



Damage to and vulnerability of industry in earthquakes in Turkey

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Over the past ten 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. The 1999 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 by the insurance industry of total insured losses were in the order of \$1.5-\$3.5 billion. 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. 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 type 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, non-

building 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.

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.

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. 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. 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 non-structural damage and the triggered technological disasters.