities should preferably be based on performance-based methodologies with the objective of controlling structural and nonstructural damage.

Bibliography

ATC-25 (Applied Technology Council). 1991. "Seismic Vulnerability and Impact of Disruption of Lifelines in the Coterminous United States, ATC-25." Redwood City, California.

Johnson, Laurie A. 2000. "Earthquake Loss Modeling Applications for Disaster Management: Lessons from the 1999 Turkey, Greece and Taiwan Earthquakes." Proceedings of *EuroConference 2000 on Global Change and Catastrophe Risk Management: Earthquake Risk in Europe*. Laxenburg, Austria. Available from <http://www.iiasa.ac.at/Research/RMS/july2000/>.

MCEER (Multidisciplinary Center for Earthquake Engineering Research). 2000. "The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report." Charles Scawthorn, ed. University of Buffalo, New York.

Rahnama Mohsen, and Guy Morrow. 2000. "Performance of Industrial Facilities in the August 17, 1999 Izmit Earthquake." *Proceedings of the 12th World Conference on Earthquake Engineering.* On CD. Paper No: 2851, Auckland, New Zealand.

RMS (Risk Management Solutions). 1999. "Event Report, Kocaeli, Turkey Earthquake." San Francisco, California.