Event Report

Kocaeli, Turkey Earthquake

August 17, 1999 3:01 a.m. M7.4 40.7N 29.9E 17km depth

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The RMS reconnaissance team arrived in the earthquake-affected area on August 21, four days after the event, to survey damage, interview experts, and collect data. The team presented preliminary findings at seminars in London, California, and Japan. Several members returned one month after the earthquake for a follow up survey focusing on the industrial facilities recovery and the collection of additional loss data.

Acknowledgments

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Finally, we extend our sincerest thanks to the managers and personnel of industrial facilities and utility and insurance companies who took time out of their busy post-disaster schedules to provide tours of their facilities and share information and insights about the disaster's impacts and their recovery-related decisions. We sincerely hope that their recovery progress is swift and successful.

Editorial and Production Team: John Abraham, Lois Kiriu, Shannon McKay, Yaping Xie, and members of the RMS reconnaissance team.

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The Kocaeli Earthquake

The magnitude 7.4 Kocaeli earthquake was one of the few large magnitude events to strike a highly urban and industrialized region of the world in the last fifty years, and it was the lead item on world news networks for six continuous days. Damaging ground shaking intensities covered a 2,000 square kilometer (770 square mile) area in the provinces of Izmit and Istanbul in northwestern Turkey, home to one-third of the country's 65 million people.

Search and rescue teams brought thousands of bodies out from the wreckage of collapsed buildings. More than 17,000 deaths have been confirmed and another 20,000 people are declared missing and presumed dead. This level of casualties is attributed primarily to the total "pancake" collapse of thousands of unengineered multi-story apartment buildings. The earthquake struck at three o'clock in the morning, when the buildings were filled with sleeping residents.

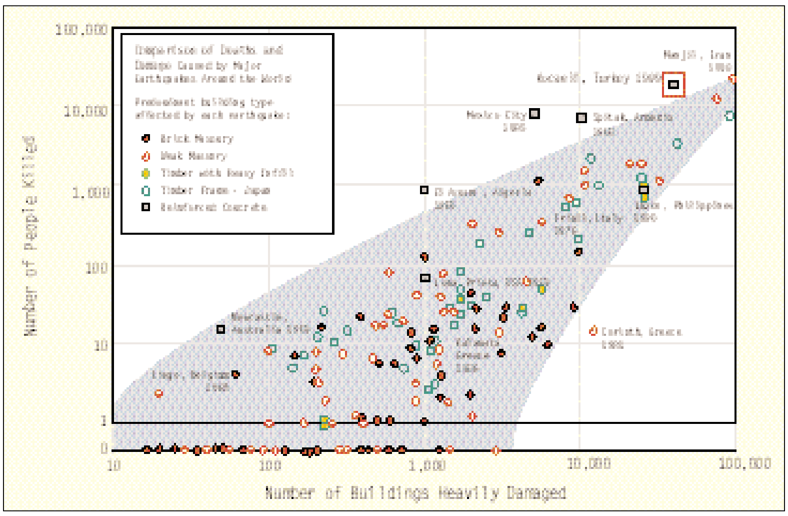
The extent of damages far exceeded the operational resources and response capabilities of local and national agencies, which had performed reasonably well in previous smaller disasters. Hospitals and rescue teams were quickly overwhelmed and the survivors themselves performed much of the initial search and rescue. Assistance from national and international rescue teams increased over the course of the first week, and thousands were extricated successfully. The national response plan was in full activation by the fourth day of the disaster, but food, clothing, and sheltering efforts generally lagged behind the needs of the region's people.

The August 17 (magnitude 7.4) and November 12 (magnitude 7.2) earthquakes struck the western industrialized corridor of Turkey, southeast of Istanbul.

Industrial heartland hit hard

The August 17 earthquake ripped through the industrial corridor of Turkey, affecting plants and production facilities along the transportation spine that links Turkey's largest city, Istanbul, with its capital, Ankara. Development in the region is concentrated in the alluvial plains between the hills and mountain ranges surrounding Izmit Bay and the Marmara Sea. Forty percent of the country's annual manufacturing production of US$75 billion comes from this region.

Over 1,000 individual plants and special risks were shaken to intensity VIII or worse, including the country's largest refinery, which burned for six days after the earthquake. Telecommunications were severed when the fault rupture cut the main fiber optic cable that runs between Istanbul and Ankara, and damage to two substations initially interrupted power across much of northwestern Turkey. The Istanbul-Ankara motorway and the railroad also sustained heavy damage, including a collapsed overpass, which impeded transportation into and out of the region during the first week of the disaster.



The Kocaeli earthquake was both more destructive and more lethal than most recent earthquakes.

Insurance impact moderate

The earthquake occurred during a period of rapid growth for the insurance industry in Turkey, following a decade of strong growth in the Turkish economy. Still relatively small in international terms, Turkey's insurance

As seen here in Golcuk, the neighborhood fabric has been completely destroyed in some of parts of the region's hardest hit towns, as nearly every building suffered either partial or total collapse.

industry had a 1999 property premium income of US$240 million and a total insured value of about US$93 billion. Nearly three-quarters of the insured value comes from industrial and large commercial risks, for which earthquake penetration rates are 85%. Smaller value commercial and personal property lines have grown rapidly in recent years, but the market penetration and earthquake coverage penetration are still less than 10%.

Estimates of the total economic loss for this disaster vary widely from US$8 to $40 billion, but many reports predict the total to be US$15 to $20 billion (7% to 10% of Turkey's Gross Domestic Product, or GDP). The insurance liability will likely be limited to US$1.5 to $3.5 billion. In the first two months after the disaster, 10,000 earthquake-related claims were submitted, with estimated damages of US$750 million. Most of the claims loss reportedly resulted from physical damage to insured industrial risks and nearly all of this risk is reinsured internationally. Lost production caused by earthquake-related disruptions is estimated at US$4 to $6 billion (2% to 3% of GDP), but few businesses have business interruption coverage. It is therefore likely that these losses will be borne by the industries themselves, with only a small percentage entering the international market.

Construction quality a concern

More than 120,000 housing units were heavily damaged or collapsed, leaving 400,000 to 600,000 people homeless. While the residential sector is largely uninsured, Turkey's Natural Disaster Law obligates the national government to replace all owner-occupied dwellings, an implicit insurance with zero premium. Housing reconstruction estimates are approximately US$5 billion.

On November 12, another damaging earthquake struck western Turkey and extended the fear that this catastrophic episode is far from over. The magnitude 7.2 earthquake, centered in Duzce (population 80,000), about 105 kilometers (65 miles) east of Izmit, took at least 800 more lives and destroyed over 2,000 buildings.

Both the general public and international financing agencies are now closely scrutinizing deficiencies in building code enforcement practices and insurance coverages. The government has started a campaign with private companies to quickly construct prefabricated housing, and it established an October 2000 deadline for rebuilding all the damaged housing stock. However, reconstruction will probably take many years, and there is also concern that intense rebuilding pressures may result in some of the same construction practices that compounded damage in these events.

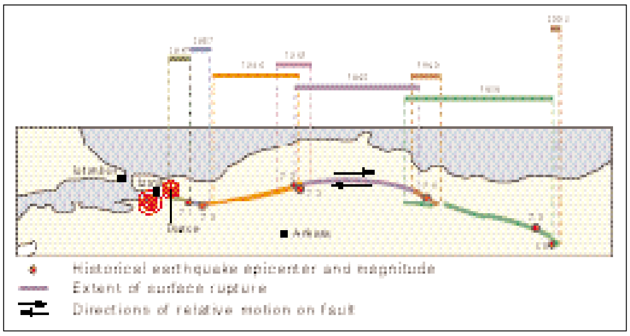
Turkey has lost nearly one in every thousand of its population, and these catastrophes have personally touched the captains of industry and decision makers of Turkey's rapidly changing society. The Kocaeli earthquake will have lasting consequences on the way risk is perceived in Turkey. It also offers sobering lessons for risk managers worldwide on how rapid urbanization and economic growth in emerging markets can raise the human and economic costs of natural disasters to catastrophic proportions.

The Earthquake and its Geologic Effects

The magnitude 7.4 earthquake ruptured more than a 110-kilometer (70-mile) section of the northernmost strand of the North Anatolian Fault (NAF) system. One of the world's longest tectonic systems, the NAF is the dominant fault in Turkey, stretching 1,500 kilometers (930 miles). It serves as the boundary between the Eurasian Plate and the Anatolian and Arabian plates, and is similar in characteristics to the San Andreas Fault in California, with predominantly right lateral strike slip movement (meaning that the land on each side of the fault moves to the right relative to the other side). The fault experiences about 20 to 30 millimeters of slip annually, more than the San Andreas, which has about 17 to 24 millimeters of slip each year.

This earthquake was not a surprise

In addition to being one of the world's longest systems, the NAF is also one of the most active. This earthquake filled a 150-kilometer (93-mile) seismic gap in the NAF that was first noted in 1979. A rich historic record shows that the town of Izmit was destroyed at least 7 times between 69 AD and 1719, and a large event was well overdue. Recent studies by the U.S. Geological Survey (USGS) and other researchers have estimated a 12% to 20% chance of a magnitude 6.5 or greater earthquake occurring in this area before 2025. By comparison, in 1999 the USGS estimated a 21% chance of the San Francisco Bay Area experiencing an earthquake of magnitude 6.7 or greater on the San Andreas Fault in the next 30 years.



The August 17 and November 12 earthquakes add to the westward progression of ruptures along the North Anatolian Fault that began in 1939. (Original source: U.S. Geological Survey, 1993)

Faulting rupture reveals many lessons

Strong motion records suggest that the August 17 event caused a double (bilateral) rupture along the NAF, starting from a point southeast of Izmit and extending west into Izmit Bay and east to the town of Duzce. Three to four meters of right lateral surface rupture were measured along most of the 110-kilometer (70-mile) break, with as much as 4.9 meters (16 feet) observed in some locations. The fault ruptured through several major lifeline and transportation systems, and also passed through hundreds of structures of all types and uses (including several new industrial plants).

There were also at least three significant and unexpected "step-overs" in the fault's rupture path. The rupture stepped north about 2 kilometers (1.2 miles) in the vicinity of Golcuk and displacements along this step were mostly vertical (rather than right lateral) with heights of 2 to 5 meters (6 to 16 feet). The rupture path also crossed Lake Sapanca and then skipped over onto the nearby Duzce Fault, with mostly vertical displacements in these steps as well. It is believed that the August 17 earthquake loaded stress onto the Duzce Fault, which subsequently ruptured on November 12.

The fault ruptured through this recently built but unoccupied 180-unit vacation development near Kular, completely destroying 7 of 8 buildings. The remaining building and all surrounding structures were also heavily damaged.

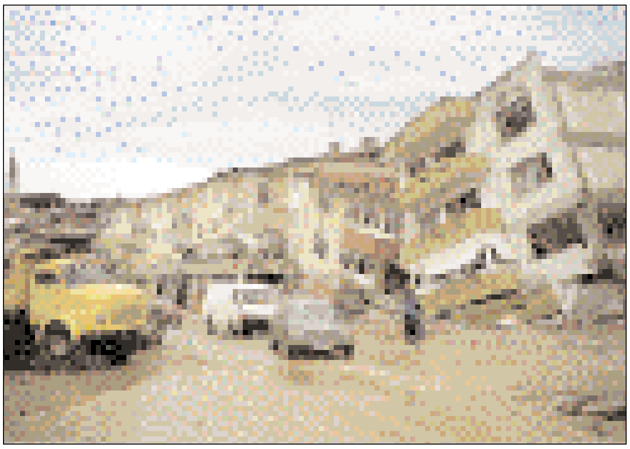
Shaking correlates with damage

Some twenty strong motion instruments were triggered in the earthquake. Damage was concentrated in the area within 40 kilometers (25 miles) of the earthquake's epicenter, where free-field peak horizontal ground accelerations (PGAs) were 0.32 g to 0.41 g. By comparison, PGAs in the Istanbul area (80 kilometers, or 50 miles, from the epicenter) ranged from 0.04 g to 0.25 g. Pockets of intense shaking and damage were dispersed across the region, including the west side of Istanbul, Yalova at the tip of the Izmit peninsula, and Bolu in the east.

The earthquake accelerations were somewhat lower than those recorded for other comparable magnitude earthquakes, which may have been caused by a slower than average release of energy from the fault rupture and geologic conditions at the recording stations. Yet, acceleration spectra correlate with damage observed near the recording stations. In Yarimca and Gebze (both on the north shore of Izmit Bay), the spectra peaks at 0.9 and 1.4 seconds, corresponding with the heavy damages observed in taller structures, such as nearby refinery stacks and tanks. By contrast, the Sakarya and Izmit spectra show a higher response at shorter periods of 0.3 seconds or less, roughly correlating with heavy damages to 3 to 6 story structures.

Liquefaction and soft soils cause widespread damage

Soil effects played an important role in localized damage concentrations. For example, nearly every building along a 2-kilometer (1.2-mile) stretch of the main street in Adapazari's city center was completely destroyed. Buildings punched through the highly saturated soil layer that liquefied in the earthquake, sinking by more than 1 meter (3.3 feet), and often collapsing as a result. Some structures with adequately reinforced mat foundations stayed intact, saving the occupants and some building contents, but earthquake-induced differential settlement caused them to slowly sink or lean onto their sides.



Adapazari means "island market" and the city center was settled in the last century as residents moved from adjacent hills and filled in the swampy lands of an old riverbed near a new railway and roads. As shown here, much of the city center's buildings and infrastructure were heavily destroyed in the August 17 earthquake. An earthquake similarly destroyed Adapazari's center in 1967, and efforts to redirect development into the hills gave way to urbanization pressures of the past 30 years.

Several city blocks of streets and buildings were submerged when the Marmara Sea coastline at Golcuk and Degirmendere suffered severe subsidence of about 3 meters (10 feet). The shoreline shifted inland 100 to 300 meters (330 to 980 feet) along the stretch of coastline, as shown here.

Although not as dramatic as in Adapazari, settlement was the main cause of dock and port-related damages to the industrial facilities that ring Izmit Bay. Damages included concrete piers, loading equipment and piping fractures, pavement buckling, and foundation failures. Nearly half of the jetties in the region were destroyed.

The Istanbul neighborhood of Avcilar is more than 90 kilometers (56 miles) from the earthquake fault, but severe shaking destroyed more than 60 buildings and rendered another 1,000 uninhabitable. PGAs of 0.25 g were recorded here, and the area's soft alluvium was vulnerable to long-period motions. The region's subsurface geology may also have focused energy into certain areas, even at great distances from the fault. These long-distance effects are reminiscent of the localized damage patterns observed in San Francisco's Marina District and in West Oakland after the magnitude 6.9 Loma Prieta Earthquake in October 1989.

In the past three decades, Turkey has undergone tremendous economic growth and industrialization. Simultaneously, the country's population has shifted from more than 70% rural to more than 70% urban. The Kocaeli region and Istanbul have averaged 5% to 6% annual population growth during this time, as people were attracted by the region's employment and education opportunities. Land development and building construction occurred quite quickly, as property owners and builders capitalized on housing demands, and the rapid growth swamped local government capabilities to enforce building codes and control development. They often relaxed inspection processes and repeatedly raised allowable densities in an effort to help facilitate market needs.

Turkey first instituted seismic building design requirements in 1944, and more recent seismic revisions occurred in 1975 and 1997. The code provisions are comparable to the Uniform Building Code (UBC) in the western U.S. Newer planned residential developments, and commercial and industrial facilities (built to code standards) generally performed well in this earthquake. However, the majority of development in and around the Marmara Sea occurred between 1975 and 1996 (under 1975 building code provisions), and more than 50% of the region's building stock is poorly designed, non-ductile reinforced concrete buildings. Non-ductile concrete is brittle and has little flexibility when subjected to ground shaking.

CRESTA Zone	Province	Population	Dead	Injured	Destroyed Houses	Uninhabitable Houses
		1	2	3	4	5
3.1	Kocaeli	1,177,379	10,868	18,447	31,327	27,830
3.2	Sakarya	731,800	3,046	6,884	19,043	12,200
3.3	Yalova	163,916	2,539	5,937	9,462	7,917
1	Istanbul	9,198,809	984	7,204	3,073	13,339
11.1	Bolu	553,022	263	1,159	3,095	4,180
4.1	Bursa	1,958,529	239	2,375	29	104
6.1	Eskisehir	660,843	75	375	76	47
11.1	Zonguldak	612,722	3	26		
2.3	Tekirdag	194,834	0	35		
	Total	15,191,854	17,997	42,442	66,105	65,597

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5 [illegible] (Source: [illegible], August 25, [illegible])

Damage statistics by province.

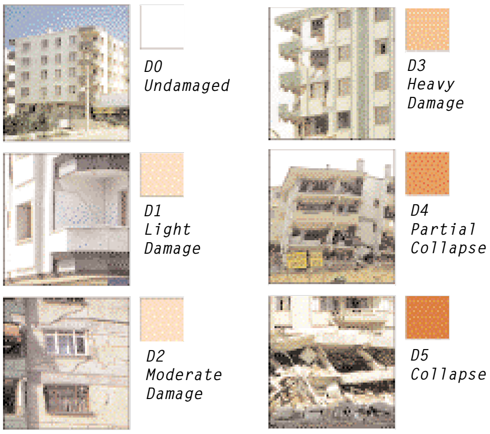
Poor construction has deadly consequences

The region's decades-old housing boom was largely met by the construction of large five-story reinforced concrete walk-up apartments – referred to by RMS as the *beshkat* (meaning "five floors") property type. Most of these buildings have five floors, but they can range from 3 to 7 stories, with an average of ten units per building and five people per unit. Built with non-ductile reinforced concrete frames and hollow clay tile infill walls, these structures suffered catastrophic levels of damage and life loss.

Recent reports estimate that over 6,000 buildings collapsed or sustained heavy damage in the 1999 earthquakes, displacing nearly 70,000 households. An additional 70,000 housing units sustained moderate damage and must be repaired before reoccupancy can occur. Most buildings collapsed because the columns lacked adequate transverse steel reinforcement to resist lateral loads. Shear failures occurred in the structural columns and at the beam-column connections. Many buildings were also designed with an open ground floor to accommodate other uses, such as parking, and the soft story conditions exacerbated the non-ductile failures.

Commonly seen throughout the epicentral region, a portion of this reinforced concrete building's first floor was partially destroyed. As shown in the inset, columns generally lacked an adequate amount of steel reinforcement.

In the last 10 years, another wave of regional development



RMS' rapid quantitative survey of the damage states of reinforced concrete apartment buildings showed the extent of losses to residential property and illustrated the spatial distribution of the earthquake's intensity.

focused on providing vacation and rental housing around the Marmara Sea. Towns such as Yalova and Chernarcek have grown rapidly, driven by investments in vacation properties. In some towns, summertime populations swell to as much as four times the normal population. High collapse rates in these developments are being attributed to poor construction practices and lack of engineering supervision or code enforcement.

Residential damage survey illustrates shaking intensities

RMS carried out a rapid quantitative survey on more than 2,200 *beshkat* structures during its 5-day mission shortly after the earthquake. Team members conducted surveys of the external damage state of each building. A damage state value, ranging from D0-No Damage to D5-Total Collapse, was assigned to each building, and the percentage distributions of each value at a location were then used to assess damage distributions and to map intensity across the region.

In some areas, over 75% of the apartment buildings were destroyed (D3-Heavy Damage to D5-Total Collapse). Collapse rates of 40% or more are rare in buildings built with more modern methods of construction. The only other recent example was when thousands of precast concrete buildings collapsed in the 1988 Spitak, Armenia earthquake.

Commercial losses due to construction quality

Substantial losses were also inflicted on commercial property across the region. While a growing percentage of these buildings are insured, the majority are not. The losses will have to be covered by the businesses themselves and any government recovery financing programs.

Quality and age of construction were primary factors in commercial building damage. Engineering and construction contractor procurement methods have come under scrutiny, and some differences in quality appear to relate to the scale of the business. Larger commercial organizations tend to build and own their facilities, whereas small and medium-sized enterprises usually lease or buy speculatively-built buildings from property developers. Small and family-owned businesses often take space within residential apartment buildings. The way that different companies commissioned their property design and construction appears to be directly tied to the loss levels that they experienced. Good quality construction gave worthwhile returns to those who invested in it.

Infrastructure Damage

The earthquake's fault rupture, with offsets of 3 to 4 meters (6 to 13 feet), severed regional and national telecommunications, water, road, and rail arteries, further burdening the already overwhelmed emergency response efforts following the earthquake. Ground settlement also caused severe damage to local infrastructure and road systems. Yet overall, infrastructure damage was not as severe as seen in other recent urban earthquakes, including the Loma Prieta (1989), Northridge (1994), and Kobe (1995) earthquakes, and in most cases lifeline restoration was relatively quick.

The main fiber optic cable between Istanbul and Ankara was cut by the fault crossing just east of Izmit, and widespread usage the day after the earthquake overloaded the already damaged telephone system, causing it to fail completely. Repair was swift, however, and the link was restored within 24 hours.

The fault rupture also caused a freeway overpass to collapse on the main motorway between Izmit and Ankara. Additional heavy damage along a 50-kilometer (30-mile) section of the motorway hampered relief vehicles for more than a day, until the roadway was cleared and temporarily repaired. The railway track between Adapazari and Istanbul was also warped by the fault rupture and had to be replaced.

The fault rupture severed this bridge from its approach, along the Istanbul-Ankara motorway.

The earthquake severed power lines throughout the epicentral region, and damaged many transmission towers and two main electrical substations. Because the country's power grid was built with redundancy in the main transmission lines, power authorities were able to reroute the grid to restore

Repairs to damaged equipment at this substation in Adapazari were well underway less than one week after the earthquake.

power to Istanbul and other regions shortly after the earthquake. Outside the epicentral region, power was restored within 8 to 10 hours, and most of the epicentral region had power within 48 hours.

Local water and wastewater systems were severely damaged, particularly in areas that suffered ground settlement. The Izmit regional water supply had little

damage, but the fault rupture near Kular severed the main trunk line leading from the regional water treatment plant to the distribution network circling Izmit Bay. Water reservoir distribution sites throughout the region were drained empty by leaks in heavily damaged local distribution systems. Water had to be trucked from reservoirs to damaged towns, and repairs are expected to take considerable time and resources.

The full extent of damages to utility distribution systems such as water, wastewater, natural gas, cable television, and telephone lines is still being investigated and may never be fully known. Some systems may never be repaired since damage will be costly to locate. Instead, new systems might be constructed and service upgrades are expected as a result.

Underground water piping systems sustained heavy damage, and water trucks made several trips a day delivering water from the Izmit treatment plant to epicentral communities. Local residents also took advantage of water leaking from damaged washouts along the region's main trunk line.

Case Study: regional water system

A major new regional water supply came online only months before the earthquake. This system is designed to provide 143 million cubic meters of treated water per year to one million residents of Izmit province. Located south of Golcuk, near the villages of Kular and Yuvacik, this facility lies in the heart of the high-intensity epicentral shaking area. The earthquake provided a unique opportunity to evaluate the performance of three of the system's major components: an earthen dam holding about 53 million cubic meters of water located 6 kilometers (4 miles) from the fault rupture; a state-of-the-art water treatment plant located 3 kilometers (2 miles) from the fault rupture; and a 2.2-meter (7-foot) diameter pipeline that crosses the fault before connecting to the distribution system that circles Izmit Bay.

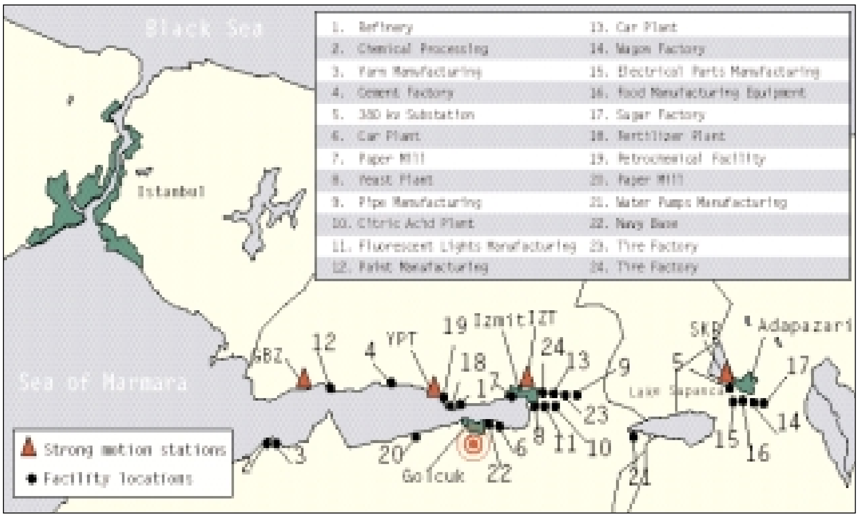
Earthquake damage to the overall system was relatively minor and water distribution was resumed within four days. The dam was filled to approximately 75% of normal capacity at the time of the earthquake, but was undamaged by the event. Several engineering teams inspected the dam within the first week after the disaster.

The water treatment plant suffered light damage, with some minor damage to equipment and plant components. There was a small chlorine leak, but automatic shut-off valves minimized the release. Ironically, the biggest potential impact to plant operations was the threat of losing their chlorine source. The plant's chlorine supplier, located near the burning Tupras refinery, was unable to reopen until the refinery fire was contained. Plant managers spent several days trying to secure an alternative chlorine supply at a time when their attention was critically needed elsewhere.

Lastly, the trunk line on the water system's pipeline network survived a displacement of 3.5 meters (12.5 feet) without catastrophic damage. The trunk line broke in three places, but leaking was minimal. About 10% of the system's output was unaccounted for through leaking. However, the system was able to continue transporting water to the region's 17 reservoir sites. Plans were to finish repairing a break in the older regional water system and construct a temporary rerouting until the fault break could be excavated and the trunk line repaired.

The Kocaeli region is responsible for nearly 40% of Turkey's annual industrial production and approximately 7% of the country's GDP. About 700 individually insured risks (mostly industrial facilities) are concentrated around the Marmara Sea from Istanbul in the west, to Izmit, Golcuk, and Adapazari in the east.

The August 17 earthquake was the first large magnitude earthquake in recent times to impact a substantial industrialized production center. It therefore provided an important opportunity to assess the performance of modern industrial facilities in the epicentral area of a large magnitude event.



RMS collected data on more than 73 facilities in the Kocaeli earthquake damage zone and conducted detailed case studies on 24 of these facilities.

Extensive survey of industrial facilities

RMS is nearing completion of the development (in cooperation with the insurance and reinsurance industries) of a new vulnerability model for analyzing industrial risk in earthquake-prone areas worldwide. RMS conducted two week-long reconnaissance surveys to assess the performance of industrial facilities in each of the model's major classes: refining and chemical processing facilities, heavy manufacturing, and light manufacturing. The first survey provided data on the performance of structures, machinery and equipment, and stock for each class of industrial facilities. The second, performed one month after the earthquake, provided an opportunity to gauge business interruption impacts and resumption status.

Data was gathered on 73 major industrial facilities, 24 of which were documented in detail as case studies, with analyses of damage and interviews with plant managers. The case study sample represented a wide range of occupancies and ages, and included plants with insured values from US$5 million to over US$1 billion, with an average of US$300 million. The facilities were mostly within 20 kilometers (12 miles) of the fault, with two facilities located on the fault rupture. The survey also included a mix of age of facilities, often on the same site. Many were built within the past ten years, but some date back to the 1960s.

Refining and chemical processing

A refinery and four other large chemical processing plants evaluated as part of the reconnaissance were originally built in the 1960s and 1970s with additions in later years. Each has large outdoor processing units as well as spherical and/or cylindrical chemical and gas storage tanks. Overall property damage to these facilities was minor to moderate, with isolated cases of severe damage due to ground failure, or failure of the structures supporting process equipment. Losses due to business interruption and downtime were more significant than property losses for these large facilities.

Many of the region's refinery and chemical processing facilities are located on soft alluvial soils in the coastal plains around the Marmara Sea. These soils amplified long-period ground motions affecting tall structures such as smoke stacks and oil tanks. Although process equipment in tall structures often performed well, the concrete and steel structures housing and supporting this equipment were sometimes not adequately designed, and sustained extensive damage. For example, concrete structures at a fertilizer plant experienced heavy localized damage as concrete cracked and spalled, whereas machinery and equipment damage was relatively minor. Smaller structures and equipment performed better.

Vertical ground settlement damaged port facilities and equipment. The labyrinth of piping at some facilities was also damaged as a result of differential ground settlement, but was not heavily impacted by ground shaking effects. In some cases, distribution, cooling systems, and fire suppression were compromised by multiple fractures in the piping runds.

Infrastructure serving these facilities was similarly affected, adding to business interruption impacts. A refinery, a nearby petrochemical facility, and other industrial facilities in the region get their primary water supply from Lake Sapanca, about 25 kilometers (16 miles) east of Izmit. Strong ground shaking, fault rupture, and ground failure at Lake Sapanca caused extensive damage to pump stations and pipelines. For example, one pipeline failed at 20 locations, causing a four-week interruption in water supply to the plant it supplied.

Case Study: Refinery

Turkey's largest refinery is located in Korfez, about 10 kilometers (6 miles) northwest of Golcuk on the north shore of Izmit Bay, and 5 kilometers (3 miles) from the fault. The plant was first built in 1960, with expansions in 1974 and 1983. It experienced strong ground shaking with damage concentrated at the tank farm, a crude oil processing unit, and the port and unloading area.

The plant has more than 110 tanks of varying sizes containing water, crude oil, and other oil substances, with both floating and fixed roofs. Ground shaking vertically displaced the floating roof of one tank, creating sparks that ignited escaping oil, and the fire spread to completely destroy a nearby wooden cooling tower. Shell buckling at another tank base and resulting oil leakage may have contributed to the fire's spread.

A 115-meter (380-foot) tall, 10.3-meter (34-foot) diameter reinforced concrete stack collapsed onto a boiler and crude oil processing unit, significantly damaging the processing unit, boiler, pipeway and surrounding facilities. Fuel released from piping systems caused a second fire that spread to destroy the adjacent crude oil processing unit (built in 1983 as part of the most recent expansion).

The refinery's cooling towers also sustained heavy damage, including one collapse. Ground settlement also damaged the port and loading area, a common problem at most port facilities around Izmit Bay.

Extensive damage to the pump stations and pipelines cut the supply of water into the site. Stored water at the plant was insufficient to deal with the two major fire outbreaks. The fire at the crude unit was brought under control quickly, and the available resources were then concentrated on the fire at the tank farm, including aerial water bombardment. The fire took three days to control and three more to extinguish. After initial cleanup and repair of minor damage, the plant was able to resume operations at about half capacity using the undamaged production facilities.

Heavy manufacturing facilities

The 10 heavy manufacturing facilities evaluated in the RMS survey ranged from older state-owned facilities to relatively new privately-held plants. Most facilities had a number of large buildings that housed major production equipment, large silos and tanks, and an extensive amount of indoor and outdoor process piping.

The facilities' performance depended primarily on the age and seismic resistance capability of the structures that housed the process equipment. Older buildings constructed of concrete or steel frames with hollow clay or brick infill sustained heavy damage, and portions of the buildings collapsed in areas of strong ground shaking. Newer buildings suffered less damage. When damage did occur, these facilities were better prepared to make repairs and resume production.

Large production equipment performed well when it was at least minimally anchored. Equipment sensitive to ground movement is an exception to this observation. For example, strong shaking knocked assembly line sensors out of alignment at a car manufacturing facility. The equipment was nearly realigned when an aftershock knocked it out again and the realignment had to be restarted. Although building damage was limited, production was severely impacted by this equipment damage.

Several incidences of hazardous chemical releases in the earthquake were identified. Although population centers were not threatened, some plant personnel had to be hospitalized, and plant emergency plans that included the issuance of breathing apparatus were implemented. Failed water supplies meant that some escapes could not be sanitized for several days after the earthquake.

Light manufacturing facilities

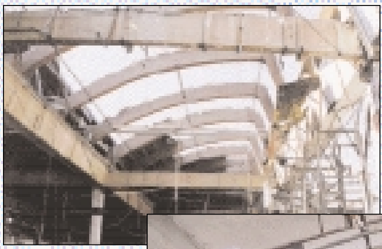
Several light industrial facilities were surveyed around Izmit Bay and Adapazari. Most facilities are privately owned with 50 to 350 employees, and building damage depended on the type of construction. Traditional concrete frame and hollow clay tile infill wall buildings performed poorly. However, since most did not have open or "soft" first stories, they tended to perform better than similar residential and commercial buildings with open first floors. Steel buildings performed consistently better, except for damage to hollow clay tile exterior walls.

Precast concrete frame structures have become a popular construction type for warehouse and low-cost production facilities in recent years, and this earthquake offered one of the first chances for engineers to evaluate their performance. In general, these structures performed very poorly, lacking seismic detailing at beam column connections as well as at the column bases. Pin-connected precast frames showed damage to columns and excessive lateral drift at the tops of the columns.

Case Study: Wagon factory

The main production and maintenance facility for train cars in Turkey is located in Adapazari, and structural damage was extensive at this large facility. One of the large maintenance buildings totally collapsed and several other structures suffered partial collapses and may be a total loss. Damaged buildings had high-bay steel frames with steel roof trusses and concrete roof decks. Most damage occurred when the roof truss to column connections and column anchor bolts failed, contributing to the full or partial collapse of the buildings. A two-story administration building, adjacent to the collapsed production facility, had a non-ductile concrete frame and hollow clay tile infill walls, yet the building exterior showed no signs of damage.

Case Study: Tire factory



A tire factory located outside of Izmit (about 15 kilometers, or 9 miles, from the epicenter) suffered extensive building damage. The plant was built in the early 1960s and was repeatedly expanded. Four weeks after the earthquake, the factory had only resumed 20% of its operational capacity, and full operation was not expected for one year.

The heating unit and mixing unit buildings were both concrete frame structures with exterior hollow clay tile infill walls. The concrete roof of the heating unit building collapsed and destroyed 80% of the machinery and equipment. Poor beam column connections, use of mild steel, and inadequate confining steel reinforcement all contributed to the building collapse. The mixing unit building (which contains the plant's major processing unit machinery and equipment) experienced only minor damage in columns and at beam-column connections. Column repairs, using jacketing techniques, were underway one month after the earthquake. Part of this upgrade included the addition of cross bracing between columns. An initial quick repair was done to prevent additional structural damage from aftershocks but further detailed design and retrofit of critical elements was still needed.

A third production facility, built in the late 1980s, is a steel frame structure with infill walls between exterior frames. It suffered only minor damage at the base connection of two columns. Excessive lateral movement at the column base sheared the connecting bolts right off.

As in the case of heavy manufacturing, production machinery at light industrial facilities sustained relatively minor damage when anchored, with the exception of equipment sensitive to ground movement. For example, moderate damage to a glass furnace at one facility shut down plant production for more than a month. Damage to the feeder, leading from the furnace to forming machinery, caused molten glass to leak out. Workers quickly shut the furnace off and drained the remaining molten glass. Repairs in process one month following the earthquake included the addition of cross bracing to the steel structure supporting the furnace.

Business interruption impacts at industrial facilities

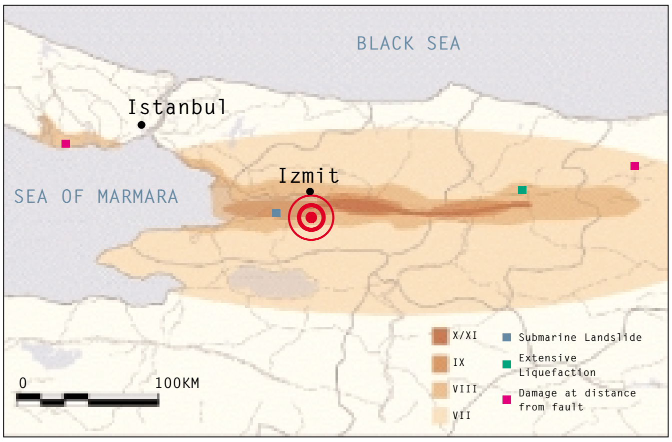
Nearly all of the 24 industrial facilities studied in detail as part of this survey lost some production time following the earthquake, ranging from 10 hours to more than a year. In one case, facility managers decided not to reopen an older facility that suffered heavy damage. Average downtime exceeded 40 days, and initial downtime estimates generally increased as managers tested systems and discovered more damage.

In this earthquake, there were several key causes of business interruption. Damage to production facilities, buildings, and machinery was the most significant cause, often exacerbated by loss of essential services. Loss of services, such as power and water supplies, was also a common factor. Loss or extended absence of staff further delayed recovery, especially when nearby towns were badly damaged and staff were absent due to injury or personal loss.

Only a few of the case study facilities had business interruption insurance coverage. On average, business interruption costs are expected to be more than three times the costs of physical damages. Most companies will have to absorb these costs.

Insured and Economic Losses

Although a complete catalogue of insured losses will not be available for some time, RMS developed and presented a preliminary estimate of losses to the international market within two weeks of the August 17 disaster. The majority of insured earthquake coverage is for large commercial and industrial facilities, and this risk is routinely transferred to international markets in London and Continental Europe. However, earthquake cover generally carries a 5% deductible, which reduces the insurers' losses from the earthquake.



Preliminary intensity map developed by RMS, two weeks after the Kocaeli earthquake, and based on the "beshkat" survey. It was used to develop a preliminary insured loss estimate.

An emerging insurance industry

The insurance industry in Turkey is relatively small in international terms, with a 1999 property premium income of US$240 million and a total insured value of about US$93 billion. However, it has been growing rapidly in recent years, with a growth of insurance policies in both small commercial and personal lines.

The number of insurance policies issued has doubled in the last three years, but the demand for insurance has not boosted premium income. In fact, insurance rates have softened due to international insurance pricing trends, the entrance of foreign players into Turkey's domestic marketplace, and unprecedented levels of competition. Earthquake cover remains a fairly expensive additional cover, and it has a standard 5% deductible and 20% co-insurance requirement.

Nearly three-quarters of Turkey's total insured value comes from special risks. These are mainly large industrial plants and major commercial centers insured for more than US$183,000. These risks have an average sum insured of over US$4 million per policy. Insurance penetration rates for these risks are estimated at 91%, and earthquake insurance penetration is also high at about 85%. Many of the larger facilities are believed to be under-insured to a significant degree.

Small or simple risks make up additional portfolios, and contain the many individual property policies of homeowners and small or medium-sized commercial enterprises. These are smaller properties and individual apartments within a building, averaging US$21,000 per risk. Market penetration here is much lower at about 8%, with only a 5% penetration for earthquake insurance cover.

Estimating physical damage costs to insurers

The footprint of the August 17 earthquake covered a large part of CRESTA zones 3 and 1, and also affected zones 2, 4, 6 and 11. Over two-thirds of the area of zone 3 was shaken to intensity VIII or stronger. By mapping the various industrial facilities, population distributions, and aggregate sums insured, RMS developed an overall picture of the insurance inventory affected by the earthquake. Shaking intensity VIII or stronger affected over 1,000 individual risk policies with earthquake cover, and around 50,000 simple risks.

The total loss incurred by insurance companies will depend significantly on the performance of the individual risks – i.e. the major industrial plants. The costs will be driven by the number of major

	Individual Risks*	Other Property
Total number in Turkey (Estimated)	17,000	15,000,000
Number of insurance policies	15,450	1,174,774
% Insurance penetration	91%	8%
Average SI	$4m	$21,281
Total Insured Value	$68 bn	$25 bn
Premium Income (March 31, 99)	$190m	$50m
Earthquake Cover		
Number of policies	14,483	718,192
Average sum insured	$4m	$21,281
Penetration of earthquake insurance	85%	5%
% of insurance polices with quake cover	94%	61%
TIV Earthquake	$66 bn	$16 bn
Earthquake Premium Income	$92m	$22m
Earthquake Deductible	5%	5%
Earthquake Co-insurance	20%	20%

*Individual risks are facilities with a sum insured of over $183,000
All $ are US$. Source: Sigorta Gazetesi, April 1999

Summary of insurance exposure in Turkey.

plants with structural damage above their 5% deductible limit, and insurance companies will then face claims for 80% of the losses in excess of the deductible.

RMS used average loss numbers from other earthquakes and estimates of the number of facilities affected by shaking to generate early estimates of losses to the insurance industry from this event. RMS developed preliminary loss estimates which it released on August 31, estimating US$600 million to $2 billion in physical damages to insured industrial facilities and US$300 million to $750 million for other insured risks.

Shaking Intensity	Insured Value	
	Industrial	Simple Risks
VI	$10-30 billion	$2-6 billion
VII	$5-10 billion	$1-3 billion
VIII	$3-8 billion	$0.5-1 billion
IX	$1-2 billion	$50-150 million
X/XI	$0-250 million	$10-50 million
Physical Damage		
Industrial Loss:	$600 million to $2 billion	
Other Property Loss:	$300 million to $750 million	
Total Physical Loss:	$900 million to $2.75 billion	
Business Interruption		
BI Loss Potential:	$500 million +	
All $ are US$		

RMS preliminary loss estimates released on August 31, 1999.

In the first two months after the disaster, 10,000 earthquake-related claims were submitted with estimated damages of US$750 million, and more recent industry loss estimates are between US$1.5 and $3.5 billion.

Losses will increase

Business interruption (BI) costs far exceeded the estimated costs to repair earthquake-induced damages at most industrial and commercial facilities surveyed. However, few facilities surveyed had BI coverage and insurance penetration is low throughout the affected area, minimizing the impact of BI losses on the insurance industry.

BI losses are expected to rise with delays in business resumption caused by slow repairs and demands on skilled labor forces. Damage discovery may also increase losses. Typically, damages are more extensive and complex than first estimated, and this becomes apparent when repair work begins or more detailed investigations are done.

High national and economic losses

Until the downturn in 1997, Turkey had sustained an annual GDP growth of more than 6%, currently estimated at US$200 billion. However, the earthquake struck Turkey at an economically vulnerable time. The government has been struggling to tame annual inflation rates of 80% or higher, and the country's 1998 debt/GDP ratio was more than 50%.

Estimates of total economic loss from this event vary widely from US$8 to $40 billion, but many reports predict that it is likely to be US$15 to $20 billion (7% to 10% of GDP). The cost to the government is estimated at approximately US$6.5 billion, which will result in a 1.5% to 3.5% reduction in GDP in 1999. A major portion of the government's costs will be for housing, business, and infrastructure reconstruction. Turkey's Natural Disaster Law obligates the national government to replace all owner-occupied dwellings, and this provision is estimated to cost at least US$5 billion for the August 17 earthquake.

The government has established an October 2000 deadline for rebuilding all of the more than 120,000 housing units that were heavily damaged or collapsed. However, reconstruction will probably take many years, and the costs will undoubtedly add to the country's existing burden for upholding the rebuilding obligation of other disasters, which is estimated to have an annualized cost of 1% GDP.

A major cost of the Kocaeli earthquake, and a considerable loss to the Turkish economy, is the lost production in the region caused by business disruptions. These are estimated at 2% to 3% of GDP. The affected region produces 7% of Turkey's GDP, and an overall loss of output equivalent to 2.25% of the country's 1999 GDP growth rate is expected. As is often observed in the aftermath of large disasters, rebuilding is expected to boost GDP growth over time. Growth rates are expected to hit 6% again in 2000 and hover around 4% in 2001.

To initiate reconstruction, Turkey has negotiated more than US$1.8 billion in loans from the World Bank and US$400 million in loans from the European Bank for Construction and Development. It also applied to the International Monetary Fund (IMF) for assistance, which has already approved a US$325 million credit.

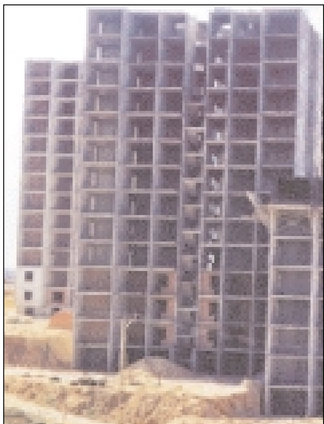
Consequences and Implications

The Kocaeli earthquake catastrophe, particularly its high death toll, will have lasting consequences on the way risk is perceived in Turkey and other emerging economies. Turkey's voting public and the international financing agencies are closely scrutinizing deficiencies in building code enforcement practices and insurance coverages, and the Turkish insurance industry is likely to experience a number of changes. Furthermore, key factors contributing to the scale of this catastrophe, including rapid urbanization and economic growth in high-risk areas, exist in many other emerging markets.

What the Kocaeli earthquake means for risk modeling

The fault's rupture through hundreds of structures and across many major lifeline and transportation systems offers a wealth of data for fault-related engineering and land use planning in other parts of the world. The unexpected "step-overs" in the fault's rupture path raise concerns about other complex faulting systems, such as the San Andreas in California. The November 12 Duzce earthquake also raises concerns about earthquake-induced stress on nearby faults and the possible triggering of additional events. This suggests that different, and perhaps more severe, earthquake scenarios may need to be considered in other regions of the world.

The catastrophic failures of non-engineered reinforced concrete buildings occurred in several recent earthquakes in Turkey, and did not surprise many engineers. Collapses were mainly caused by inadequate seismic design and construction practices. Precast concrete frame buildings also suffered badly, failing when poor quality connections led to the collapse of structural members. Newer steel-frame buildings generally performed well. While Turkey's reinforced concrete and precast concrete construction types are not common in most of the major insurance markets, they are prevalent in other seismically-active regions of the Middle East, Central and South America, and parts of Asia.



Industrial facilities that were designed to international quality standards generally performed well even in the highest intensity areas, but performance varied substantially depending on the age and type of structures at each plant. The most susceptible components tended to be the large process structures and storage tanks. Although the equipment in tall structures often performed adequately, the supporting concrete and steel structures were extensively damaged. Overall, machinery and equipment that were appropriately anchored performed adequately.

While the extent of building damage is often a key determinant of business impacts and economic recovery, it is expected that business interruption losses will be substantially higher than physical damages for industrial facilities affected by this earthquake. Key drivers of business interruption losses in this earthquake were infrastructure damages, repair downtimes, personnel losses, and the time required to replace damaged parts.

Is Istanbul next?

While some seismologic and geologic aspects of this event were extraordinary, an earthquake of this magnitude and location on the NAF has been predicted for some time. The NAF was the

Housing development pressures continue, and recently built structures vary greatly in seismic quality and code compliance.

source of some of this century's largest earthquakes, and the August 17 earthquake is the system's 11th event with a magnitude of 6.7 or greater since 1939. Seven of these events occurred in a progressive westward migration of ruptures along the fault between 1939 and 1967.

Months prior to the August 17 disaster, residents of the heavily damaged town of Yalova had reported mud and silt infiltration and temperature rises in the town's famous thermal baths. Further research is now underway to determine if this may have been a precursor to the August 17 event or a future event.

The magnitude 7.2 earthquake of November 12 caused a 30-kilometer (19-mile) rupture that began at the western end of the Duzce Fault. Duzce was also the easternmost boundary of the August 17 rupture, and it is now believed that the August 17 earthquake may have loaded stress onto the Duzce Fault, helping to provoke the subsequent rupture. If so, the next NAF event could occur at the eastern end of the August 17 rupture, off the coast of Yalova in the Marmara Sea, and much closer to the 12 million residents of Istanbul.

A magnitude 7.4 earthquake nearer to Istanbul could kill hundreds of thousands of people and cause over US$100 billion in damage. While many buildings currently under construction in the Istanbul area appear to incorporate better seismic design (especially taller buildings), the majority of Istanbul's existing residential and commercial buildings are substandard concrete frames with hollow clay tile infill walls (just like those which caused most of the recent events' heavy casualties). Without drastic measures to improve construction quality, Turkey may not be able to mitigate the future human loss potential that the country's thousands of non-engineered structures pose.

Foreseeable changes in Turkey

Following these recent earthquakes, Turkey's residents and political leaders have been openly questioning many aspects of earthquake risk management, including safe construction practices and enforcement, the government's ability to adequately recover from this disaster and to respond to future events, and the need to purchase earthquake insurance and other forms of protection for the future.

Turkey's insurance industry is expected to continue to change. With increased risk awareness in Istanbul and the perceived increased threat to the city from a future event, the market demand for earthquake cover may also increase. Most major businesses in Turkey are also likely to review their risk management strategies, possibly increasing their cover, revaluing their sums insured, and adding some level of business interruption cover to their current policies.

Some insurance companies are designing new insurance products aimed at the emerging marketplace. Non-standard and flexible coverages are being discussed, especially for small and medium-sized businesses. The biggest growth in new insurance will probably come from medium-sized businesses. This increase in demand will be tempered by a likely increase in the earthquake tariff and an increase in rates for other components, such as the already expensive business interruption cover.

The insurance industry in Turkey is also being looked to for leadership in mitigation activities. The government is exploring various public-private sector partnerships to fund the quality assurance processes needed to reduce risk by building better. A mandatory residential disaster insurance pool is also under review.

Lasting concerns for global markets

The Kocaeli earthquake was a wakeup call, not only for Istanbul, but for major population and economic centers worldwide. In addition to Istanbul, other "mega-cities" with populations of more than 10 million and a significant seismic hazard include Tehran, Jakarta, Mexico City, Manila, Shanghai, Taipei, Cairo, Tokyo, and Los Angeles. Innovative solutions, including public-private partnerships, are going to be necessary in order to develop comprehensive recovery financing strategies that will effectively meet the demands that catastrophic urban earthquake disasters in these areas would inevitably require.

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