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Seismic risk assessment of storage tanks in Turkish industrial facilities

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ABSTRACT

In 1999, two earthquakes in northwest Turkey caused heavy damage to a large number of industrial facilities. This region is the most industrialized in the country, and heavy damage has a significant economic influence. Industrial storage tanks, ruptured by earthquakes, exascerbate damage through the spread of fire. Storage tanks are uniquely structured, tall cylindrical vessels, some supported by relatively short reinforced concrete columns. The main aim of this study is to evaluate the earthquake performance of Turkish industrial facilities, especially storage tanks in terms of earthquake resistance. Modeling a typical storage tank of an industrial facility helps to understand the structure's seismic response. A model tank structure was modelled as a solid with lumped mass and spring systems. Performance estimation was done with 40 different earthquake data through nonlinear time history analyses. After the time history analyses, fragility analyses produced probabilistic seismic assessment for the tank model. For the model structure, analysis results were evaluated and compared. In the study, vulnerability of storage tanks in Turkey was determined and the probabilistic risk was defined with the results of the analysis.

1. Introduction

Turkey is one of the most earthquake prone countries. On August 17, 1999, the Kocaeli earthquake struck northwestern Turkey causing widespread property loss and claiming over 30,000 lives (USGS, 2000). The earthquake occurred in the western region of the North Anatolian fault system, and its epicenter was about 100 km southeast of Istanbul. The area struck by the Kocaeli earthquake (Fig. 1) supports approximately 40% of Turkey's heavy industry.

Industrial facilities have incurred heavy damage during recent earthquakes, and the extensive uncontrolled fires, secondary to by seismic activity in crease the level of damage. The earthquakes of Kocaeli (Turkey) in 1999, Niigata (Japan) in 1964, and Alaska (USA) in 1964 caused significant damage to industrial facilities. The Tupras (Turkish Petroleum Refineries Corporation) oil refinery, located approximately 2 km from the fault rupture and constructed in 1960s according to the U.S. standards, incurred significant damage from the Kocaeli earthquake.. The refinery, originally owned by the state since 1999, became privately owned in 2006 and underwent additional construction during subsequent years. The Tupras refinery is economically important in the sense that it is similar to Western U.S. refineries built at its time as it was designed according to the same building standards as the U.S. refineries (Korkmaz, Çarhoglu, & Sari, 2008). Prior to the earthquake, the Tupras refinery produced, per day, 220,000 barrels of oil-related products, which was approximately one-third of Turkey's total output, making it the seventh largest refinery in Europe. The refinery also serves as a major port for liquid natural gas (LNG) and a domestic and export natural gas distribution hub. The strong shaking damage and resulting fire damage to the Tupras refinery affected port facilities, storage tanks, cooling towers, stacks, and crude oil processing units. The fire, which exhausted all on-site water available for extinguishing the blaze, continued for more than 5 days, even after being under control after 3 days. An aerial view of Tupras Refinery after the Kocaeli Earthquake appears in Fig. 2 (Turkish Press, 1999).

Tanks used as storage for fluids are of special concern because failure of the tanks due to an earthquake may cause uncontrolled fires which ignite adjacent tanks and buildings, and spillage of toxic chemicals may cause much more damage than the earthquake itself (Akatsuka & Kobayashi, 2010).

Tupras refinery included 45 storage tanks in three tank farm areas; the tanks contained naphtha fuel, crude oil, or LPG. Due to the shaking of the floating roof, the naphtha fuel flowed from the top of the tank and was ignited by the sparks generated by the collision between the floating roof and the side walls. The most affected area was the naphtha tank farm area in which the fire melted six steel storage tanks. Overall, 30 of the 45 floating roof tanks were heavily damaged. Most of the damaged tanks were built according to western (U.S.) design codes of their time of construction. The tank farm fire also spread to an adjacent cooling tower and destroyed it

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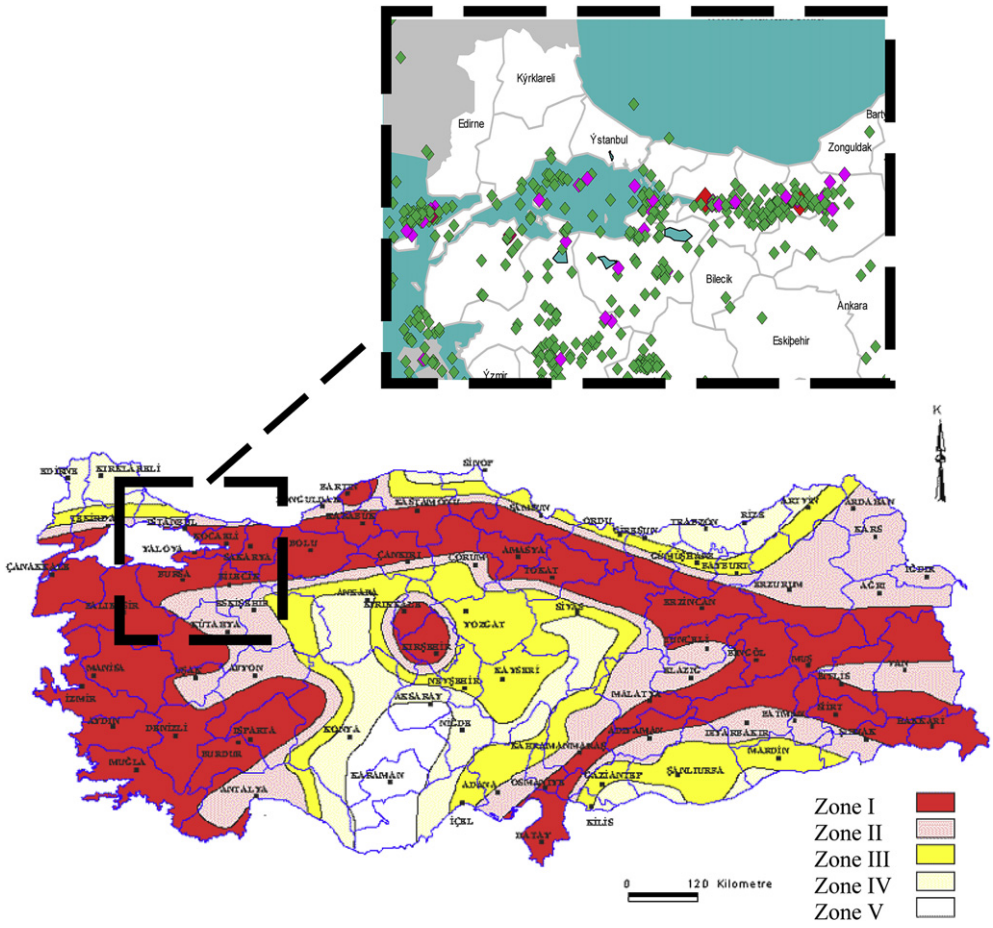

Fig. 1. Turkish seismic map and north Anatolia (MPWS, 1996; Turkish Earthquake Site, 2009).

(Harmsen & Leyendecker, 2006; Sari & Korkmaz, 2007; Sezen & Whittaker, 2006; Sezen, Livaoglu, & Dogangun, 2008).

Two incidences of chemical spillage into the Izmit Gulf were the result of the Kocaeli earthquake. In the first, a ship, at the loading/unloading naphtha port terminal, tore loose and broke the pipe connections, causing a leakage of naphtha to the Izmit Gulf. A broken LPG loading/unloading arm, which released approximately 35 tons of LPG into the bay at the jetty caused the second incident. These two incidents produced a thick layer of oil on the shoreline of the Marmara Sea (Johnson, 2002; Sezen et al., 2008).

2. Contribution and motivation

The failure of a storage tanks leads to catastrophic collapse of entire structures. In the literature, various investigations consider damage to, and failure of storage tanks; however, in many cases, conventional procedures are not sufficient to accurately define structural behavior. Therefore, accurate definitions of structural behavior require nonlinear analyses or finite element analysis of the interaction of contained liquid tank structures and foundation systems (Rossetto & Elnashai, 2003).

Dogangun, Karaca, Durmus, and Sezen (2009) investigated silo damage and failure and discuss their causes. Damage and failure of silos in different regions of the world are presented and discussed in their research work. Sezen et al. (2008) published research of storage tanks damaged in the Kocaeli earthquake in Turkey. Their findings are important for the storage tanks. Kieselbach (1997) studied large storage tanks and explained environmental damage and economic loss. Housner (1957) investigated dynamic pressures on liquid tanks. Abramson (1963) and Cooper (1960) investigated tank water interaction and structural behavior. Epstein (1976) investigated cylindrical and rectangular tanks' structural behavior. They used earthquake response spectra in their analyses. They changed the heights of the liquid and found higher load values for the full containers. Ramiah and Gupta (1966) investigated structural behavior of single degree of freedom water tanks under earthquake effects. James and Raba (1991) also investigated

Fig. 2. Aerial view of Tupras refinery after the Kocaeli earthquake (Turkish Press, 1999).