4 Industrial Facilities

4.1 Overview of Construction and Damage

4.1.1 Introduction

Several areas of concentrated heavy industry surround the Sea of Marmara and Izmit Bay, extending west to Adapazari; approximately 40% of heavy industry in Turkey was located here before the earthquake. Figure 4-1 is a map of the eastern end of Izmit Bay showing the locations of several cities mentioned in the remaining sections of this chapter. Figure 4-2 is an aerial photograph of Körfez looking west along Izmit Bay. Extensive damage to many industrial facilities was observed over a wide strip that was centered on the fault line.

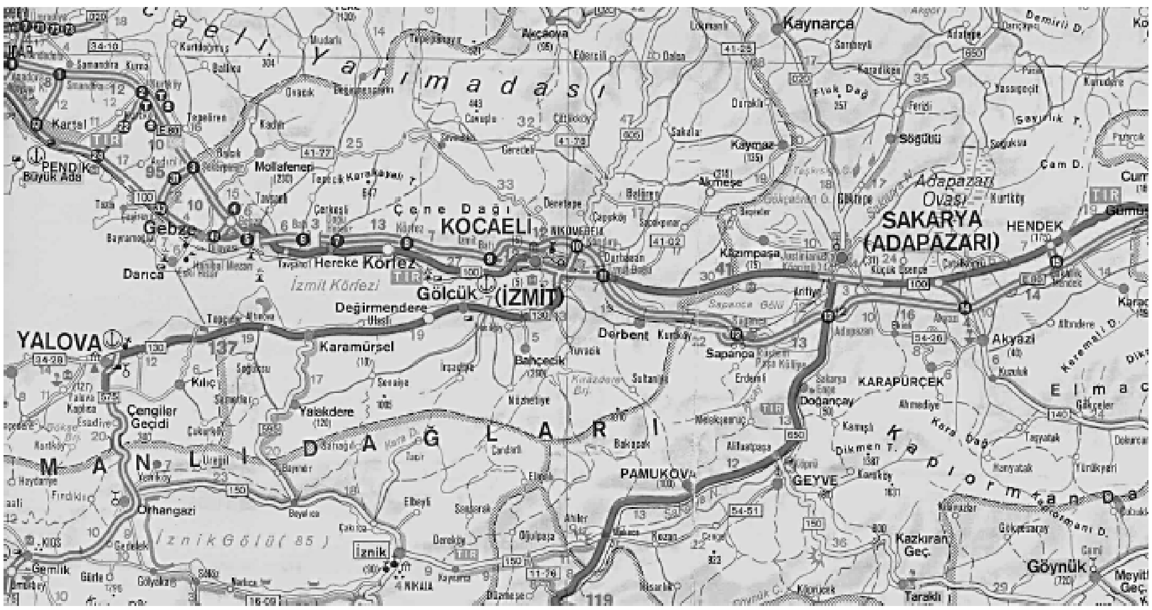


Figure 4-1 Map of the eastern end of Izmit Bay

Twenty-four facilities representing different industries in the Izmit and Adapazari regions were surveyed in the weeks following the earthquake. Since many of these facilities were designed according to current U.S. and European standards, their performance is relevant to other seismically active regions of the world. The following sections summarize observations from some of those industrial facilities visited by members of the PEER reconnaissance team. An alphabetical list of the facilities visited by the reconnaissance team, relevant construction information, and an approximate number of employees are presented in Table 4-1. The construction date for facilities under construction at the time of the earthquake is listed as 1999+ in the table; zero employees are listed for these facilities.

The managers of the industrial facilities visited by the reconnaissance team were most generous in granting the team permission to tour damaged buildings and structures. In a number of facilities permission to enter was granted on the clear understanding that no photographs be taken. A number of these facilities are described in the following sections but no photographs are presented.


Figure 4-2 Aerial photograph of industrial facilities in Körfez looking west

The widespread damage to industrial facilities had a substantial impact on the economy of the region, measured here in terms of direct and indirect losses. Direct losses were a result of structural damage and nonstructural damage, including damage to mechanical, electrical, and plumbing systems. For the purpose of this report, classification schemes for structural and nonstructural damage were developed; these schemes are presented in Tables 4-2 and 4-3, respectively. The observed structural and nonstructural damage to the facilities of Table 4-1 are listed in Table 4-4.

The following three subsections present summary information on typical industrial-facility construction practice in Turkey, followed by information on damage to petrochemical facilities, automotive facilities, power generation and transmission facilities, and assorted industrial facilities.

Table 4-1 Industrial facilities visited by the PEER reconnaissance team

Facility	*Function/Product*	*Construction Date*	*Construction Type*[1]	*Employees*
Adapazari Substation	Power distribution	—	Assorted	NA
Bastas	Fluorescent tubes	1960s	RC	NA
BekSA	Steel cord	1987	RC	240
BriSA	Tires	1974, 1989	RC	100
Çamlica	Soft Drinks	1999+	RC	NA
Çap Textile	Textiles	1997	RC	650
Çiti	Glass vials	NA	RC	NA
DuSA	Chemicals	1987	Assorted	NA
DuSA	Chemicals	1999+	Steel	NA
EnerjiSA	Power	1997	Steel	50
Ford	Automotive	1999+	RC	NA
Goodyear	Tires	1963	Steel	500
Habas	Liquid gases	1995	Assorted	NA
Hyundai	Automobiles	1997	Steel	850
KordSA	Tire cord	1973	Steel	1100
Mannesmann	Pipe	1955	Steel	200
Pakmaya	Food processing	1976	Steel	300
Petkim	Petrochemical	1967-1975	RC	2500
Pirelli	Tires	1962	RC	900
SEKA	Paper Mill	1936-1960	RC	NA
Toprak Drug	Drugs	1990	RC	240
Toprak Clean	Cleaning supplies	1993	RC	250
Toyota	Automobiles	1994	Steel	NA
Tüpras	Refinery	1961	Assorted	1350

1. Assorted = steel and reinforced concrete; RC = reinforced concrete
NA = not available

Table 4-2 Structural damage classification

Level	*Damage*	*Function*	*Repair*	*Typical Damage*
1	None	Fully operational	None	Negligible
2	Minor	Partially operational	Minor	Minor cracks in RC components; bolt failures in steel frames.
3	Moderate	Out of operation for days or several weeks	Modest repair	Significant cracks in RC components; yielding in steel moment frames
4	Major	Out of operation for months	Major repair or replacement	Spalling and crushing of RC components; fracture of rebar in RC components; anchorage failure in precast RC components; buckling of braces in steel frames; fracture of steel moment frames; modest permanent drift of building frame
5	Collapse	None	Not possible	Multiple component failures; part or full loss of floors or roofs; gross distortion of steel frames; large permanent drifts

Table 4-3 Nonstructural damaged classification

Level	*Damage*	*Function*	*Repair*	*Typical Damage*
1	None	Fully operational	None	Negligible
2	Minor	Partially operational	Clean up	Small movement of unanchored equipment; overturning of cabinets and shelved products
3	Moderate	Out of operation for days or several weeks	Engineered repair	Modest damage to architectural, mechanical, electrical, and plumbing systems; failure of equipment anchorage and movement of equipment.
4	Major	Out of operation for months	Major repair or replacement	

Table 4-4 Damage to industrial facilities visited by the PEER reconnaissance team

Facility	*Construction Date*	*Construction Type*[1]	*Structural Damage*[1]	*Nonstructural Damage*[2]
Adapazari Substation	—	Assorted	1	4
Bastas	1960s	RC	1	4
BekSA	1987	RC	4	3
BriSA	1974, 1989	RC	4	3
Çamlica	1999+	RC	4	3
ÇapTextile	1997	RC	5	4
Çiti	NA	RC	3	3
DuSA	1987	Assorted	4	4
DuSA	1999+	Steel	1	NA
EnerjiSA	1997	Steel	2	3
Ford	1999+	RC	3	NA
Goodyear	1963	Steel	2	3
Habas[3]	1995	Assorted	5	4
Hyundai	1997	Steel	4	4
KordSA	1973	Steel	3	3
Mannesmann	1955	Steel	3	3
Pakmaya	1976	Steel	4	4
Petkim	1967-1975	RC	5	3
Pirelli	1962	RC	4	3
SEKA	1936-1960	RC	4	4
Toprak Drug	1990	RC	2	4
Toprak Clean	1993	RC	3	4
Toyota	1994	Steel	1	2
Tüpras	1961	Assorted	5	4

1. See Table 4-2 for information on structural damage.
2. See Table 4-3 for information on nonstructural damage.
3. Two of three tanks completely destroyed; unknown nonstructural damage inside the undamaged tanks.

4.1.2 In-Situ Reinforced-Concrete Structures

In-situ reinforced concrete beam-column frame construction is common in smaller and older industrial facilities in Turkey. The quality of the construction in these facilities was typically substantially better than the quality of residential or commercial construction. Of the 24 facilities visited by members of the PEER reconnaissance team, 14 were constructed with reinforced concrete moment-resisting frames. Most of the damaged in-situ concrete structures viewed by the reconnaissance team were constructed without the use of modern ductile details.

4.1.3 Prefabricated Reinforced-Concrete Structures

For reasons of economy and speed of construction, prefabricated or precast reinforced concrete members are used commonly for the construction of industrial facilities. Typical spans in the facilities visited by the reconnaissance team varied between 15 m and 25 m. The typical height of these precast structures ranged between 6 m and 8 m.

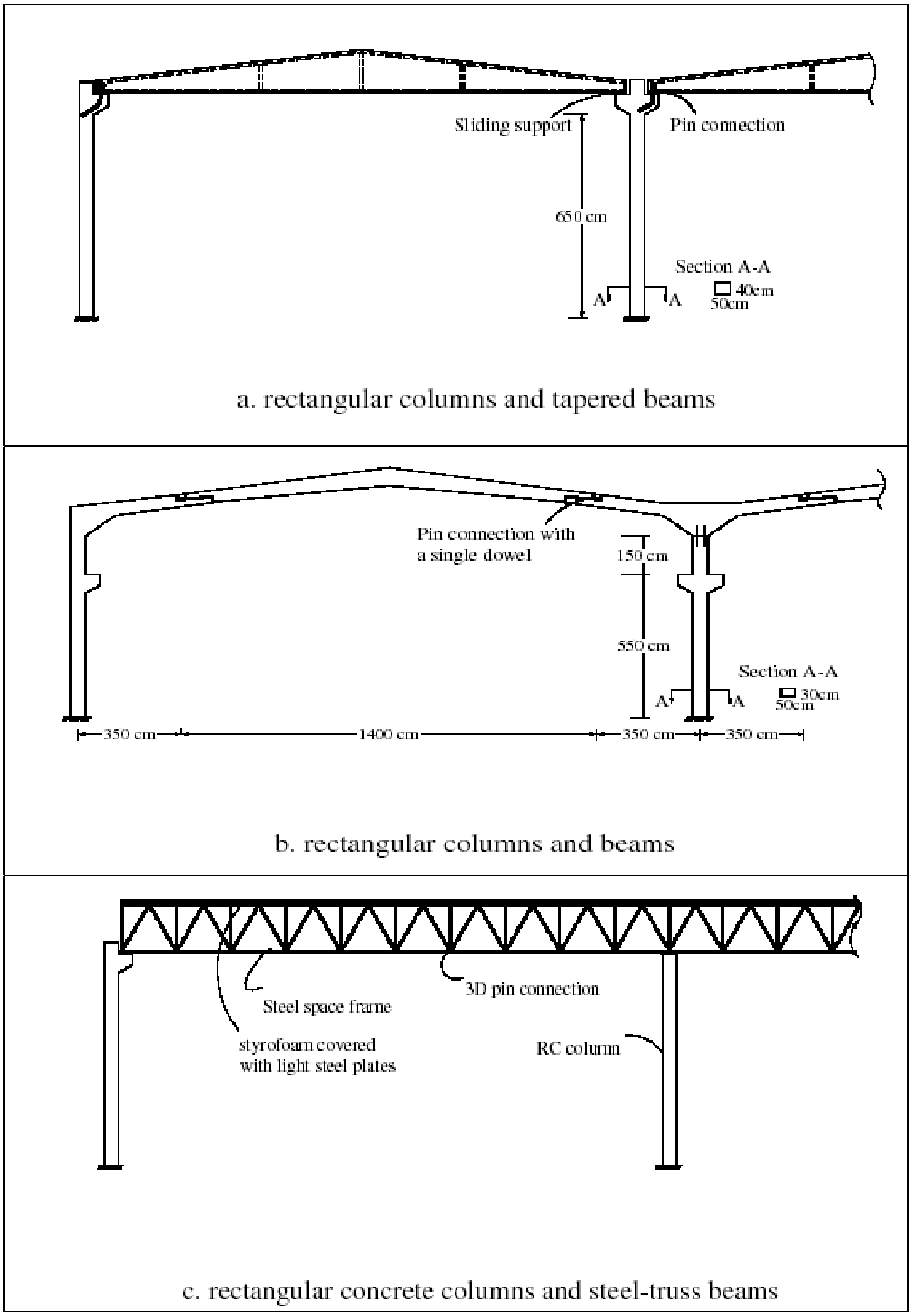
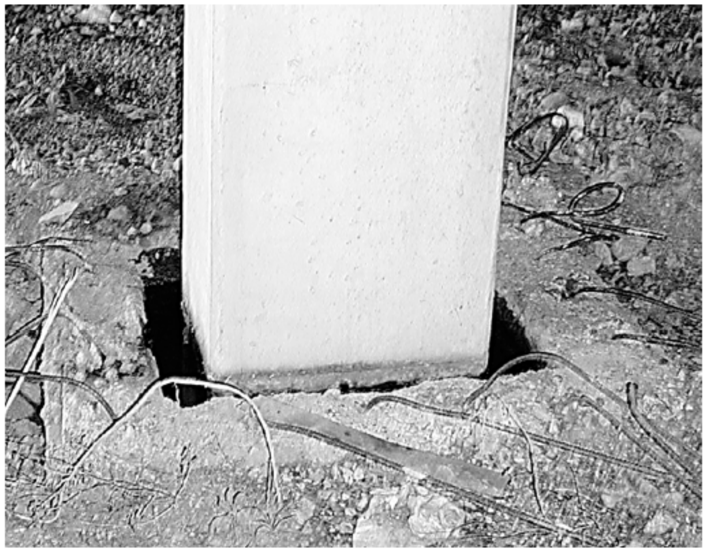


Figure 4-3 Prefabricated reinforced concrete construction

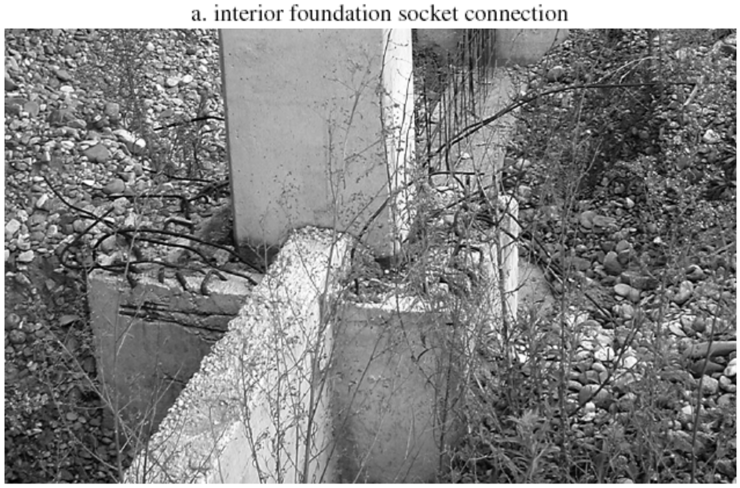
Three of the popular precast structural systems in Turkey are shown in Figure 4-3. The frame of Figure 4-3a is composed of individual columns and long-span rectangular or tapered beams, each with a pinned support at one end and a sliding support at the other end. The typical spacing of these frames was approximately 6 m. The pinned support was typically composed of one or two anchorage dowels, which served to prevent lateral movement but permitted rotation. The sliding support permitted lateral displacement and rotation. Typical plan dimensions of columns in these frames were 400 mm x 400 mm to 500 mm x 500 mm. Reinforced concrete planks spanned between the frames and were supported on pockets cast into the precast beams. Typical plank construction and a damaged dowel connection are shown in Figure 4-4; the beam and slab on the right-hand side of the column were close to collapse. Substantial damage and a lack of transverse reinforcement are evident in the column and beam corbels. Fixity at the base of the columns of Figure 4-3a was achieved by grouting the column in a deep socket or footing that was linked to other footings by grade beams and a thick slab at the top of the foundation. Typical interior and exterior foundation socket-column base details are shown in Figures 4-5a and 4-5b, respectively. The grade beams between the exterior socket foundations can be seen in Figure 4-5b. (The 6.5-m high columns in the Çamlica Soft Drink production facility [Figure 4-3a] were reported to be installed in 4-m-deep socket foundations.)

Figure 4-4 Typical plank roof construction and damaged doweled connections

Another common prefabricated structural system in this part of Turkey is shown in Figure 4-3b. This system includes a precast T-shaped member at the top of the central column that serves to connect the column to simply supported roof beams. The connection of the T-shaped unit to the column is detailed to transfer moment and shear, but likely for gravity-load effects only. The lengths of the T-shaped unit and the simply supported roof beams are selected on the basis of gravity-load actions in a two-span continuous beam; namely, the doweled connections between the units are located at the points of contraflexure. Such an approach would minimize the volume of material in the roof beams for gravity-load effects only. Figure 4-6 shows damage to a steel pipe production facility, which was under construction at the time of the earthquake. The roof panels had not been installed, and as such there was no diaphragm at the roof level. The seismic load paths in this building, both parallel and perpendicular to the frames of Figure 4-3b, would have been questionable even if the roof panels had been installed. As is evident in the figure, many of the columns acted as cantilevers and hinged at their bases during the earthquake. The precast T-units of Figure 4-3b rotated off the top of the two central columns in the middle of the photograph Figure 4-6 and are upside down. There was minimal reinforcement joining the T-shaped units to the columns below.



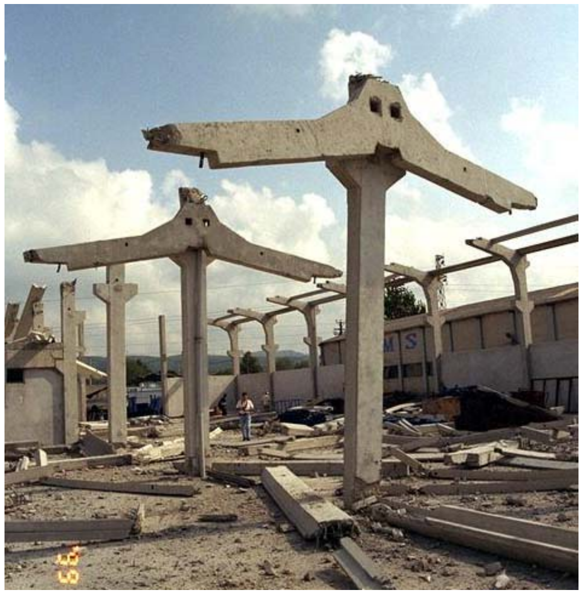
a. interior foundation socket connection



b. exterior foundation socket connection

Figure 4-5 Foundation connection for prefabricated reinforced concrete facilities

A cross section through a third prefabricated framing system in use in Turkey at the time of the earthquake is shown in Figure 4-3c. The gravity-load framing system in this figure is composed of a light steel (3-D) space frame that is supported by steel trusses that span between the precast reinforced concrete columns. Socket foundations of the type shown in Figures 4-5a and 4-5b were typically used for the precast columns. Such construction was somewhat common in modern facilities constructed by joint ventures of Turkish and international companies, such as the KordSA, BekSA, Ford, and Toprak Cleaning facilities.



a. failed central columns and T-shaped units

Figure 4-6 Damaged precast reinforced concrete framed building

4.1.4 Steel-Frame Structures

Braced and moment-resisting steel frames are used for some single-story and many multistory industrial facilities. One such facility, under construction at the time of the earthquake for DuSA, is shown in Figure 4-7. The framing system in this five-story building suffered no damage but much of the reactive weight in the form of the concrete-on-metal deck floors and masonry perimeter walls was not present at the time of the earthquake. The building was designed and detailed in the United States using U.S. standards for such facilities. The seismic moment-resisting frame in the elevation of (Figure 4-7a) used bolted end-plate connections. On the perpendicular elevation (Figure 4-7b), eccentrically braced steel frames were used to resist seismic loads. On this elevation, part of a three-story masonry wall peeled off the exterior steel framing and collapsed; the remaining part of the wall can be seen to the right of the crane base.

a. elevation showing steel moment frames

b. elevation showing steel eccentrically braced frames

Figure 4-7 Five-story steel-framed industrial facility under construction

4.2 Petrochemical Industry

4.2.1 Introduction

There is a heavy concentration of petrochemical facilities near Körfez on the northern side of Izmit Bay. Many of the badly damaged facilities were located within 15 km of the epicenter where levels of earthquake shaking were moderate to high. The fiscal health of many of the companies operating these facilities is highly dependent on an adequate supply of raw materials, and product from other industrial facilities in the region. The failure of or gross damage to some facilities in the epicentral region had a cascading fiscal effect on other businesses in the region. The Tüpras refinery (Section 4.2.2) and the Petkim petrochemical plant (Section 4.2.3) were two such facilities.

4.2.2 Tüpras Refinery

4.2.2.1 Introduction

The most spectacular damage to an industrial facility was observed at the state owned and managed Tüpras oil refinery near Körfez (see Figure 4-8: a photograph taken shortly after the earthquake by an unknown photographer). Prior to the earthquake, the Tüpras refinery produced more than 200,000 barrels of oil-related product per day, approximately one-third of Turkey's total output. The Tüpras product was primarily for domestic consumption, much of which was local to industry in the Körfez region. The Tüpras refinery was designed and constructed in the early 1960s by U.S. contracts and according to U.S. standards of practice at that time (Danis 1999). As such, the damage observed to the Tüpras refinery would not be unexpected at refineries of a similar age that are located on the West Coast of the U.S. The plant was expanded in size and production in 1974 and 1983.

Figure 4-8. Tank farm fires at Tupras refinery

Figure 4-9. Tupras refinery showing part of the tank farm

Figure 4-10. Tupras refinery

Figure 4-11. Loading and unloading jetty at Tupras refinery

The damage to the Tüpras refinery was widespread and included port facilities, storage tanks, cooling towers, stacks, and crude-oil processing units. Much of the damage was fire related: an indirect consequence of the earthquake shaking. The fire-fighting capability of the refinery was lost immediately following the earthquake because of multiple ruptures of the water pipeline from Lake Sapanca, 45 km east of the refinery. (The refinery received all of its water from this lake.) In the days immediately following the earthquake, the resulting fires were contained by aerial bombardment with foam (Danis 1999). At the height of the conflagration, a 3-km region around the refinery was evacuated (Danis 1999). The fires were extinguished by water drawn from Izmit Bay by using portable diesel pumps and flexible hose that didn't arrive at the refinery until three days after the earthquake. Had this fire-fighting equipment been stockpiled at the refinery in advance of the earthquake, the fires that took five days to extinguish would have been put out much sooner. For information, the reconnaissance team visited the Tüpras refinery on September 1, 1999, two weeks after the earthquake and approximately ten days after the fires had been extinguished. (Valuable lessons for refineries on the West Coast of the U.S. can be learned from the problems encountered by the fire-fighting and emergency-response staff at the Tüpras refinery.)

Figures 4-9, 4-10, and 4-11 are aerial photographs of the refinery taken by members of the reconnaissance team two weeks after the earthquake. Figure 4-9 shows the main processing facility and part of the tank farm (in the foreground). The jetty that serviced the refinery is not shown but is located at the left-hand edge of the figure. Another view of the main processing facility shows the failed heater stack (see the circled section in Figure 4-10). Some of the burned fuel-oil tanks can be seen in the upper right middle of the figure. The remains of the timber cooling tower that burned following the earthquake can be seen in the middle right of the photograph between the burned tanks and the northern perimeter of the main processing facility. Substantial pollution can be seen (Figures 4-9 and 4-10), which resulted from the failure and breaching of fuel-oil tanks, much of which was successfully contained by the earthen berms that surrounded the tanks. According to refinery staff, some oil spilled into Izmit Bay due to fractured pipes and from an oil tanker that pulled away from the loading jetty immediately following the earthquake.

4.2.2.2 Loading Jetty

The loading and unloading jetty shown in the aerial photograph (Figure 4-11) serviced the refinery only. Failure of this jetty prevented the loading and unloading of all fuel-oil products at the refinery. Ships tied up to the long arm of the T-shaped jetty (oriented north-west to south-east in the figure, where the top of the page is north). The jetty was composed of a reinforced concrete deck that was supported on steel piles. Modest ground failure was observed around the approach to the jetty. The support to the crude-oil pipeline (Figure 4-12) that ran along the seawall near the jetty was lost. Figure 4-13 is a photograph of the damaged jetty from point A of Figure 4-11. Gross damage to the jetty and the elevated pipeway and pipes is evident to the left of the tug. These pipes transferred fuel oil and other products between the refinery and ships tied to the jetty. Figure 4-14 is a photograph of the damaged jetty, from point B of Figure 4-11, that resulted from the failure of some of these piles. The loading and unloading jetty was separated from the vertical leg of the jetty. Refinery staff told members of the reconnaissance team that the heavy steel grating joining the two components of the jetty dropped into the water, indicating that the two components moved independently during the earthquake. The reconnaissance team observed steady leaks from one of the pipes at ground level, which was filled with volatile gasoline, more than ten days after the earthquake.

Figure 4-12. Failed crude oil pipeline along the sea wall at the Tupras refinery

Figure 4-13. Damaged loading and unloading jetty

Figure 4-14. Damage to jetty and elevated pipeway in Tupras refinery

4.2.2.3 Tank Farms and Floating Roof Tanks

Because fires burned out of control for several days in the tank farms, international attention was focused on the Tüpras refinery immediately following the earthquake. Refinery staff reported that the first major fire ignited in a floating-roof tank that contained naphtha, which is a highly volatile flammable liquid mixture distilled from petroleum. The fire reportedly spread quickly because the refinery staff had on site only sufficient foam to fight a small fire, not fires associated with the breaching and ignition of a fuel tank.

Many of the 100+ tanks in the Tüpras refinery farm were constructed with floating roofs. Figures 4-15, and 4-17 are photographs of Tank 211, which is located immediately adjacent to many of the burned tanks (see Figure 4-18). Figure 4-17 is a photograph of the detail at the junction of the edge of the floating roof and perimeter wall, showing the perimeter seal. Sloshing of the fluid in the tank likely damaged the perimeter seal, which permitted the fluid to escape from the containment. Such observations have been made in other earthquakes (ASCE 1997). Oil evident on the top of the floating roof (Figure 4-17) spread over much of the roof. Danis (1999) reported substantial damage to a large number of tanks (30+) in the farm; the inability of perimeter seals to retain the sloshing fluid in the tanks resulted in failure or sinking of these floating roofs. Each of these damaged floating roofs required repair or replacement before the tanks could be returned to service. Repair of the damaged or sunken roofs would have involved draining the tanks, decontamination of the roof, and replacement of the perimeter seals.

Figure 4-15. Tank 211 in the Tupras refinery tank farm

Figure 4-17. Perimeter seal of floating roof in Tank 211

Sloshing of fluid produced overtopping in several tanks (see Figure 4-19) and gross damage to the tank wall near the tops of walls in other tanks (see Figure 4-20). The oil lost from these tanks was contained within the earthen berms surrounding the tanks.

Members of the reconnaissance team found no evidence of substantial sliding of the tanks although none were anchored to their foundations. According to the refinery staff, this is typical practice in Turkish tank farms. Although hard piping was attached at the base of each tank, there was no evidence of pipe failure at any (unburned) tank visited by members of the team. Had there been appreciable movement of the tanks, many pipe failures would have occurred (ASCE 1997).

igure 4-18. Partial view of Tupras tank farm showing Tank 211 and two burn zones

Figure 4-19. Overtopping of tank wall due to sloshing and failure of perimet seals

Figure 4-20. View of tank wall damage

Figure 4-21. Photograph from top of Tank 211 facing south

Figure 4-22. Photograph from top of Tank 211 looking approximately south

Figure 4-23. Tank destroyed by fire in burn zone

Considered write-offs by the management (Danis 1999), approximately 20 tanks in the Tüpras refinery farm were damaged or destroyed by fire. Figures 4-21 and 4-22 are overlapping left-to-right photographs of burned tanks taken from the top of Tank 211 looking south toward the main processing facility. For reference, the mountains in the background of these photographs are located on the other side of Izmit Bay, to the south of the cities of Gölcük and Degirmendere. An overtopped tank can be seen to the left of the middle of Figure 4-21. Figures 4-23 and 4-24 are photographs of two tanks destroyed by fire. The tank in Figure 4-23 is located in tank burn zone 1 of Figure 4-18. The tank of Figure 4-24 is located in tank burn zone 2 of Figure 4-18. Twisted wreckage of the walls, walkways, and floating roof of the tank in Figure 4-24 can be seen in Figure 4-25. Figure 4-26 is a photograph of one tank, located immediately adjacent the burned tank of Figure 4-25 and linked to this tank by hard piping. Gross expansion of this fixed roof tank due to intense heating from the burning tank is evident. This tank can be seen to the right of the middle of Figure 4-22.

Figure 4-24. Tank destroyed by fire in burn zone

Figure 4-25. Destroyed walls, walkways and floating roof of tank in Figure 4-24

Figure 4-26. Gross expansion of fixed roof tank adjacent to tank of Figure 4-24

Although the Tüpras refinery tank farm suffered gross damage as a result of the fires following the earthquake, the damage could have been truly disastrous. The fire-fighting skills of the refinery staff and good decision making by the refinery management team kept these fires from spreading to other tanks on the farm and to adjacent industrial facilities, many of which contained large amounts of volatile materials, such as the adjacent IGSAS plant that produces ammonia and fertilizer.

4.2.2.4 Main Processing Facility

The main processing facility is located between the tank farm and the loading jetty. An earthen berm and a road separate the facility from the tank farm. A total of four cooling towers, three made of wood and the fourth of reinforced concrete, were sited at the edge of the berm. One of the three wooden towers burned to the ground, another wooden tower was destroyed by earthquake shaking, and the third wooden tower suffered only slight damage. The reinforced concrete cooling tower appeared to be undamaged.

The main processing facility is composed of three crude-oil processing units. Constructed in 1983, one of the three units was destroyed by the collapse of an approximately 110-m-tall reinforced concrete heater stack in the middle of the unit. Figure 4-27, a photograph of the failed heater stack, was taken from the end of the loading and unloading jetty. The upper two thirds (approximately) of the heater stack collapsed. Failure of the stack likely initiated at a stiffness discontinuity in the reinforced concrete stack where large-size ductwork entered the stack. (See the undamaged heater stack to the left of the collapsed stack. Large-size ductwork enters this stack at approximately the same level at which the collapsed stack failed.) The top of the stack fell into a heater unit (Figure 4-28) and the lower portion of the failed stack collapsed onto pipework at the perimeter of the facility (Figure 4-29). Refinery staff reported that some pipework was fractured by the collapsing heater stack, which ignited fires in the crude-oil unit. These fires buckled structural components that supported the furnace and the pipeways.

The reconnaissance team did not observe any substantial damage to other parts of the main processing facility. Typical steel and reinforced concrete framing in the facility are shown in Figures 4-30a and 4-30b.

Figure 4-28. Damage to heater unit caused by collapse of heater stack

Figure 4-29. Damage to pipework caused by collapse of heater unit

Figure 4-30a. Undamaged steel-braced framing, Tupras refinery

Figure 4-30b. Undamaged reinforced concrete framing, Tupras refinery

Figure 4-31. Collapsed wooden cooling tower at the Petkim petrochemical facility

Figure 4-32. Damage to nonductile reinforce concrete in Petkim cooling tower

4.2.3 Petkim Petrochemical Plant

The Petkim (or Yarimca) petrochemical facility at Körfez is one of the largest state-owned facilities in Turkey. Similar to the Tüpras refinery, the Petkim facility supplies many industrial facilities in the region in and around Körfez, including a number of companies manufacturing components of tires. The Petkim petrochemical facility was constructed between 1965 and 1975; the main plant in the facility was fully operational in late 1969.

Parts of the Petkim facility were severely damaged. Maximum accelerations of approximately 0.32g were recorded at the YPT station (see Chapter 1), which was located within 200 m of the collapsed three-cell tower. Figure 4-31 shows the complete collapse of an older three-cell wooden cooling tower; but a four-cell tower adjacent to the collapsed tower suffered no damage. A reinforced concrete cooling tower approximately 400 m from the YPT station was badly damaged. Nonductile reinforced concrete columns at the perimeter of the cooling tower and atop a continuous reinforced concrete perimeter were severely damaged at the bases (Figure 4-32). Figure 4-33 shows typical damage and rebar details at the base of one column. The column in this figure was constructed with round longitudinal rebar. The transverse ties were widely spaced and 90° hooks were employed. It is evident in the figure that the transverse ties failed leading to dilation and failure of the core concrete in the *hinge* zone.

Figure 4-33. Rebar details and damage in reinforced concrete cooling tower at Petkim

Figure 4-34. Loading and unloading facility, Petkim petrochemical plant

Figure 4-35. Failure of battered reinforced concrete piles beneath jetty, Petkim facility

The Petkim petrochemical plant, similar to the Tüpras refinery, had a dedicated port facility through which much of the plant's raw material and processed product passed. Ground failure was observed near the jetty entrance. This port, like the port that serviced the Tüpras refinery, was badly damaged by the earthquake and was not operational afterward. Many of the battered piles beneath the jetty (Figure 4-34) were badly damaged. Typical damage to these battered piles is shown in Figure 4-35.

4.3 Automotive Industry

4.3.1 Introduction

Ford, Hyundai, and Toyota operate motor vehicle assembly plants in the epicentral region. Multinational industrial companies including Pirelli and Goodyear are located east of Izmit within a few miles of each other in the Köseköy and Alikahya regions. The Sabanci company has several joint-venture facilities in the epicentral region, including BekSA (a joint venture with Bekaert of Belgium), BriSA (a joint venture with Bridgestone, Japan, to manufacture rubber goods and tires), DuSA (a joint venture with Du Pont, USA), EnerjiSA, and KordSA. All of these companies contribute in one form or another to the construction of motor vehicles or components. With the exception of EnerjiSA, which is discussed in the following section, information on those facilities visited by the members of the reconnaissance team follows.

Figure 4-36. Framing of new body shop in Ford plant near

4.3.2 Ford Assembly Plant

The body-shop building of a new Ford plant near Gölcük was under construction at the time of the earthquake. The single-story building was composed of 6-m-tall square reinforced concrete columns supporting one-way steel trusses and a lightweight space frame spanning between the trusses. The roof and walls were constructed of lightweight steel panels. Figure 4-36 is a photograph of the interior of the new body shop.

This building was damaged during the earthquake by a combination of shaking and fault rupture and ground failure beneath the building. Figure 4-37 shows the degree of ground movement within 100 m. Damage included permanent deformations in the building frame, hinges in the cantilever columns (Figure 4-36), badly cracked and separated floor slabs, and collapse of some wall panels. Figure 4-38 shows the damaged building.

Figure 4-37. Ground movement near Ford plant, Golcuk

Figure 4-38. Exterior view of damaged Ford body shop

4.3.3 Hyundai Assembly Plant

The Hyundai plant located in Alikahya opened in late 1997. The lateral force-resisting system in the plant was composed of steel moment-resisting frames supported on a 0.6-m-deep raft foundation. The roof was constructed using a steel space frame and galvanized steel roof panels. Hyundai representatives reported that tensioned bolts in several column-to-roof truss connections sheared. Nonstructural mechanical and electrical components in a utility penthouse, approximately 9 m above ground level, suffered severe damage that included separations of elevated ducts from air handlers, movement of air handling units due to inadequate or no anchorage, and collapse of large-size ducts and cable trays due to inadequate attachments and anchorage.

4.3.4 Toyota Assembly Plant

The Toyota factory, which is located about 40 km west of Izmit in Adapazari, was constructed in 1994 with an annual vehicle production capacity of 100,000 cars. The lateral force-resisting system in the main plant building was composed of steel moment-resisting frames. Many of the columns in the building were jumbo shapes with flange thicknesses of up to 125 mm. Each column in the main building is supported on twelve 400-mm-diameter piles driven to rock at a depth of 14 m. Approximately 3,800 piles were driven beneath the building. No structural damage was observed in this building but nonstructural damage was widespread, including the failure or collapse of skylights, light fixtures, storage racks, and one substation transformer. Ground movement damaged the parking lot approximately 100 m from the main plant, the waste treatment plant. No structural damage was observed in other buildings or facilities visited by the reconnaissance team.

4.3.5 Pirelli Tire Plant

The Pirelli tire plant in Izmit consists of approximately 20 interconnected buildings, with a total floor area of more than 200,000 m^2 according to Pirelli representatives. The oldest construction dates back to the 1960s. One section of the oldest building in the plant, whose lateral force-resisting system was a nonductile reinforced concrete moment frame, collapsed killing one person and injuring 20. Modest-to-severe structural damage was reported in other buildings in the facility, including hinging of reinforced concrete columns. Nonstructural damage was widespread and included fallen light fixtures and cable trays.

The key pieces of equipment in the plant were Banbury extrusion machines, which process all raw elastomeric materials in the plant. Although these machines were undamaged by the earthquake, Pirelli representatives noted that these machines could not be restarted because of the degree of structural and nonstructural damage to the buildings where the machines were located, and they could not be easily moved elsewhere in the plant due to their size.

4.3.6 Goodyear Tire Plant

The Goodyear plant, a 500-person factory in Izmit at the time of the earthquake, is a steel-frame plant built in 1963. Only modest nonstructural and contents damage was observed, including collapse of light fixtures and localized failures of the fire-protection system that doused building contents with water. The reconnaissance team did not observe any structural damage in the office buildings.

4.3.7 BekSA

BekSA was established in 1987 and is apparently the largest independent steel wire manufacturer in the world. (The steel wire or cord is a key component in tires, bead wire, hose wire and spring wire.) The 57,000 m^2 BekSA plant (Figure 4-39) was partially operational ten days after the earthquake. The plant and the office buildings (to the left of the plant building in the photograph) were constructed of reinforced concrete. The main plant building suffered no apparent structural damage, but some nonstructural damage occurred including breakage of the windows at the top of the perimeter infill walls and cracking of infill masonry walls. One of the reinforced concrete framed office buildings collapsed completely. Many of the nonductile reinforced concrete columns in the main office building failed in shear but did not lose their ability to carry modest gravity loads.

Figure 4-39. BekSA plant

4.3.8 DuSA

The DuSA plant in Alikahya exports tire cord fabric and nylon yard, which are a key components in the production of automotive tires and industrial fabrics. The framing in the main plant building was a precast reinforced concrete frame supported on a 1-m-thick raft foundation. The reconnaissance team was not permitted to enter the main plant building. Heavy damage was reported by DuSA representatives and observed by the team. Figure 4-40 is a photograph of the perimeter of the main plant building that shows a partial collapse of the main building and unseating of precast beams from the corbels on the precast reinforced concrete columns. Substantial nonstructural damage was reported by DuSA representatives, including the failure of a continuous hot-process unit, equipment movement, overturning due to anchorage failures, and fracture of pipes due to relative movement of equipment.

Figure 4-40. Damage to the DuSA main plant building

A new steel-frame building was under construction at the time of the earthquake. Photographs of the framing were presented earlier in Figure 4-7. The structural frame suffered no damage. No damage was observed to nonstructural components in (ductwork and process equipment) and around (unanchored tanks and piping) of the new building.

4.3.9 KordSA

KordSA is a large producer of tire-cord fabric and industrial fabric. KordSA representatives reported that the plant was 50% operational one week after the earthquake. The main plant building (Figure 4-41) was constructed in 1973 with braced steel framing in the tower and precast reinforced concrete framed construction elsewhere. Only minor structural damage was observed in the tower, with buckled steel braces and damaged bolted connections. (No photographs were permitted by KordSA inside the main plant building.) The precast reinforced concrete framing in the main plant building suffered little-to-no structural damage (Figure 4-42). Some of the parapets atop the precast framing collapsed, as can be seen in the photograph. Only modest nonstructural damage was observed in the interior areas visited by the reconnaissance team.

Figure 4-41. KordSA main building showing steel braced-framed tower

Figure 4-42. Perimeter of precast reinforced concrete framed KordSA main plant building

A product storage area was added to the main plant after the original construction. The light steel-framed roof of this storage area collapsed (Figure 4-43), likely due to the differential movement of two parallel walls, also visible. A number of the *short* columns in the wall to the right failed in shear. The masonry infill above these short columns fell through the roof of the storage area.

Figure 4-43. Roof collapse in storage area of KordSA plant

4.4 Power Generation and Transmission Systems

4.4.1 Introduction
The seismic vulnerability of substation equipment and the damage experienced by power generation and transmission systems in the epicentral region was of much interest to PEER. The EnerjiSA power generation facility was visited by the reconnaissance team 11 days after the earthquake. Summary information on EnerjiSA is presented in Section 4.4.2. The loss of the substation at Adapazari, one of the key substations in the epicentral region, substantially hampered recovery efforts in the first few days following the earthquake. Much effort was focused on restoring the substation to service as quickly as possible. The substation was back in service before the reconnaissance team visited the substation ten days after the earthquake. Information on the observed damage in the Adapazari substation is presented in Section 4.4.3.

4.4.2 Power Generation
EnerjiSA supplies electricity and processed steam for selected Sabanci companies, including BriSA, ToyotaSA, KordSA, DuSA, and BekSA. EnerjiSA began production in 1997 as a 40-MW single-unit power plant. At the time of the earthquake, EnerjiSA was bringing online a 130-MW power unit and an additional 160 ton/hr of steam-generation capacity.

Transformers in the EnerjiSA facility were mounted on rails to facilitate installation and maintenance. Simple braking mechanisms were used to prevent movement of the transformers and protect the equipment that is attached to the transformer such as bushings. Figure 4-44 shows one of the rail-mounted transformers in the EnerjiSA transformer yard. Movement along the rails of each transformer in the yard was observed. The typical movement, ranging between 50 and 100 mm, was most likely too small to endanger the interconnected equipment. However, one transformer, which was not in service at the time of the earthquake, rolled or slid more than 1 m, dropped off the ends of the two support rails, and overturned (Figure 4-45). Two low-voltage bushings failed during the earthquake and had been replaced by the time the reconnaissance team visited EnerjiSA.

Figure 4-45. Toppled transformer in EnerjiSA transformer yard

A heat-recovery steam boiler (Figure 4-46a) that had been installed but not brought online at the time of the earthquake slipped off its foundation during the earthquake. The fillet welds joining the boiler framing to the base plates atop the reinforced concrete foundation failed (Figure 4-46b); these welds were small and of very poor quality.

The base plate connections of steel framing to components of both the existing and the new steam generation systems failed. Figure 4-47a shows two-level framing to an in-service chimney. Figure 4-47b shows the damage at the base plate connection. Figure 4-48a is a photograph of steel braced framing in the new steam-generation system. Figure 4-48b shows damage to the grouted base plate connection and steel brace that was located on the far side of the steel bracing in Figure 4-48a. The shear key (Figure 4-48b) was not embedded in the concrete pedestal beneath the grout pad but in the grout pad only.

4.4.3 Power Transmission

The 380 kV substation in Adapazari services the city of Adapazari and surrounding townships and industrial facilities. The reconnaissance team visited the substation ten days after the earthquake by which time much of the damaged hardware had been replaced by components stockpiled at the substation and in Ankara.

Figure 4-46a. Damaged boiler, EnerjiSA plant

Figure 4-46b. Failed fillet-weld connection of boiler framing to baseplate

Figure 4-47a. Damage to steel framing to EnerjiSA in-service steam generator

Figure 4-47b. Damaged baseplate connection, EnerjiSA in-service steam generator

An aerial photograph of the substation is shown in Figure 4-49. Much switching gear and two power transformers can be seen in the photograph. Numerous porcelain insulators failed during the earthquake; some of the fractured units can be seen in Figures 4-50a and 4-50b. Figure 4-51 is a view of pre- and post-earthquake-installed circuit breakers in the substation; rigid bus connectors span the service road. The V-headed shaped circuit breakers were in service at the time of the earthquake. The T-headed circuit breakers replaced the failed V-headed circuit breakers and had been installed well prior to the visit by the reconnaissance team. Those V-headed circuit breakers that failed during the earthquake typically had longer runs of interconnected equipment than those V-headed circuit breakers that survived the earthquake.

Figure 4-48a. Damaged framing to new steam generator, EnerjiSA

Figure 4-48b. Failed fillet weld connection of new boiler framing to baseplate, EnerjiSA

Figure 4-49. Aerial view of the Adapazari substation

V-headed gas circuit breakers from a number of manufacturers were in service at the time of the earthquake. Many of the cantilever ABB circuit breakers failed during the earthquake. None of the braced Hitachi circuit breakers of Figure 4-52 were damaged.

The substation staff reported that no bushings failed during the earthquake. The reconnaissance team also found no evidence of failed transformer bushings. The power transformers of Figures 4-53a and 4-53b were carefully inspected for damage; no damage was found. The brakes on these rail-mounted transformers failed to function during the earthquake; the maximum movement of these transformers was approximately 300 mm. Such movement appeared not to damage the transformers, the transformer bushings, or the interconnected equipment.

Figure 4-50a. Failed porcelain insulators

Figure 4-50b. Failed porcelain circuit breakers

Figure 4-51a. View along service road showing pre- and post- earthquake circuit breakers

Figure 4-51b. New T-shaped circuit breakers

Figure 4-52. Braced Hitachi gas circuit breaker, Adapazari substation

Figure 5-53a. Elevated support frames and power transformers, Adapazari substation

Figure 4-53b. Power transformer, Adapazari substation

4.5 Other Heavy Industry

4.5.1 Bastas Plant

Bastas manufactures fluorescent lightbulbs. Although the plant suffered no structural damage from the earthquake and power was available immediately after the earthquake using on-site emergency generators, nonstructural damage to a glass furnace forced the shutdown of the plant. The furnace was mounted on an unanchored frame that moved approximately 35 mm.

Compressed air to the furnace was lost when a valve was damaged on a temperature-control rack. The resulting change in the fuel-air mixture led to molten brass solidifying in the lines of the furnace and the destruction of a custom-made tube in the furnace. The lead-time to replace the custom-made tube was at least six to eight weeks, forcing the plant to close for this time because the tube was key to the function of the furnace and the plant.

Figure 4-54 Collapsed precast reinforced concrete building, Cap textile plant.

4.5.2 Çap Plant

The Çap textile facility is located 3 km west of Akyazi, which is east of Adapazari, on alluvium deposits between two rivers that are 500 m apart near the plant. The plant was composed of two 3-bay (transverse) by 15-bay (longitudinal) precast reinforced concrete buildings. The framing of the two buildings appeared to be most similar. The typical interior column was 6 m high and 250 mm by 600 mm in plan, with the strong direction of the column in the transverse direction. Figure 4-3b is part of the transverse cross section in the building. One of the two precast buildings collapsed (Figure 4-54). The second building suffered severe damage. In this precast building, many of the columns hinged at the bases, and wall and roof panels collapsed.

4.5.3 Habas Plant

The Habas plant in Izmit provides liquefied gases to commercial plants and medical facilities in the Izmit and surrounding regions. The major damage at Habas was the collapse of two of the three liquid gas storage tanks shown in Figure 4-55.

Three identical 14.63-m-diameter tanks were built in 1995. Each tank consisted of two concentric stainless steel shells, one with an outside diameter of 14.63 m and the other with an outside diameter of 12.80 m. Figure 4-56 is a photograph of the undamaged tank. The gap between the shells is filled with insulation. Both shells were supported on a 14.63-m-diameter, 1.07-m-thick reinforced concrete slab that was in turn supported by sixteen 200-mm-diameter reinforced concrete columns. Each column was 2.54 m in height and reinforced with 16 No. 16-mm-diameter longitudinal bars and 8-mm-diameter ties at 100 mm on center.

Figure 4-55. Liquid gas plants at the Habas plant

Figure 4-56. View of Reinforced concrete framing at base of undamaged tank, Habas plant

The two tanks containing liquid oxygen collapsed as seen in Figure 4-57. The tank and supporting structure containing liquid nitrogen was undamaged except for some hairline cracks in the columns. Habas representatives reported that the liquid oxygen tanks were 85% full, and the liquid nitrogen tank was 25% full at the time of the earthquake. The outer shells of the collapsed tanks buckled (Figure 4-58). Photographs of some of the failed columns beneath one of the liquid nitrogen tanks are presented in Figure 4-59.

Figure 4-57. Collapse of liquid oxygen tanks

Figure 4-58. Buckling of the outer stainless steel shell in liquid oxygen tank

Figure 4-59a. Failed columns beneath slab under liquid oxygen tank, Habas facility

Figure 4-59b. View of failed columns beneath liquid oxygen tank, Habas facility

4.5.4 Mannesmann Boru Plant

The Mannesmann Boru steel-pipe plant in Izmit was constructed in the mid-1950s. The plant is composed of two separate facilities for the fabrication of small- and large-diameter pipe. Each facility includes production buildings and warehouses. An administration building and storage yards are common to both facilities.

Figure 4-60a. Undamaged crane at

Damage was observed in reinforced concrete and steel buildings. In two buildings, shear cracking was prevalent in nonductile columns with short shear spans due to the presence of infill masonry walls. In one of the large-pipe production buildings, the anchor bolts of a steel moment-resisting frame elongated and fractured. In the storage yard at the large-pipe area, two cranes that were constructed in the early 1970s suffered identical failures of the box sections supporting one leg of the crane. Figure 4-60a is a photograph of an undamaged crane in the yard. Figure 4-60b shows the failed leg of another crane in the yard.

Mannesmann Boru used the adjacent SEKA paper-mill port facility for

Figure 4-60b. Collapsed crane leg, Mannesmann Boru pipe storage facility

handling raw materials and pipe product. As discussed in the following section, the SEKA port facility was badly damaged in the earthquake, forcing Mannesmann Boru to use alternative and less efficient methods for moving raw materials and product.

4.5.5 SEKA Plant

SEKA is a state-owned paper mill that is located next to the Mannesmann Boru plant. Paper and cardboard products are produced and processed in this plant, which includes five paper mills, each with two paper machines. Before the earthquake, SEKA moved raw materials and finished product through its port facility. The SEKA port facility is composed of two separate jetties, both of which failed during the earthquake. Figure 4-61a shows one of the two jetties that were supported on hammerhead reinforced concrete columns that were constructed in the 1960s. The influence of the horizontal framing immediately above the waterline on the failure of the hammerhead columns is not known. Figure 4-61b is a photograph of the second jetty that is of reinforced concrete construction like the jetty of Figure 4-61a but with substantially different framing. The jetty of Figure 4-61b was also severely damaged with one section of the jetty dropping more than 300 mm below the adjacent sections.

Three reinforced concrete silos containing water collapsed. Figures 4-62a and b are photographs of an undamaged and a collapsed silo, respectively. The diameter of the silos was approximately 6 m. The collapsed silos were supported on six small square nonductile columns with minimal longitudinal reinforcement. The undamaged silos of Figure 4-62a were supported on larger (square) columns than those of the collapsed silos.

Figure 4-61a. Failure of hammerhead reinforced concrete jetty piers, SEKA paper mill

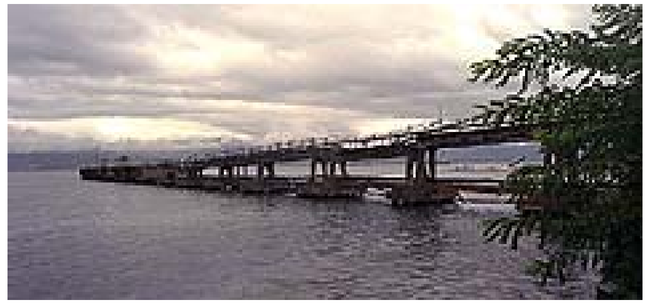


Figure 4-61b. View of failed jetty, SEKA paper mill

Figure 0-14-62a. Undamaged silo at SEKA paper mill

Figure 4-62b. Collapsed silo, SEKA paper mill

4.5.6 Liquid Gas Tanks

Cylindrical (bullet) liquid gas tanks of the type shown in Figure 4-63 were common in the Körfez industrial parks. Most of the tanks of this type were not anchored and had hard pipe connections of the type seen in Figure 4-63b. These connections are most susceptible to damage due to movement and rotation of the tank with respect to the supporting saddle. Movement and rotation of the tank with respect to the pedestal are clearly evident in Figure 4-63b.

Many spherical liquid petroleum gas (LPG) tanks were located in the epicentral region in a large number of industrial facilities. These tanks were typically supported by braced steel frames or reinforced concrete frames. No damage to these tanks was observed by members of the reconnaissance team.

Figure 4-63a. Typical support arrangement for cylindrical liquid gas tanks

Figure 4-63b. Typical damage to liquid gas tanks