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Izmit, Turkey Earthquake of August 17, 1999 (M7.4)

An EQE Briefing

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General Overview

A 45-second earthquake of Richter magnitude 7.4 (M7.4) occurred in Turkey on Tuesday, August 17, 1999 at 3:01 a.m. local time. The epicenter was approximately 7 miles (11 km) southeast of Izmit, an industrial city approximately 56 miles (90 km) east of Istanbul. The earthquake was felt over a large area, as far east as Ankara, which is about 200 miles (320 km) away. Unofficial estimates place the death toll between 30,000 and 40,000. Most of the deaths and injuries were caused by collapsed commercial and residential buildings, typically 4 to 8 stories high.

Within 2 days following the earthquake, EQE International had a team of 7 engineers (3 from California, 3 from the United Kingdom, and 1 from Bulgaria) on the ground in the damaged area, investigating and researching the damage, providing support to our clients, and documenting lessons learned to prevent such catastrophic losses in future earthquakes. This report is a preliminary briefing of our findings on the effects of the earthquake on the people, structures, and country of Turkey. EQE is in the process of collecting and compiling more data, including videos and photographs, which can be viewed on our website, www.eqe.com.

The Earthquake

This was one of the strongest earthquakes ever to hit western Turkey and is the largest event on record to have devastated a modern, industrialized area since the 1906 San Francisco and the 1923 Tokyo earthquakes. The earthquake originated at a shallow depth of about 10.5 miles (17 km) and generated strong ground motion (and moderate to high accelerations) in a zone along the Gulf of Izmit of the Sea of Marmara to east of Adapazari. It occurred along the northernmost strands of the North Anatolian fault system, which has produced seven earthquakes with magnitudes greater than 7.0 since 1939.

A 2-meter high escarpment along the North Anatolian fault, east of Gölcük. Note the leaning minaret.

Epicentral area, showing areas of extensive damage.

The North Anatolian fault system is one of the most studied and best-understood fault systems in the world. This earthquake produced spectacular right lateral faulting over at least 37 miles (60 km) of the fault. Our team observed offsets greater than 8 feet (2.5 m) in the region of Gölcük, along the coast of the Gulf of Izmit. Significant vertical offsets along the fault were also observed. In the vicinity of a new automobile assembly plant being constructed east of Gölcük, the vertical offset was about 6 feet (2 m). Typically, the ground to the north of the fault dropped with respect to the ground to the south. This vertical movement or drop, and accompanying ground settlement and lateral ground flows in soft soils caused extensive and permanent flooding of large areas along the coast. The bottom photo shows flooded areas along the coast in Gölcük.

One of the most spectacular aspects of this earthquake is the damage to buildings inflicted directly by the faulting. This was the first earthquake with major faulting to strike

Collapsed and damaged buildings along the waterfront of Gölcük along the Sea of Marmara. The inundation is caused by a down drop of several meters along the North Anatolian fault (behind the building), combined with settlement and other ground failures.

A typical, collapsed 7-story reinforced concrete commercial building in Gölcük, near the shoreline. Rescue operations in this area are in progress (middle photo). Practically undamaged shear wall building under construction in the heart of the damaged area of Gölcük (right photo).

through heavily populated areas. Many, possibly hundreds of buildings which straddled the trace of the fault collapsed because their foundations were torn apart, undoubtedly causing hundreds or more casualties.

The earthquake is particularly important to California because it is very similar to the 1906 San Francisco earthquake, which experienced fault offsets of about 15 ft. (4.5 m) within the San Francisco Bay Area. Although the quality of construction in the affected regions was considerably below that which is found in the United Sates or Japan, the effects of the Izmit earthquake on the built environment are important in understanding the seismic risk to regions of the world that have high population densities, modern infrastructure, industry and buildings, and are in the immediate vicinity of major fault systems.

Buildings

Several thousand buildings collapsed in the earthquake. Although, there are currently many conflicting reports, we estimate that at least 20,000 buildings collapsed or suffered heavy damage. Most of the buildings are typically multi-story commercial/residential structures built of reinforced concrete. Most have nominally reinforced concrete frames with architectural (non-structural) unreinforced masonry infill walls. A large percentage of the severely damaged and collapsed buildings were typically in the 6- to 8-story range, either under construction or built within the last few years.

Partial collapse of and damage to new reinforced concrete apartment buildings between Gölcük and Yalova.

These buildings, like all recent construction in Turkey, are supposed to be designed and built to a code which incorporates sophisticated earthquake-resistant provisions. The code is an adaptation of the Uniform Building Code in California. Therefore, most of the collapsed multistory buildings were believed to be highly earthquake resistant. They were not for some or all of the following reasons:

1. Most of the buildings did not meet the design requirements of the code and included details that are not earthquake resistant. Those include inadequate vertical and horizontal reinforcing steel and the widespread use of smooth (as opposed to deformed) reinforcing steel.

2. Typically, the design structural engineer, who is an employee of the contractor, does not inspect the on-going construction to verify that the contractor has built the building according to the intent of the design drawings. This lack of construction oversight by the design engineer allowed for on-the-spot field design modifications and other measures to occur (i.e., no checks and balances), which compromised the earthquake resistance of the buildings.

3. Many of the buildings were built with poor and inappropriate construction materials and utilized poor workmanship.

4. Many buildings were knowingly allowed to be built on active faults and in areas of high liquefaction potential.

5. Many buildings were not engineered, but built according to past experience.

The most disturbing aspect of the damage to multi-story commercial and residential reinforced concrete buildings was that many hundreds of modern buildings, possibly

thousands, collapsed completely. Many other buildings had partial collapses and will be torn down. The majority of partial collapses involved the first two floors. Our observations indicate that, proportionally, the newest buildings suffered the most collapses. That indicates deterioration in the quality of design, construction, and building control of modern buildings in Turkey, despite the presence of a modern and highly earthquake-resistant code. Our observations, from numerous EQE projects on all continents around the world, indicate that this practice is not uncommon in many countries.

Industrial Facilities

The epicentral area is one of Turkey's most industrialized regions, home to much of Turkey's heavy industry, including petrochemical plants, car manufacturers, tire companies, paper mills, steel fabrication plants, cement plants, pharmaceutical firms, and other industries visited by our engineers.

The most widely publicized and spectacular damage occurred at the massive Tüpras refinery in Korfez. This refinery accounts for about 1/3 of Turkey's oil, and is a major supplier to much of the industry in the area. The plant was designed and built in the early 1960s by the state owned oil company, with American assistance. The $2.5 billion refinery was considered to be the cornerstone of Turkey's privatization program, and had been slated to begin privatization in early 2000.

A fire in the tank farm burned out of control for several days, prompting the evacuation within a 3-mile radius, for fear of explosions. A 300-foot (90 m) high reinforced concrete heater stack catastrophically collapsed, destroying one crude unit and knocking down equipment and pipeways, causing additional fires.

The Tüpras refinery fires will certainly be the subject of intense investigations over the next several months. These investigations will be of special significance to petrochemical facilities in earthquake-prone regions. Throughout the world, no refinery has experienced such a large earthquake at such a short distance since the 1964 earthquake in Japan.

The burning Tüpras oil refinery at Korfez three days after the earthquake.

Collapsed cooling tower at Petkim petrochemical plant.

One of the surprising aspects of this earthquake was the amount and severity of damage to modern engineered structures and equipment in industrial facilities, especially in light of the relatively low ground motion readings. Among the over 20 sites visited, very few escaped damage. The damage included cooling tower collapses,

One of two collapsed cranes at the steel pipe factory in Izmit (left photo). Partial collapse of the structure caused extensive downtime at a tire manufacturing plant in Izmit (middle photo). Stack collapsed in Crude Unit, Tüpras Refinery (right photo).

Damage due to faulting and lateral spreading at the main pier and seawall of the Gölcük Naval Base.

failed cranes, building collapses, collapse of steel-framed structures, storage rack collapses, damage to ports, and severe equipment and nonstructural damage. Very few of the facilities were able to resume operations within one week, and several large facilities were facing extended shutdowns of up to two or more months. We believe that the frequency content and long duration of the ground shaking will ultimately be shown to be very important contributors to the severity of damage.

Fire Following

Fire following can be a major problem following an earthquake, and this event resulted in a significant fire at the Tüpras Refinery (see Industrial Facilities section above). There were also a number of ignitions and in-building fires in collapsed structures. However, due to the prevailing reinforced concrete and masonry construction typical of the area, these fires did not spread beyond the building of origin. Fire following earthquake has not been regarded as a significant hazard in Turkey, with the exception of Istanbul, where a significant inventory of old wood-frame buildings in portions of Istanbul are at significant risk to fire following a future earthquake.

Firefighters containing tank fires at Tüpras Refinery.

The collapsed Officer's Club at the Gölcük Naval Base. The building straddles the fault which displaced 2-3 meters. Note the faulting in the foreground.

Infrastructure

Lifelines

Electric Power: The entire country of Turkey lost power shortly after the earthquake because of damage to the central 380 kV substation at Adapazari. However, effects were minimal to the 154 kV substations and no power plants were located within the highest ground shaking regions, so electric power was restored in most damaged areas within a few days, except where distribution systems were severely damaged due to building failures.

Ports: There was extensive damage at the Turkey Naval Base in Gölcük, with collapsed buildings killing several hundred military personnel, including senior officers. Several buildings were ripped apart by the fault, which bisected the base. Here, fault displacement was primarily right lateral approximately 2 to 3 meters with perhaps 30 centimeters of vertical displacement. The main docks just behind the sea walls were heavily damaged by the fault, and two large cranes were damaged by a combination of

Damage to a bridge to the pier at the SEKA Paper Mill in Izmit.

lateral spreading of the soil below the supporting structures and spreading of the rails. Numerous other port facilities along the Gulf of Izmit suffered severe damage.

Water Supply: Much of the affected area and virtually all of the urbanized communities on the shore of the Gulf of Izmit are served by the newly constructed Izmit Water Project (IWP), built and operated by Thames Water. IWP is supplied from a newly constructed 60,000,000-cubic meter reservoir impounded by a 40-meter high earthen dam, which experienced 2-meter sloshing in the event. The water treatment plants and major distribution systems performed reasonably well, sustaining minor damage. However, local distribution systems in Gölcük, Izmit and other areas served by IWP were generally not functional due to local pipe failures. Water needs of the population were being served by tanker trucks throughout the area, as well as by purified water supplied by military ships.

Road Network: The main motorway between Istanbul and Ankara passes through Izmit and Adapazari and is intersected by the fault at several locations. Damage to the main motorway was generally confined to isolated bridge collapses at fault crossing locations. Otherwise, the majority of the bridges, the motorway, and local roads all performed well structurally, but were overwhelmed in the days following the earthquake by rescue efforts and other traffic.

Implications for the Insurance Industry

As much as one third of Turkey's GNP is produced in the affected area. Over 1.1 million fire policies and over 600,000 earthquake policies are in force in Turkey. The total insured sum of all of Turkey's quake policies is over $100 billion. In the affected area, over 26,000 policies with more than $7 billion in coverage are in force. One refinery alone may have $1 billion damage. The London Times (8/21/99) quotes Lloyds as saying only 10% of the loss is insured. International financial assistance may well be required to rebuild this economy.

The substantial damage to structures, contents, and infrastructure in a location where the building codes include sophisticated earthquake-resistant provisions must be a significant concern to insurers and reinsurers. One obvious issue is the need for independent, reliable information on the quality of construction, building design and adherence to local building codes. As more information about the differences between the damaged structures and those left standing emerges, insurers will gain valuable insight on the underwriting, loss mitigation and catastrophe modeling strategies. This knowledge must also be used to evaluate portfolios and financial risk. Implications from this earthquake extend far beyond Turkey to any geographic area where there is significant investment and building infrastructure on or near areas of high seismic exposure.

Conclusions

The Izmit Earthquake has wide-ranging lessons for the science of earthquakes, earthquake engineering, building code development and application in earthquake regions, construction quality, risk management, and insurance. A few of these lessons are discussed below.

- **Loss of life and building collapse was avoidable**. Almost all of the damage caused by the earthquake, and almost all of the deaths caused by the collapse of inadequately designed and constructed buildings was avoidable. That is particularly true for buildings built during the last decade. Turkey has a modern building code for earthquake design, very similar to that used in California. Therefore, modern buildings should have had moderate-to-light damage, given that the intensities of shaking in this earthquake were moderate. In fact, new buildings performed very poorly because they were not properly designed, not properly constructed, or located on ground that failed from shaking or faulting. This is a fact that building owners around the world need to clearly understand. The presence of an advanced building code, whether in California, Japan, Italy, or Turkey does not guarantee adequate performance of buildings and their contents.

  Many buildings in the most heavily damaged areas survived without significant damage. Typically, these buildings were designed with earthquake-resistant features, were well-constructed with obviously good quality materials, and were on firm ground or rock.

- **Severe industrial losses also were avoidable**. Industry suffered heavy losses. Most of the losses, and particularly business interruption losses and market share losses, were predictable. Many of the losses were caused by the collapse of structures that would have been expected to collapse, had they been adequately

Collapsed and partially collapsed just completed 5-story buildings in Gölcük.

Reinforced concrete industrial building at Gölcük. The front third of the building has collapsed completely. The middle section has two floors collapsed .

Identical liquid oxygen and nitrogen tanks at Habas facility in Izmit. Reinforced concrete supports collapsed on full tanks left and center, but not on 1/4 full tank on right.

evaluated by experienced structural engineers. Other losses were caused by equipment that was not properly anchored or braced to resist earthquakes. Again, such damage is well understood - there should have been no surprises. To date, there are no significant new lessons with respect to structural behavior.

The heavy damage at the Tüpras Refinery and other petrochemical plants merits special attention. Fundamentally, nothing surprising happened to cause the damage. The site is on soft soils, near a major fault. The ground motion was relatively strong, with long duration. However, the effects of this earthquake, including severity of damage, business interruption losses, and environmental impact (fires, toxic releases, and oil spills) at petrochemical facilities, were much more severe than previously experienced in strong motion earthquakes. The loss at Tüpras could have been even larger, had the fire spread into the nearby process units.

The major damage at these facilities could have been avoided with better earthquake resistant structural design, systems design, and planning. Numerous oil, gas, chemical, storage, and other large facilities around the world face similar risks. The concentration of such facilities around Tokyo Bay is probably the largest single property risk in the world. Many such facilities face earthquake risks that have not been properly evaluated and mitigated. The losses and the resultant environmental damage could be staggering.

- **Ground faulting and rupture losses from poor land use planning**. Faulting and the resulting ground ruptures caused the collapse of hundreds of structures in the affected region. These structures were built over a well-known fault without due regard to the dangers posed by faulting. Since the early 1970s, California has had a law limiting development within known and active fault zones. However, hundreds of structures, possibly thousands of structures, built before the law went into effect, are located directly on top of or immediately adjacent to active fault traces. That is also the situation in many countries around the world. This is the first modern earthquake to show, unequivocally, the consequences of not restricting development in active earthquake fault zones.

- **Limited earthquake insurance availability**. According to the World Bank, only 15% of the residences in the Istanbul urban area are insured for earthquake, while in other areas of the country the estimates are as low as 2%. In addition, domestic insurers have insufficient expertise and capital (the World Bank estimates that total accumulated industry earthquake reserves are $27 million at year end 1998!) to adequately protect their policyholders. Clearly, the insured losses will greatly exceed this amount, resulting in either insolvency or failure to pay policyholders. Improvements in hazard mapping and use of sophisticated catastrophe management software will enable Turkey to improve insurance availability through risk-based catastrophe pricing. Risk-based underwriting and pricing will also provide support for changes in land use planning, mitigation and building retrofit programs, and improvements in building construction practices

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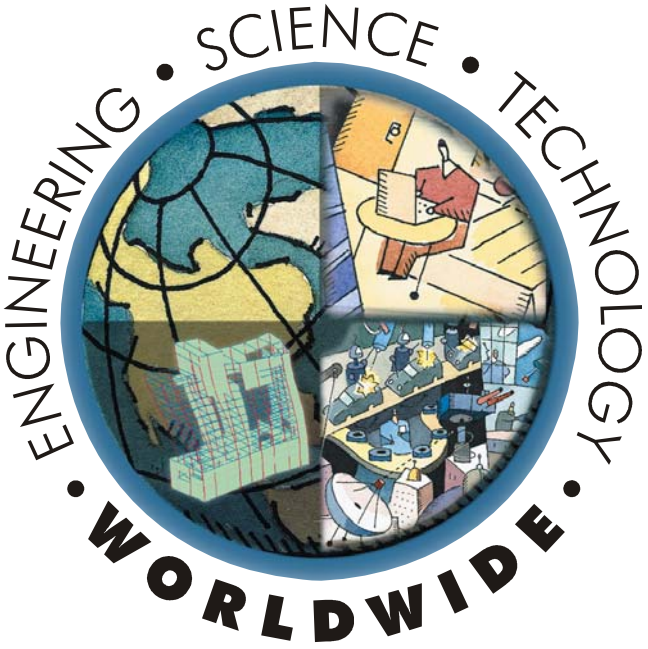

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