PERFORMANCE OF INDUSTRIAL FACILITIES IN THE AUGUST 17, 1999 IZMIT EARTHQUAKE

Mohsen RAHNAMA[1] And Guy MORROW[2]

SUMMARY

The 7.4 magnitude earthquake that struck western Turkey on August 17, 1999 mostly affected Kocaeli, Sakarya, and Yalova provinces, causing extensive destruction to residential, commercial and industrial facilities in the region. The epicentral area around Izmit Bay is a highly developed industrialized region of Turkey. This paper summarizes the performance of industrial facilities in this event based on two separate site visits. The visited industrial facilities are grouped into three occupancies: petrochemical processing, heavy industrial facilities and light industrial facilities. The extent of damage to these facilities depended on many parameters such as, distance to epicenter, site conditions, and quality, type and age of construction. Overall, in heavy and light industrial facilities, anchored machinery and equipment performed well. Concrete structures performed poorly and their failures caused extensive damage to machinery, resulting in business interruption. For several facilities, water supply and fire following the earthquake were major issues in this event. Overall, losses due to business interruption and recovery were a major concern as compared to property damage. The nature of fault rupture along the North Anatolian Fault, characteristics of ground motion, and performance of industrial facilities provide a unique opportunity to learn from this event and apply lessons to other parts of the world.

INTRODUCTION

The region impacted by the Kocaeli (Izmit) earthquake is one of the heaviest industrial areas of Turkey. A wealth of industrial facilities are situated around the Sea of Marmara from Istanbul in the west to Izmit, Golcuk and Adapazari to the east. This earthquake provided a unique opportunity to evaluate the performance of industrial facilities subjected to strong ground shaking.

Reconnaissance of the performance of industrial facilities consisted of two separate week-long site visits to the impacted area. The initial visit occurred within the first three days following the earthquake and the second trip was performed one month after the earthquake. The second trip provided the opportunity to not only observe physical damage sustained by facilities, but also to gauge business interruption impacts of the event.

In all, a total of twenty-four industrial sites were visited, representing a wide range of occupancies. These sites are identified in Figure 1. At each site, the physical damage at the plant was ascertained and plant personnel were interviewed in order to assess the amount of lost production. The following sections highlight the characteristics of recorded ground motions near the visited sites and the performance of some of the facilities.

CHARACTERISTICS OF RECORDED GROUND MOTIONS

The Izmit Earthquake of August 17, 1999 is the largest to occur in Turkey during this century. The earthquake was a result of about 110 km of fault rupture along a segment of the North Anatolian Fault. The point of initial rupture, or epicenter, was southwest of the city of Izmit, about 80 km southeast of Istanbul. The magnitude 7.4

[1] *Risk Management Solutions, Inc., 149 Commonwealth Drive, Menlo Park, California 94025, US. Email, mohsenr@riskinc.com*
[2] *Risk Management Solutions, Inc., 149 Commonwealth Drive, Menlo Park, California 94025, US. Email: guym@riskinc.com*

earthquake was felt over 600 square kilometers in northwest Turkey. The unique characteristics of fault rupture, 2 to 5 meters offset along a major length of the fault, soil conditions around Izmit Bay, and liquefaction at Adapazari, all played a very strong role in the destruction of many residential and commercial buildings, industrial and port facilities and lifelines.

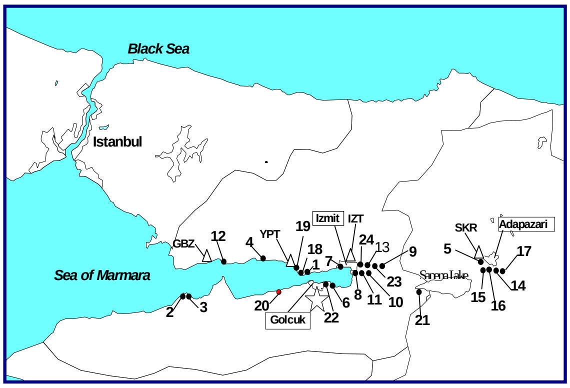

Figure 1: Locations of Industrial Sites Visited

Table 1: Visited industrial facilities

1- Tupras - Refinery	13- Hyundai - Car Plant
2- AKSA - Chemical Processing	14- Wagon Factory
3- Yalova Yarn Manu.	15- Federal Elecrik - Electrical Parts
4- Herek - Nuh Cement Factory	16- Kromel - Food Manu. Equip.
5- 380 kv Substation	17- Sugar Factory
6- Ford - Car Plant	18- IGSAS - Fertilizer
7- Seka - Paper Mill	19- Petkim - Petrochemical
8- Pakamaya - Yeast Plant	20- Ipek Kacit - Paper
9- Bana Buro - Pipe Manu.	21- Water Pumps
10- Fursan - Citric Acid	22- Navy Base
11- Bastas - Florescent Lights	23- Pirelli - Tire
12- Polisan - Paint	24- Goodyear - Tire

Recordings of earthquake ground motions were made at stations maintained by Bogazici University, Kandilli Observatory, Earthquake Research Department Directorate of Disaster Affairs, and several other research organizations. Within the region, free-field peak horizontal ground accelerations (PGA) were 0.32g at Yarimca and 0.41g at Sakarya, 40 km from the epicenter. The PGA in the Istanbul area 80 km from the epicenter ranged from 0.04g to 0.25g depending on the soil condition. The soil characteristics at instrument stations are not yet available. For a 7.4 magnitude earthquake, the maximum recorded PGA values in the epicentral region are lower than expected for such a large event. This may be due to the nature of fault mechanism and geological condition of recording stations. However, it would be misleading to assess seismic demands imposed on structures according to PGA alone, without regard to frequency characteristics of the ground motions. Figure 2 shows the time history of recorded ground motion at the Yarimca Petrochemical Complex about 10 km northwest of Golcuk. The high frequency motions recorded around 40 seconds could be an indication of a second rupture, which needs to be verified with further research.

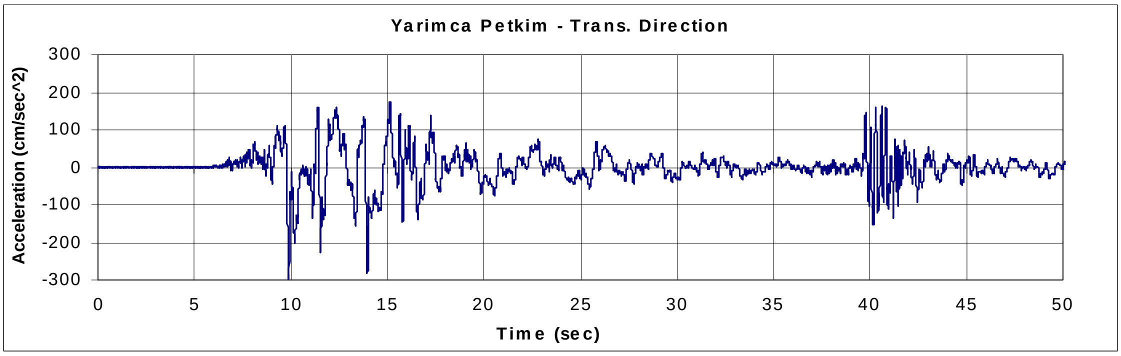

Figure 2: Acceleration time history at Yarimca Petrochemical Complex

The following discussion focuses on the characteristics of four ground motion recordings near the visited industrial facilities within the epicentral region along the fault. These four ground motions were recorded at Izmit (IZT), Yarimca (YPT), Gebze (GBZ) and Sakarya (SKR) with epicentral distances of 5, 10, 35 and 40 km and PGAs of 0.23g, 0.33g, 0.27g and 0.41g respectively. Figure 3 shows the acceleration and velocity spectra of the larger component of these records with 5% damping.

The shapes of acceleration spectra, which are shown in Figure 3, are very different for all records as clearly demonstrated in the normalized acceleration spectra in Figure 4. Both the Yarmica and Gebze records exhibit a relatively low high-frequency content, represented by small Dynamic Amplification Factors (DAFs) at periods shorter than 0.5 seconds, while both records show two peaks around periods of 0.9 and 1.4 seconds with wide humps extending to and beyond a period of 2.5 seconds in the Yarimca spectra. The acceleration and velocity spectra at Yarimca show a clear signature of soil amplification at this station which needs to be verified with the soil conditions at this location. This signature is most evident at a period of 1.4 seconds with a DAF =2.0 as shown in Figure 4. In the Gebze and Yarimca areas, short-period structures performed relatively better as compared to long-period structures such as the stack and tanks at Tupras

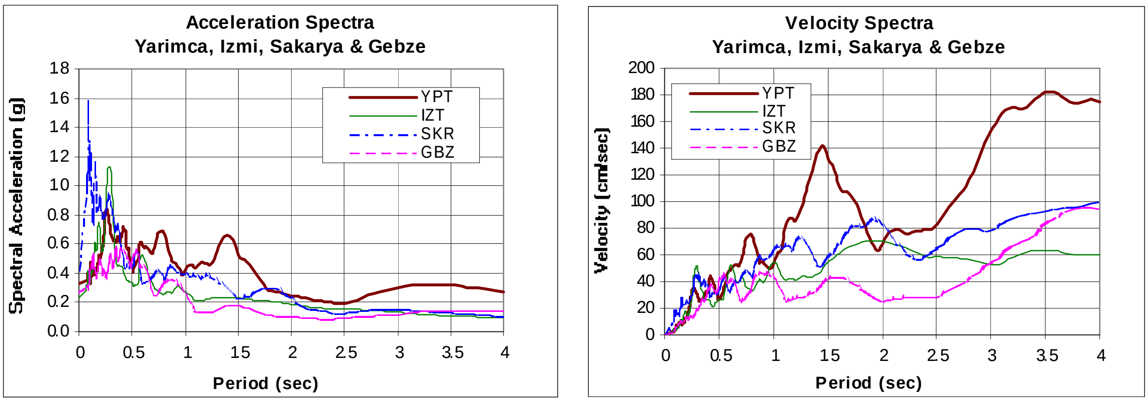

Figure 3: Acceleration and velocity spectra of selected ground motions within epicentral region

The Sakarya and Izmit records exhibit a greater high high-frequency content, represented by large DAFs at periods shorter that 0.30 seconds. This may help to explain the poor performance of most short-period structures in these areas. The pattern of velocity spectra for all four records for periods less than 0.6 seconds is similar, while at periods greater than 1.0 second the velocity spectra of Yarimca is much higher with a peak at a period of 1.4 seconds as shown in Figure 3. The differences in shape of these spectra reflect the sensitivity of ground motions to source-site distance, directivity, travel path through geologic media, and local soil conditions.

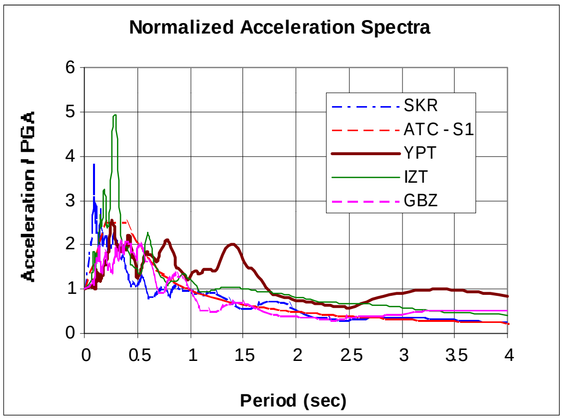

Figure 4: Normalized Acceleration Spectra

3. PERFORMANCE OF INDUSTRIAL FACILITIES

3.1 Refinery and Petrochemical Processing Facilities

Tupras Refinery

The Tupras Refinery is located in Korfez about 10 km northwest of Golcuk on the north shore of Izmit Bay. The refinery is a main supplier of oil in the effected industrial region, and produces more than one-third of Turkey's retail and industrial fuel. The plant was built in 1960 with a capacity of one million-tons per year, and was expanded in two phases during 1974 and 1983. At the time of the earthquake the plant had a capacity of about twelve million tons per year. The total number of employees is approximately 1,400. Damage to the refinery was extensive due to ground shaking and fire following the earthquake. The majority of damage was concentrated at the tank farm area, a crude oil processing unit, and the port and unloading area.

The tank farm has more than 110 tanks of varying sizes containing water, crude oil, and other oil substances. Sizes range from 1,200 m^3 to 135,000 m^3 and roofs are both floating and fixed. Table 2 shows geometric information of the six tanks that were damaged due to ground shaking and fire. It appears that ground shaking caused oil leakage and vertical movement of the floating roof created sparks which led to the fire ignition. Shell buckling at the base of tanks and resulting oil leakage may have contributed to spread of the fire. Additional investigation will be needed to verify how the fire started and spread to the nearby tanks. The extreme heat caused the steel to melt and tanks to experience a significant amount of deformation. Figure 5 shows the

Figure 5: State of damage to tanks

burned floating roof tanks and buckling of the wall and roof of tanks with a fixed roof.

Table 2: Characteristics of damaged tanks

Tanks No.	Dim. (m)	Heigh t (m)	D/H	Roof Type	Damage
202	36.5	16.42	2.22	Floating	Collapsed
203	36.5	16.42	2.22	Fixed	
241	13.7	12.80	1.07	Floating	
242	21.30	14.6	1.46	Floating	
221	27.4	14.6	1.88	Fixed	Buckling of wall & Roof
222	27.4	14.6	1.88	Fixed	

The fire from the burning tanks spread to a nearby wood cooling tower and destroyed it completely. A second cooling tower collapsed due to support failure caused by ground shaking. The third cooling tower did not collapse, however, its wooden columns experienced severe damage at the connection to the concrete piers.

Figure 6: Stack collapsed in Crude Unit

The collapse of a 115-meter tall, 10.30-meter diameter reinforced concrete stack was a separate source of fire and destruction at the crude oil processing unit. This crude oil unit was the most recent addition to the refinery, built in 1983 as the third phase of expansion. Part of the collapsed stack fell on the boiler and crude oil processing unit, which caused significant damage to the processing unit, boiler, pipeway and surrounding facilities. The release of fuel from piping systems was the primary cause of the fire at the crude oil unit. Figure 6 shows the collapse of the stack in the processing unit. Figure 7 shows damage to the piping system due to collapse stack and fire. In the Crude Unit, columns supporting the furnace were exposed to extreme heat due to the fire and buckled. Figure 7 shows the buckling of the steel column which supports the furnace. Similar types of failure mode have occurred in past events, which could be prevented if steel elements were covered by fire proofing materials.

Figure 7: Destruction of the piping system and buckling of steel columns supporting furnace

The main source of water for the Tupras Refinery, the nearby Petkim petrochemical facility, as well as some other industrial facilities in the region, is pipelines originating from Sapanca Lake about 25 Km east of Izmit. Strong ground shaking, fault rapture, and ground failure at Sapanca Lake caused extensive damage to pump stations and pipelines. The source of water to put out the fire at Tupras Refinery was limited to the storage water at the plant, which was not enough to deal with such a large fire at two different locations simultaneously. The fire at the crude unit was brought under control quickly, and all the available resources were dedicated to controlling the fire at the tank farm, which took three days to extinguish. Lack of redundancy in the water supply, temporary power shortages, and limited resources available in the area to deal with such a big fire all contributed to the extension of the fire to nearby tanks and other facilities in the plant.

The refinery port and loading area experienced damage due to ground settlement, a common problem at most of the port facilities around Izmit Bay. Along the coastal wall, a few hundred meters of 12” pipeline carrying crude oil from ships to the plant collapsed due to failure of cantilever supports.

After the initial cleanup of the heavily damaged area and repair of minor damages to supporting facilities, the plant will be able to begin operations at approximately 50% capacity utilizing the undamaged production facilities.

Petkim – Petrochemical Facility

The Yarimca Petrochemical Complex located at Izmit Bay next to the Tupras Refinery is part of Petkim petrochemicals, a large government owned petrochemical operation. The plant was built in 1965-1969 and operations began in 1970. There are a total of 2,000 employees and the plant's main products are Ethylene, PVC, thermoplastics, rubber raw material, Vinyl Chloride Monomer (VCM), Styrene Butadiene Rubber (SBR), Cis Polybutadiene Rubber (CBR), and other chemical products. Raw materials are imported primarily by ship.

In general, this facility performed well with isolated cases of minor to moderate damage. The most significant damage was the collapse of a wood cooling tower. The port facilities and surrounding areas adjacent to the coast experienced damage due to vertical ground settlement. The foundation of a compressor at the Ethylene Processing Unit experienced about three inches of vertical settlement. In the same area a 5,000-ton Ethylene storage tank, which is supported by 50 inch tall columns and a pile foundation system performed well without any damage. There were no reports of major damage to the machinery and equipment in this facility.

The water supply to the plant was a major problem during and after the earthquake for this and other nearby facilities. A 28 inch pipeline supplies water to the site from Sapanca Lake. Damage to the water pump station and pipeline at Sapanca Lake disrupted water supply to the plant following the earthquake. The pipeline failed at 20 locations due to the fault rupture and ground failure around Spanaca Lake. It took four weeks to fix the pipeline and restore the water to the plant. Five weeks after the earthquake, the plant was able to operate with limited capacity. Full capacity operation is scheduled for later in the year after finishing construction of a new cooling tower. The property damage to this plant was insignificant compared to the loss of production.

IGSAS – Fertilizer Plant

The Igsas Fertilizer Plant is a state owned facility located at Korfez next to the Tupras Refinery. Design and construction of this facility started in 1972 and was complete in 1977. The plant produces ammonia and fertilizer and has a total of 900 employees. The fertilizer processing plant performed well without any major damage. The main damage occurred to the ammonia processing unit, ammonia packing building, port facilities, and a partial collapse of a six-story administration building.

The ammonia building is a tall concrete frame-wall structure, which houses heavy processing equipment, storage tanks, pipes, a boiler, and a tall cylindrical reactor vessel. This structure experienced extensive damage at the upper levels, especially at beam-column connections. A two inch wide concrete crack extended one-third of the column height at the top levels of the structure. The concrete column lacked adequate confining steel reinforcement to resist the seismic loads to which the structure was subject. A thick concrete slab at level four of the processing unit building, which supports a reactor vessel, cracked and was severely damaged due to rocking and uplift of the reactor. A steel stack was attached by horizontal angles to the top of the exterior wall of the processing unit building. The connections of the angles to the wall failed. However, the stack remained standing without the lateral support provided by the angles.

Figure 8: Damage at the base of reactor vessel

The ammonia packing building is a 3-story concrete moment frame structure with a concrete slab. In several locations the exterior beam-column connections were severely damaged. Concrete spalled, reinforcement of columns deformed, and beams experienced vertical deformation. There was no significant damage to the machinery and equipment in this building. The port facility and loading dock area, which was built on fill, experienced vertical settlement at several locations.

Overall, damage to this facility was limited to the isolated structural damage in two locations with limited damage to the machinery and equipment. Four weeks after the earthquake the ammonia unit was not operational but the fertilizer plant was operating.

Polisan – Paint and Port Facility

The Polisan facility is a producer of paint, resin, and another chemical products. It is located in Gebze, and employs approximately 650 workers. The plant has been constructed in stages over the last 25 years. The facility consists mostly of one story light steel buildings, many having clay tile exterior walls. During the site visit it was noted that the facilities were well maintained. Ground shaking at this facility was moderate. Most of the damage was nonstructural in nature with some of the hollow clay tile walls damaged. Office furnishings were strewn about and some electrical transformers suffered minor damage. Additionally, a fair amount of product was spilled, much of it in 5 gallon containers. Due to the power outage immediately following the earthquake, resins in process equipment hardened and had to be removed which took approximately 10 days. None of the large storage tanks at the site suffered damage.

The facility also maintains a port, which can accommodate four ships at one time and also has bonded warehouse space. Some cracking occurred at a wharf, but overall damage was minimal and the port was in operation during the site visit one month following the earthquake. A building at the port did suffer some extensive cracks due to ground displacement. The plant was fully operational 15 days following the earthquake, with some degree of functionality before that time.

3.2 Heavy Manufacturing Facilities

Seka Paper Mill and Seka Pump Station in Sapanca Lake

The Seka paper mill is a state owned facility originally built 1936 and expanded over time. This facility has five paper plants, which produce high quality paper, newspaper, textile paper, cardboard material and sulfate paper with a capacity of 100,000 tons per year. There was substantial damage to the plant structures and wharf facility. In addition, the Seka Pump Station at Sapanca Lake which provides water to the plant experienced extensive damage.

At the #1 paper plant, three concrete silos containing wastewater completely collapsed. The diameter of the silos was 6 meters and they had a capacity of about 200 m^3. The silos were supported on six 40cm square concrete columns. The reinforcement of the columns was less that 1% of gross concrete area and confinement was minimal. The failure of the columns occurred at the connection to the cylindrical wall. Two more recently constructed silos of similar dimension did not fail. These silos have larger support columns than the failed silos.

Figure 9: Collapsed silo at Seka Paper Plant

The #4 paper plant, a steel frame structure with steel roof trusses, had an inadequate lateral load resisting system. The roof is a 4-inch concrete panel system, supported by transverse steel beams. In few locations, the concrete roof panels dropped causing damage to the nearby equipment. At both paper plants #1 and #4, the main paper production machinery was anchored to concrete foundations and did not appear to have been damaged. The wharf facility at the Seka Paper Mill sustained extensive damage. A large portion of the wharf deck collapsed due to the failure of columns and piers. Again, a lack of adequate steel reinforcement led to significant damage to the columns and subsequent collapse of the concrete deck.

The Seka Pump Station at Sapanca Lake, about 25-km from the plant, provides water to this facility (as is the case with the previously discussed refinery and petrochemical facility). The pump station, a one story concrete structure, houses three electrical pumps and one-diesel pump. There was no damage to the building or pumps. Four 32-inch pipes with a length of about 300 meters bring the water from the lake to the pump station. These pipes were supported on a concrete platform deck with steel frames, which are supported by concrete piers. Due to strong ground shaking and fault rupture, several hundred meters of the platform sank and the pipes were separated at their connection. The pump station was visited one month following the earthquake and it was in the same condition as after the earthquake.

Figure 10: The collapse of wharf deck at Seka paper plant and collapse of pipeline at pump station

Wagon Factory

The Wagon Factory, located outside of the city of Adapazari, is the main production and maintenance facility for train cars in the country. It employs approximately 1,750 people. Structural damage to the facility was extensive. One of the large maintenance buildings suffered total collapse and numerous other structures suffered partial collapse and are likely a total loss. Additionally, the supporting structure for a large crane collapsed.

The structural systems of the damaged buildings consisted of high bay steel frames with steel roof trusses and a 3 ½" thick concrete roof deck. Lateral bracing was not present at the facility and therefore seismic loads were resisted by trusses and columns acting as moment frames, although assuredly they were not designed to resist the seismic loads to which they were subject.
The main source of damage consisted of failure of the roof truss to column connections and failure of the column anchor bolts, both of which contributed to full or partial collapse of the buildings. Of particular interest at this site was the condition of the two-story administration building adjacent to the collapsed production facility. This building is the typical concrete frame and hollow clay tile wall building found in the region and had no signs of appreciable damage on the exterior of the building.

Figure 11: State of damage to wagon factory

Sugar Factory

The Sugar Factory was built in 1960 and is 50% owned by the state. The plant is at peak operation for four months following the sugar harvest season. At the time of earthquake the plant was shut down. The plant capacity is 100,000-tons of sugar and 40,000-tons of sugar bi-products.
The plant sustained extensive damage due to high ground shaking in the Adapazari area. The power generation plant building is a steel frame structure with brick infill walls. The building was severely damaged and has a permanent offset. Outside of the processing plant, two steel stacks and one elevator pipe with heights of 36m failed at their base and completely collapsed. One of the stacks and the elevator pipe fell into the sugar processing unit building and severely damaged a portion of that building, causing extensive damage to the equipment inside. An elevated pipeline outside of the processing plant, which is connected to the finishing product building, failed at several locations. In addition, a concrete frame office and laboratory building sustained damage to the exterior columns at the lower level due to short column conditions created by brick infill exterior walls. A fire also broke out in the laboratory of this building.

Figure 12: Steel stack collapsed into processing unit

3.3 Light Manufacturing Facilities

Several light industrial facilities were surveyed around Izmit Bay and Adapazari. Most of these facilities are privately owned with 50 to 350 employees. Damage to building facilities was dependent of the type of construction. Traditional concrete frame and hollow clay tile wall buildings performed poorly. However, due to the fact that most did not have open/soft first story conditions they tended to perform better than residential/commercial construction on average. Steel buildings performed the best, the major damage being failure of hollow clay tile exterior walls where they existed. Precast concrete frame construction has recently become a popular form of construction. These building performed extremely poorly due to lack of seismic detailing at beam column connections as well as at the base of columns.

Damage to most production equipment in these facilities was relatively minor if at least minimally anchored. Exceptions were equipment very sensitive to ground motions. The following summarizes two cases of observed equipment damage:

- At one facility, steel beams supporting large steel tanks failed in weak way bending. The beam webs were being strengthened with the addition of stiffener plates during the site visit. This same plant has an extensive amount of process piping. There was some damage to piping, pumps and valves which overall was relatively minor.

- The glass furnace at one facility experienced moderate damage resulting in a production shutdown. The feeder from the furnace to forming machinery separated at the furnace resulting in a leakage of molten glass. Workers were able to quickly shut the furnace off and then drain the furnace of remaining molten glass. The furnace was in the process of being repaired during the site visit, one month following the earthquake. Part of the repair included the addition of cross bracing to the steel structure supporting the furnace.

CONCLUSIONS

The Izmit Earthquake provides the unique opportunity to investigate the performance of industrial facilities subjected to strong ground shaking. The findings from reconnaissance of a number of facilities are summarized based on the type of occupancy as follows:

Refinery and Chemical Processing Facilities

- As far as overall property damage, the impact on large refinery and chemical operations was minor to moderate. The most susceptible components of these facilities tended to be the very large process structures and storage tanks. Although the equipment in tall structures often performed adequately, the supporting concrete and steel structures were not adequately designed and in some cases were extensively damaged. Smaller structures and equipment tended to perform better. Part of the reason for this may be the nature of the ground motion, and the fact that many of these facilities are located in coastal areas with soft soil conditions that tend to amplify long period ground motions effecting large/tall structures such as the stack and oil tanks at the Tupras refinery.
- From a fire standpoint, this earthquake pointed out the need to have back up sources of water and to have emergency response plans in place. Outside supplies of water can not always be counted upon in a large event such as this.
- For these facilities the losses due to the downtime and business interruption were significant as compared to the property damage.

Heavy Manufacturing Facilities

- The performance of heavy industrial facilities varied substantially, depending on the age and type of structures at the plant. Many of the heavy industrial facilities are wholly or partially owned by the government and are relatively old. The large, tall story buildings at these facilities, constructed of concrete or steel frames with hollow clay or brick infill, tended to perform poorly with portions of the buildings collapsing in areas of high ground shaking.
- Overall, machinery and equipment that was anchored to a minimum level tended to perform adequately. The exception is equipment that is very sensitive to ground movement. An example is a relatively new car manufacturing facility where the assembly line sensors were knocked out of alignment. The equipment was almost completely re-aligned when an aftershock occurred and the alignment process had to be restarted. Therefore, although building damage was not impeding operations, production was severely impacted.

Light Manufacturing Facilities

- Overall, the damage to production machinery at light industrial facilities was relatively minor with a few exceptions in the case of equipment particularly sensitive to ground movement such as a glass furnace.
- Overall, as was the case with heavy industrial facilities, the labyrinth of production piping at these facilities was not too severely damaged as long as ground settlement did not occur. The extent of building damage was the main factor in determining how much impact the earthquake had on a facility and how quickly they can recover. Newer facilities built of steel construction faired much better than the non-ductile concrete buildings built with hollow clay tile walls. Additionally, precast concrete construction, which has become popular recently, performed very poorly in the earthquake

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