CHAPTER 4

INDUSTRIAL DAMAGE AND LOSSES OBSERVED IN PAST EARTHQUAKES IN TURKEY

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4. INDUSTRIAL DAMAGE OBSERVED IN PAST EARTHQUAKES

Within the last ten years Turkey was hit by several moderate to large earthquakes causing life and property losses. They are 1992 Erzincan, 1995 Dinar, 1998 Adana-Ceyhan, 1999 Kocaeli and Duzce earthquakes. Adana-Ceyhan and Kocaeli regions are among the most industrialized regions in Turkey and the earthquakes of 1998 and 1999 caused significant industrial losses in these regions. In Erzincan and Dinar there was very limited industrial development. In this section damage information in past earthquakes will be summarized.

4.1. Gediz Earthquake, 28.3.1970, Ms=7.1, Maximum MSK Intensity=IX

A couple of buildings in the Tofaş car factory complex in Bursa collapsed due to the Gediz earthquake, which took place at a 130km distance (Eyidoğan et al., 1991). Long distance amplification of seismic waves due to propagation path and/or site conditions are cited as possible reasons of significant ground motion experienced in the facility.

4.2. Erzincan Earthquake, 13.3.1992, Ms=6.8, Maximum MSK Intensity=VIII

Seker Fabrikası (Sugar Factory) constructed in 1956 received damage. The 36m high chimney collapsed, damaging along the roof of the main production building, which was a steel structure, and its infill walls. No damage was observed in the workshop and the cylindrical steel tanks. The reinforced concrete İplik Fabrikası (Thread Factory) sustained damage in its outer main structural frame, as well as in its beam-column connections. Production equipment was misaligned as a result of the earthquake. There was also heavy damage to the warehouse units (Gülkan, 1992). Recorded peak ground acceleration in Erzincan, in near fault conditions was 0.51g.

4.3. Dinar Earthquake, 1.10.1995, Ms=6.1, Maximum MSK Intensity= VII-VIII

There is no significant industrial production in the town of Dinar. The only industrial building at 35km distance from the epicenter had no damage (www.eeri.org/earthquakes/reconn/dinar/dinar.html). The peak ground acceleration recorded in Dinar, which is located practically directly above the hypocenter was 0.33g.

4.4. Adana-Ceyhan Earthquake, 27.6.1998, Ms=6.2, Maximum MSK Intensity= VII

Adana-Ceyhan earthquake, besides causing heavy structural damage, is marked with significant losses to industrial facilities due to structural damage and business interruption. Recorded peak acceleration at the Ceyhan station, located on soft sedimentary soils at an epicentral distance of 32km was 0.28g. Most of the damaged industrial facilities were constructed within the last ten years.

Haci Sabanci industrial park is located between Adana and Ceyhan. It consists of 314 facilities. Many administrative and industrial buildings were damaged. Administrative buildings are two story high reinforced concrete frames with masonry infill walls. Factories and warehouses are of pre-cast reinforced concrete elements with fixed columns at the foundation level and hinged joints at the column to roof connections. Roofs were of metal and infill walls were of masonry. There was damage to industrial facilities in Ceyhan as well. But in general damage to the industrial park was more severe than the damage in Ceyhan (EQE 1998). About half of the facilities in the industrial park sustained moderate damage (score 4) assessed by a 10 step scoring with score 6 indicating heavy damage. In Ceyhan the majority of facilities sustained light damage (EQE 1998).

Onur Textile: 6 months old building; roof damage; beams fell off their supports, damaging the equipment below leading to termination of production; seperation of infill walls from the columns (SAGEB, 1998).

Several precast connections failed, leading to collapse of three of the main cross girders damaging one spinning machine; 22 days business interruption; seven reinforced concrete, cast-in-place storage rooms collapsed; a series of pipes and connections destroyed due to rigid piping and connections and flexible building behavior (EQE, 1998).

Bossa Denim Factory: part of the roof fell off its supports, destroying production lines (SAGEB 1998)..

Başdoğan Carpets: Cast in place, two story reinforced concrete frame building with masonry infills; substantial damage to the columns in the first floor (SAGEB, 1998).

Pounding of two sections at an expansion joint added to the damage; no equipment damage; facility remained functional in spite of heavy damage (EQE, 1998)

Karteks Textile. Single story, precast reinforced concrete portal frame with metal roofing, damages due to pounding; administration building is a two story reinforced concrete structure with masonry infill walls, undamaged; seven spinning machines toppled; factory closed for 14 days; at 30% of production one month after the earthquake; all piping for ventilation, water supply and electricity was hidden behind false ceilings; damages to false ceilings (EQE, 1998).

Atesa Textile: Serious damage to structure and equipment; major roof deformation; damaged columns; permanent displacements reaching 30 cm sustained by the machines; pipe connections on several machines damaged due to large displacements (EQE 1998).

Cestas Textiles: Single story, precast reinforced concrete portal frame with metal roofing; partially collapsed (EQE 1998).

Amylum Starch: A facility consisting of a number of structures including tanks, towers and silos; minor damage in general; two steel tanks buckled close to the foundation level; no damage to piping and connections; one column damage without causing equipment damage (EQE 1998).

Ceyhan Un: Reinforced concrete structure; beam-column connections heavily damaged; heavy damage to glass and masonry; shifted machines; damaged connections (EQE, 1998).

4.5. Kocaeli Earthquake, 17.8.1999, Ms=7.8, Maximum MSK Intensity=X

4.5.1. Industrial Damages

Kocaeli earthquake is considered as the largest event to have caused damage in an industrialized area since the 1906 San Fransisco and the 1923 Tokyo earthquakes. In the Kocaeli earthquake 70% of the total insured losses was related to direct damage and 30% was due to business interruption. Estimations of the insurance industry towards the total insured losses as a result of Kocaeli earthquake were in the order of 1.5-3.5 billion USD (RMS, 2000) as compared to 550-750 million USD estimated to have been paid by the industry (Johnson, 2000).

The two major earthquakes that took place in 1999, namely the M=7.4 Kocaeli, Turkey and M=7.6 Chi-Chi, Taiwan earthquakes caused comparable economic and insured losses. In the Kocaeli earthquake the economic losses are estimated between 10-40 billion USD and the insured losses are estimated between 550-750 million USD, whereas Chi-Chi earthquake caused an economic loss worth of 8-14 billion USD and insured losses between 500-850 million USD (Johnson, 2000). It is worth of noting however that there is an order of magnitude difference in the human losses in these earthquakes. Kocaeli earthquake caused more than 18,000 deaths and more than 40,000 injuries, while in Taiwan there were 2,405 deaths and 10,718 injuries.

The epicenter of the Kocaeli earthquake was near town Golcuk located on the southern shore of the Izmit Bay.The northern and southern coasts of the Izmit Bay are home to a wide range of industrial facilities. On the northern coast the industrial facilities extend westerly until near Maltepe to the east of Istanbul. The facilities there are positioned mainly along the E-5 highway connecting Istanbul with Ankara. The facilities especially around the Izmit Bay were effected severely by the Kocaeli earthquake. The ones on the southern shores of the Izmit Bay are mainly on alluvial and marine deposits. Facilities along the northern shores of the bay are on relatively stiff soil.

The epicentral area of the 1999 Kocaeli earthquake can be considered as the home of Turkey's heavy industry, including petrochemical plants and car manufacturers. The major industries are automobile, petrochemicals, manufacturing and repair of motor (and railway) vehicles, basic metals, production and weaving of synthetic fiber and yarns, paint and lacquer production, tire factories, paper mills, steel pipes, pharmaceutical, sugar, cement, power plants and tourism.

Many foreign companies have affiliates nearby in the region, including Goodyear, Pirelli, Ford, Honda, Hyundai, Toyota, Isuzu, Renault, FIAT, Ford, Bridgestone, Pepsi Co, Castrol, Dow Chemical, Shell Co., British Petroleum, Mannesmann, Bridgestone, DuPont, Akza Nobel, Phillips, Lafarge and Bayer. Damage to industry was more extensive than those in other earthquakes with similar ground motion levels. The damage encompassed cooling tower collapses, damaged cranes; collapse of steel, reinforced concrete framed and prefabricated structures, damage to jetties, and extensive equipment failures. The extent of damage to industry depended on, distance to fault, site conditions, quality of construction, anchorage conditions of machinery and robustness and redundancy of fire fighting facilities. Losses due to extensive business interruption were substantial as compared to the physical damage. The Kocaeli Earthquake provides a unique opportunity to investigate the performance of industrial facilities subjected to substantial strong ground shaking under near-fault conditions.

Of the 1062 member firms of the Kocaeli Chamber of Commerce, 345 firms reported damage due to the Kocaeli earthquake. About 20% of its members are large-scale firms, the rest are classified as small and medium sized firms (KOBI, küçük ve orta büyüklükteki işletmeler). 5 % of the damaged facilities sustained total damage. In terms of size 34% of the small and medium size and 26% of the large scale firms were damaged. All of the large scale firms were insured. Of the small and large scale firms however 53% were not insured. The firms, regardless of their sector, were operating at an average capacity of 70% before the earthquake, which fell to an average 31% after the event by the end of the first month. At the end of the sixth month after the earthquake the firms were operating at an average 54% capacity. Average business interruption was 35 days in the region (Kocaeli Chamber of Commerce, 1999).

There are 340 industrial firms operating in the province of Adapazarı. 23 of them are major industrial facilities. In Adapazarı 34 facilities were heavily damaged, 73 facilities sustained medium damage and 19 facilities had light damage (http://www.sakarya.gov.tr)

Although a wide variety of industrial facilities exist in the region, petrochemical and automotive industries exhibit a strong presence in the earthquake area. In the following sections the effect of the Kocaeli earthquake on these two industries will be summarized. Damages sustained by other facilities will be covered in a separate section. Details of damaged industrial facilities are presented in Table 4.5.1. Description of structural and non-structural damage levels are given in Tables 4.5.2 and 4.5.3 after PEER, 2001.

4.5.1.1. Component Based Description of Earthquake Performance and Damages

The damages experienced by the industrial facilities in 1999 Kocaeli and Duzce earthquakes can be deaggregated in terms of the main components of these facilities.

Buildings

Nearly all the fatalities and injuries can be attributed to building collapse. The 1999 Kocaeli earthquake resulted in about 21,000 heavily damaged or collapsed buildings. In-situ reinforced concrete beam-column frame construction is common in smaller and older industrial facilities in Turkey. The quality of the construction of the buildings in these industrial facilities is believed to be substantially better than the quality of residential or commercial construction.

Reinforced-Concrete Moment Frame Structures

Overwhelmingly, the predominant building type in the industrial facilities in the region is low-rise (1 to 4 stories) reinforced concrete frame with hollow clay tile infill.

The damage to reinforced concrete buildings from this earthquake can be attributed to one or more of the following:

- Failure to meet the design requirements of the code use of poor and inappropriate construction materials.
- Soft stories at the first-floor level. (Masonry infill walls start immediately above the commercial floor. The existence of the soft story increased the deformation demands very significantly on the first-story columns leading to collapse)
- Strong beams and weak columns. (Most frame structures have strong beams, remaining elastic, and weak columns suffering compression crushing or shear failure)
- Lack of column confinement and poor detailing practice

Reinforced Concrete Shear-Wall Structures

Use of reinforced concrete shear walls is limited. These building generally performed well during the earthquake. Some shear wall buildings with older, low quality concrete was damaged extensively but the shear walls did save the structures from collapse.

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. In general, the prefabricated R/C structures did not perform well during the 1999 Kocaeli and Duzce earthquakes.

The main problem was due to failure of weak joints between the roof beams and columns. Some prefabricated buildings collapsed because of the lack of bracing due to flexible of missing peripheral walls or roof diaphragm (Figure 4.1 and Figure 4.2).

The popular precast structural system consists of frames 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. Typical spans vary between 12 and 25 m with typical heights between of 6 and 8 m. Another common framing system uses precast T-shaped member at the top of the central column that serves to connect the column to simply supported roof beams. Reinforced concrete planks span between the frames and are supported on pockets cast into the precast beams. A prefabricated framing system, common in modern facilities, uses gravity-load framing system composed of a light steel (3-D) space frame that is supported by steel trusses spanning between the precast reinforced concrete columns (Figure 4.3). Fixity at the base of the columns are 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.

Steel-Frame Structures
Braced and moment-resisting steel frames are used for some single-story and many multistory industrial facilities.

In 1999 Kocaeli and Duzce earthquakes steel buildings performed much better than the RC frames. Only a few collapsed (Figure 4.4). Typical causes for collapses include failure of anchor bolts at column bases and roof trusses and structural instability under overturning forces. Other evidence of damage includes fracture of brace connections and buckling of braces.

Figure 4.1. Collapsed prefabricated structure.

Figure 4.2. Damaged prefabricated frame system.

Figure 4.3. Damaged prefabricated building at Ford Otosan Plant.

Figure 4.4. Damaged steel structure at Adapazari rail car factory.

Electric Power

Power Generation
The natural gas fired cogeneration plant is located within 3km of the fault rupture. The partially built Heat Recovery Steam Generation facility was damaged. The transformers mounted on wheels moved by 5-10cm but without causing any damage. In the switchyard some bus bars and high-voltage bushings were broken. The Enerji SA plant has shown good performance considering the high ground motions experienced in the near field.

Power Transmission
Nine transmission substations suffered damage or disruption to transformers, switching equipment, and buildings. All of the damage was associated with strong ground shaking. The main power substation in Adapazari sustained damage to its six 380kV transformers. Damage included movement and tilting of transformers due to support failure and breakage of porcelain circuit breakers. Other damaged 380 kV Substations were at Osmanca (about 40 km north of the fault rupture), Eregli (located about 65 km north the fault rupture) and Bursa Sanayi (80 km southwest of the fault rupture). 154 kV Substations at Kosekoy, Yalova, Izmit-1, KentSA and Yarimca have also received various degrees of damage. The poor earthquake performance of the sub-stations have shown that the porcelain insulators used in high-voltage substation equipment are generally vulnerable to strong earthquake shaking and loading caused by interconnection with other equipment, unless high-strength insulators and appropriate seismic designs are used. Similarly, unanchored equipment (particularly transformers sitting on rails or inadequately attached pole-mounted transformers) is seismically vulnerable.

With the exception of a 154 kV electric transmission tower located on the fault rupture near the Ford Otosan facility, the observations have shown that the transmission towers and lines exhibited good earthquake performance in the 1999 Kocaeli and Duzce earthquakes. However, distribution power poles and towers are vulnerable to damage due to ground failures and to buildings collapsing into the poles and towers. The 1999 earthquakes also shown that the underground distribution cables are prone to damage where they connect to surface electrical supplies or buildings.

Figure 4.5. Adapazari substation.

Figure 4.6. Damaged transformer at Izmit-1 substation.

Figure 4.7. Damaged electrical equipment.

Figure 4.8. Damaged transformer at SEKA paper factory.

Tanks, Silos, Cooling Towers and Stacks

Storage Tanks

The majority of damage at the Tupras Refinery was concentrated at the storage tank farm area (Figure 4.9). The tank farm has more than 110 tanks of varying sizes containing water, crude oil, and other oil substances. Sizes range from 1,200 m3 to 135,000 m3 and roofs are both floating and fixed.

The sloshing of fluid damaged the perimeter seal producing overtopping and gross damage in near the tops of walls. The shell buckling at tank bases also caused oil leakage. The oil lost from these tanks was contained within the earthen berms surrounding the tanks. The vertical movement of the floating roof created sparks (metallic seals) which led to the fire ignition of the oil leakage. The extreme heat caused substantial deformation and damage in approximately 20 steel tanks. No substantial sliding of the anchored tanks no evidence of pipe failure in the rest of tanks at the tank farm was observed (Figure 4.10 and Figure 4.11).

Two of the three 14.63-m-diameter liquid gas storage tanks at Habas Facility were collapsed due to ground shaking (Figure 4.12). Each insulated tank consisted of two concentric stainless steel shells. Both shells were supported by sixteen 200-mm-diameter 2.5m high reinforced concrete columns.

Cylindrical (bullet) liquid gas tanks were common in the industrial parks in the earthquake-affected region. Most of these tanks were not anchored with rigid pipe connections. No significant damage to these tanks has been reported.

Numerous spherical LPG tanks were located in the industrial facilities in the earthquake-affected region. These tanks were typically supported by braced steel frames or reinforced concrete frames. No significant damage to these tanks has been reported.

Reinforced Concrete Silos
At the SEKA Paper Factory three reinforced concrete silos containing wastewater completely collapsed (Figure 4.13). The silos, supported on six 40cm square concrete columns, had a 6m diameter and 200 m3 capacity.

Cooling Towers
Cooling towers at TÜPRAŞ Refinery and PETKİM Facility were damaged (Figure 4.14 and Figure 4.15).

Stacks
In Adapazari Sugar Factory two steel stacks and one elevator pipe completely collapsed falling into and severely damaging the sugar-processing unit.

In TÜPRAŞ Facility the upper two thirds of an 110-m-tall reinforced concrete heater stack fell into one of the of three crude-oil processing units, igniting fire and creating total damage (Figure 4.16). Failure of the stack probably initiated at a stiffness discontinuity used for the entrance of a large-size ductwork.

Figure 4.9. Damaged tanks at TUPRAS tank farm.

Figure 4.10. Tank failure at TUPRAS Refinery due to fire caused pressure increase.

Figure 4.11. Fire caused buckling of a tank at TÜPRAŞ Refinery.

Figure 4.12. Damaged insulated tanks at HABAŞ Facility.

Figure 4.13. Collapsed silo at SEKA Paper Factory.

Figure 4.14. Collapsed cooling tower at TÜPRAŞ Facility.

Figure 4.15. Collapsed cooling tower at PETKİM Facility.

Figure 4.16. Collapsed stack at TÜPRAŞ Refinery.

Pipelines and Piping Systems

Water and Waste Water Systems

The water systems performed well except for the broken distribution pipes, especially in the areas having heavenly damaged buildings. There was some damage to major welded steel water transmission lines especially where they cross the fault zone or in areas of severe permanent ground movement (Figure 4.17 and Figure 4.18). A 28 inch pipeline supplies water to the Tupras Refinery, Petkim petrochemical facility, SEKA as well as some other industrial facilities in the region from Sapanca Lake, about 25-km from the plant. 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 Sapanca Lake. It took four weeks to fix the pipeline and restore the water to the plant. The distribution system, consisting mostly of asbestos concrete pipes, suffered significant damage throughout the region. Ground failure caused damage to wastewater pipelines in all regions; in Izmit at least 10 km of RC pipes had breaks.

Natural Gas System

The natural gas transmission system in the vicinity of the earthquake was limited to the BOTAS main natural gas transmission lines, and the IZGAS natural gas distribution system in the vicinity of Izmit. BOTAS high-pressure steel pipeline crosses Izmit Bay between Muallim and Hersek Peninsula. Following the earthquake the system is not damaged. IZGAS reported that none of the 380 kilometers of gas pipelines were seriously damaged by the earthquake. However 860 gas meters were damaged due to collapsed buildings. Fortunately there were no fires associated with gas leaks due to very limited residential gas use in summer. The gas system performed well. As is the case with international experience the practice for natural gas system siting, design and construction appears to be resistant to strong levels of earthquake shaking in the 1999 Kocaeli earthquake. However, for pipelines crossing active faults or in regions susceptible to permanent ground displacements failure is likely.

Figure 4.17. Steel pipe damaged due to fault effect at Arifiye.

Figure 4.18. Damaged water pipes.

Port Facilities

Most of the ports and jetties of industrial facilities along the northern shores of the Izmit Bay sustained damage ranging from minor to extensive. Damage included failure of piers, mechanical equipment, piping and the collapse of cranes. Location of damaged ports and jetties are indicated in Figure 4.19.

Extensive damage was observed at fault crossings, for example, at the navy base (Figure 4.20). It included failure of steel piers and piping systems and the collapse of cranes (Figure 4.21 through

Figure 4.23). In Derince general cargo and grain port, which handles some 2 million tons of cargo annually, suffered heavy damage to docks, cranes and warehouses, including cracks and severe subsidence (Figure 4.24). The concrete caisson type bulkhead, with a length of about 1.5 km, shifted away from the wharf up to 0.7m horizontally and 1m vertically, due to liquefaction-induced deformations, settlements and lateral spreading. Two of the three rail mounted main portal cranes were nonfunctional and some old steel warehouses were damaged. A new wharf constructed on piles had no problems.

Haydarpaşa Port in Istanbul, located about 60 km away from the closest fault break, received minor damage to quay walls. The quay walls of the Tuzla Port, located about 25 km northwest of the closest fault break, moved about 40 cm horizontally. The backfill settled about 10 cm.

Ground failure was observed near the jetty entrance of the port facility of the Petkim petrochemical plant. This port was not operational afterward. Many of the battered piles beneath the jetty were badly damaged. Some of the pipelines along the pier fell off their supports and were damaged. Ground cracking and deformations were observed along the shoreline near the pier.

The failure of the jetty and the elevated pipeway of the Tupras Refinery prevented the loading and unloading of all fuel-oil products at the refinery. The jetty was composed of a reinforced concrete deck that was supported on steel piles in-filled with concrete. The middle half of this pier is sagged due to damaged piles. Ground deformations and cracking along the shoreline were observed near the pier.

A substantial number of the jetties at the industrial facilities were also damaged. These include Petrol Ofisi (Figure 4.25), Shell Oil, Trans Turk (Figure 4.26), Seka Paper Mill (Figure 4.27 and Figure 4.28), Public Marina at Izmit, Fursan and UM Shipyard. The total estimated loss for port facilities in the region is on the order of $200 million.

Figure 4.19. Location of affected ports and jetties in Izmit Gulf in the the Kocaeli Earthquake

Figure 4.20. Fault offset on the navy port at Golcük.

Figure 4.21. Crane and rail damage at Gölcük navy port.

Figure 4.22. Damage at navy port in Gölcük.

Figure 4.23. Damage at navy port in Gölcük.

Figure 4.24. Damage at Derince Port in Kocaeli Earthquake.

Figure 4.25. Settlement at Petrol Ofisi pier.

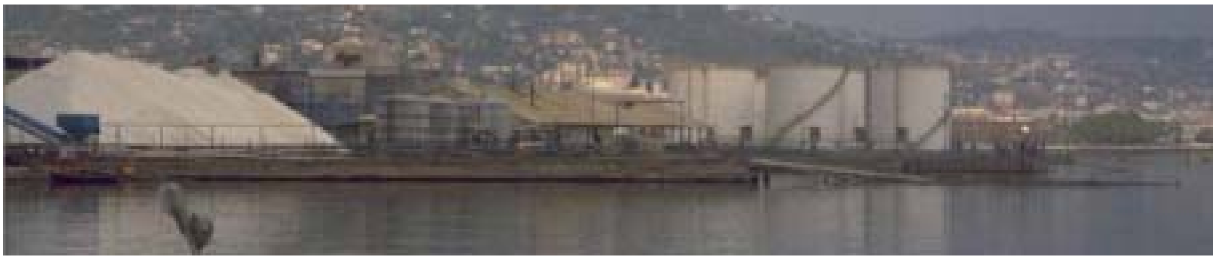


Figure 4.26. Damaged pier at Shell and Trans Turk facilities.

Figure 4.27. Failed supporting column at SEKA port.

Figure 4.28. Damage at SEKA pier.

4.5.1.2. Sector Based Description of Earthquake Performance and Damage.

Petrochemical Industry

An extensive concentration of state-owned petrochemical complexes is located within 5 km of the causative fault of the Kocaeli earthquake, including Tupras, Petkim and Igsas. The heaviest damage occurred at the Tupras facility, the largest refinery in the region producing about twelve million tons per year. The refinery was working at about 90 percent of its design capacity and can be considered a modern and efficient plant. The earthquake caused significant structural damages to the refinery itself and associated tank farm with crude oil and product jetties (Figure 4.29). The consequent fire in the refinery and tank farm caused extensive damage. Fire started in one of the Naphtha tanks continued for three days endangering the safety of the whole region. Six tanks of varying sizes in the tank farm of 112 tanks were damaged due to ground shaking and fire. There were damage to cooling towers and the port area. Collapse of a 150m high heater stack on the boiler and crude oil processing unit caused significant damage and started a second fire. The total damage is estimated to be around US$350 million.

The Petkim petrochemical facilities had limited damage, which includes settlement at the port and the collapse of a cooling tower. No damage to the equipment in the facilities is reported. The fresh water for the Tupras and Petkim complexes, as well as for several other industries in the region (e.g. Seka paper factory), is supplied from Sapanca Lake via 30 km long pipelines. Fault rupture and soil failure caused extensive damage to pump station and pipelines at about 20 locations. The failure of the water supply caused problems in controlling the fire at Tupras. Igsas fertilizer plant has experienced extensive damage in the administration building. Ammonia processing and packing units and the port facilities were partially damaged. Two of the three insulated oxygen tanks at HABAŞ Facility were damaged (Figure 4.30). At Aksa chemical industries located in Yalova region there was damage in port facilities and storage tanks. All of these facilities also experienced extensive losses business interruption.

There are at least 15 gas firms with spherical LPG storage tanks in the area situated around TUPRAS and PETKIM. No major structural damage was observable at these plants (EERI, 1999).

Cylindrical plants rest on reinforced concrete supports. Being unanchored some tanks slided horizontally on their supports.

Recorded peak ground acceleration at PETKIM was 0.32g.

Automotive Industry

The area affected by the Kocaeli earthquake includes the provinces of Istanbul, Bursa, Kocaeli, Sakarya and Yalova, which are home to 90% of the Turkish automotive industry (Main and Secondary Facilities). There are 13 firms producing several types of vehicles in the region and 800 secondary industrial firms. Especially facilities in Gebze and Sakarya were hit severely by the earthquake. There are seven active firms in these two provinces. Otokar, Otoyol and Toyotasa are in Sakarya. Anadolu-Honda, Anadolu-Isuzu and Chrysler are located in Gebze. Hyundai Assan is in Kocaeli. Ford Otosan was under construction in Golcuk, when the earthquake took place (OSD, 1999). There are 95 secondary industrial firms in Sakarya and Kocaeli.

Figure 4.29. Fire at TÜPRAŞ Refinery.

Figure 4.30. Damage at Habaş Facility.

The Hyundai factory experienced significant nonstructural damage(Figure 4.34). It had damage to its airhandling systems, cable trays and shearing of bolted connections in the steel structure (EERI, 1999). The Toyota car factory had fault ruptures in its parking lot. There was very little structural damage to the steel framed buildings. Out of thirty buildings, two building experienced damage to their columns and there was a relative displacement of 10 cm between the foundation and roof levels (AIJ, 2001). Nonstructural damage included collapsed storage racks, transformers, cars on the assembly line, sliding of the cooling tower for about 1m breaking associated piping and tilting of some manufacturing machines (AIJ, 2001) (Figure 4.35). Piping for water, electricity and fire suppressing were broken and damaged and about 1000 cars in the car pool were slightly damages as a result of bumber collisions (AIJ, 2001). Some automatic machinery in the production lines of these factories suffered from alignment problems. Ford Otosan car factory, under construction during the earthquake, has experienced significant terrain subsidence and some structural damage. Pirelli Tires, Bisa Tires and KordSa tire steel belt and Cord Company had extensive damage and business interruption. In Pirelli Tires one portion completely collapsed and the facility had difficulties in restarting since critical production equipment was in heavily damaged sections of the facility (EERI, 1999).

Other Industries

Other industry facilities include cement plants, steel mills, paper mills, and food processing plants, textile and pharmaceutical factories. TUVASAS railway wagon Production Company, Adapazari sugar factory (and Asil Celik steel Production Company has all received extensive structural damage. In TUVASAS a large maintenance building and several small building collapsed due to lack of bracing in steel structures (Figure 4.36). In the sugar factory a stack and an elevator pipe failed and fell into the sugar-processing facility, partly damaging the facility with extensive damage to the equipment inside. Example of specific damage include collapse of two cranes at the Mannesmann Boru pipe factory; roof collapse, transformer damage, and silo collapses at the Seka paper mill; collapse of a steel frame structure and movement of bioreactor vessels at the Pakmaya food processing plant; storage rack collapse, toxic releases from mixing chemicals, and damaged piping at the Toprak pharmaceutical firm; and collapse of liquid oxygen tank support structures at the Habas medical gas facility (Figure 4.30). Lafarge-Aslan Cement Plant in Darica had no major structural and equipment damage except damage to its port. The rotary kiln and other sensitive equipment had to be stopped, cleaned up and realigned under supervision. Kudos textile factory in Adapazari, Cak textile factory in Akyazi (Duzce) and Ak-Al textile factory in Yalova had extensive damage due to the collapse of the pre-fabricated reinforced concrete factory buildings. Toprak Pharmaceutical Factory had damage due to collapse of stored material on racks and some equipment had to be stopped, cleaned up and realigned under supervision. Kudos textile factory in Adapazari, Cak textile factory in Akyazi (Duzce) and Ak-Al textile factory in Yalova had extensive damage due to the collapse of the pre-fabricated reinforced concrete factory buildings. Some tanks in Aksa chemical, installation in Yalova experienced damage, which was associated with leakage of chemicals. Food processing plants that have experienced heavily damage include Pepsi Co-Uzay Gida (Izmit) and Merko Gida (Yalova). In Duzce earthquake Superlit pipe factory in Kaynasli was heavily damaged. There was limited damage to the industry in Bolu (Filiz Macaroni Factory and Kelebek Furniture Factory).

Ports of private and state-owned facilities around Izmit Bay experienced varying degrees of damages. The type of failures included damaged steel piles, collapse of cranes, damaged piping and damaged jetties. Estimated loss to port facilities is $200 million (EERI, 1999).

Private and public sector estimates of the damage to the industry as a whole range from $1.1 to $4.5 billion. The value-added loss in manufacturing is estimated by at $600 to 700 million. The value-added loss stemming from the damage to industry is estimated to be about 700 Million USD as reported by the State Planning Organization (SPO), which may have resulted in a 1.6 % decline in the growth of the production sector in Turkey. Other sources put this loss figure as much as into the 2 Billion USD range. For example, according to Kocaeli Chamber of Industry, 214 enterprises (about 19% of all enterprises in the province) reported significant damage amounting to a total of US$2.5 billion in capital losses. Many major facilities are known to face extensive business interruptions, however the biggest loss has been the loss of qualified manpower. Most of the industrial losses were covered by insurance. Payments of claims are reported to have amounted to about 600-800 million USD. State Planning Organization estimates as $880 million total loss just for the 19 affected state-owned enterprises located in the region. (Mainly in Tupras, Tuvasas, Igsas, Petkim. Seka and Asil Celik). The State Planning Organization estimates that the loss of business in these industries may have amounted to 632 Million USD. The tourism industry (based in Yalova) has been virtually destroyed and has yet to pick up even after three years from the earthquake. A fundamental regional restructuring in tourism industry may be needed.

Rahnama and Morrow (2000) note that old, heavy industrial facilities were effected more by the earthquake with especially taller structures experiencing total or partial collapses. It was observed that any type and quality of anchorage improved the performance of machine and equipment except very sensitive equipment, such as assembly line sensors in case of automotive industry and rotary kilns in cement plants. Losses associated with business interruption were more severe however for these type of facilities.

An important factor to be considered in assessing earthquake losses and for contingency planning is the damage to stored items in industrial facilities. Numerous industrial facilities experienced losses of open stored materials and rock-stored items in buildings. Figure 4.31 through Figure 4.33 provide examples of such losses.

For the case of light industrial facilities in the earthquake area, the building damage turned out to be primary reason for direct and indirect losses. Poor performance on behalf of precast concrete structures was observed, as it was the case in the 1998 Adana-Ceyhan earthquake.

In the case of refineries and other chemical processing facilities, non-building structures turned out to be vulnerable with tanks being the most susceptible ones to earthquake and fire damage.

It was observed that the damage to the industrial facilities was more severe and extensive than seen in earthquakes with similar peak ground acceleration levels and this observation was attributed to the duration and long period motion of the earthquake (MCEER, 2000). Most of the industrial facilities damaged by this earthquake are within 10km of fault rupture and are in intensity zone IX.

Figure 4.31.An example of industrial facilities experienced losses of open stored materials

Figure 4.32. An example of industrial facilities experienced losses of rock-stored items in buildings.

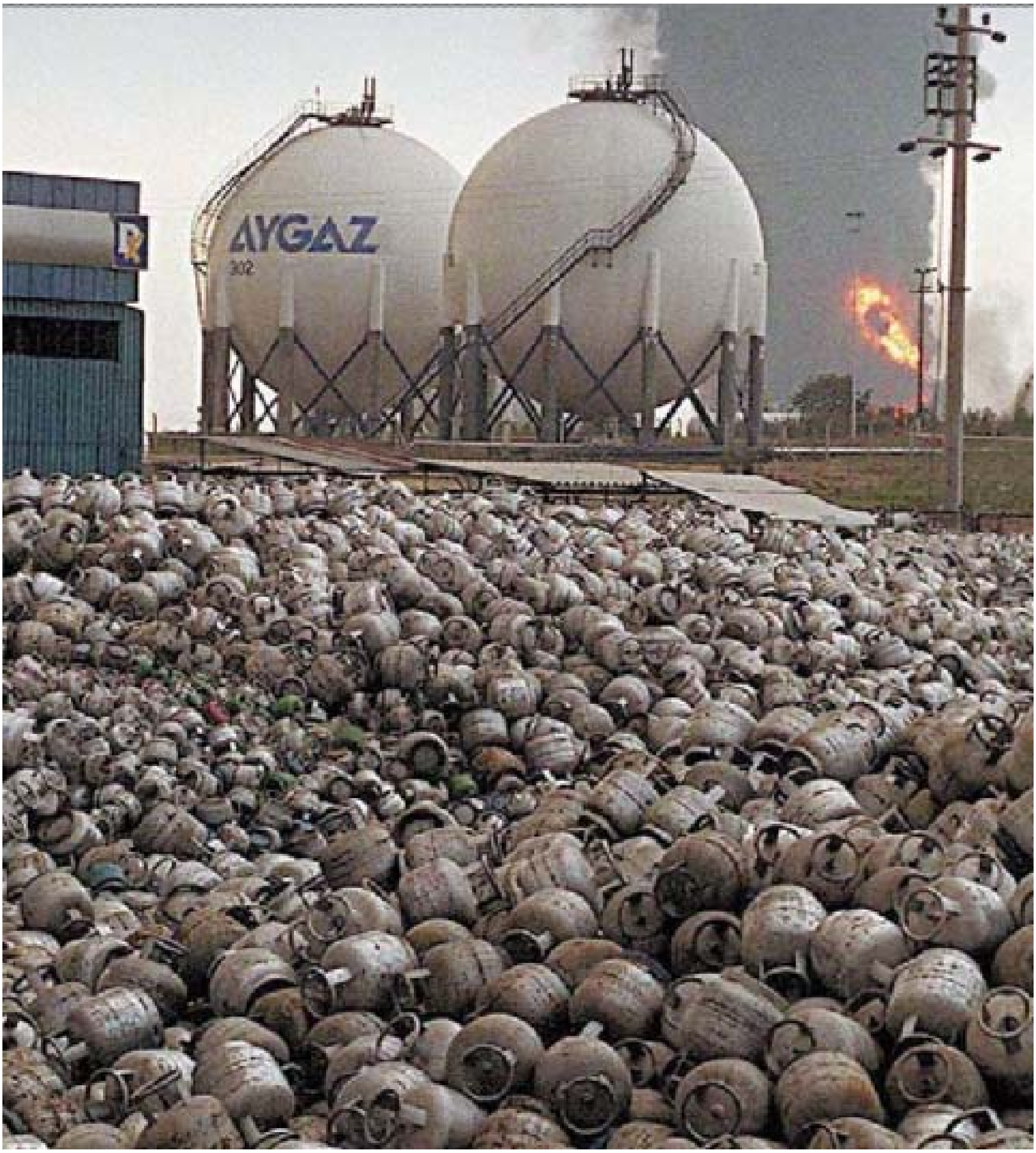


Figure 4.33. An example of industrial facilities experienced losses of rock-stored items in buildings

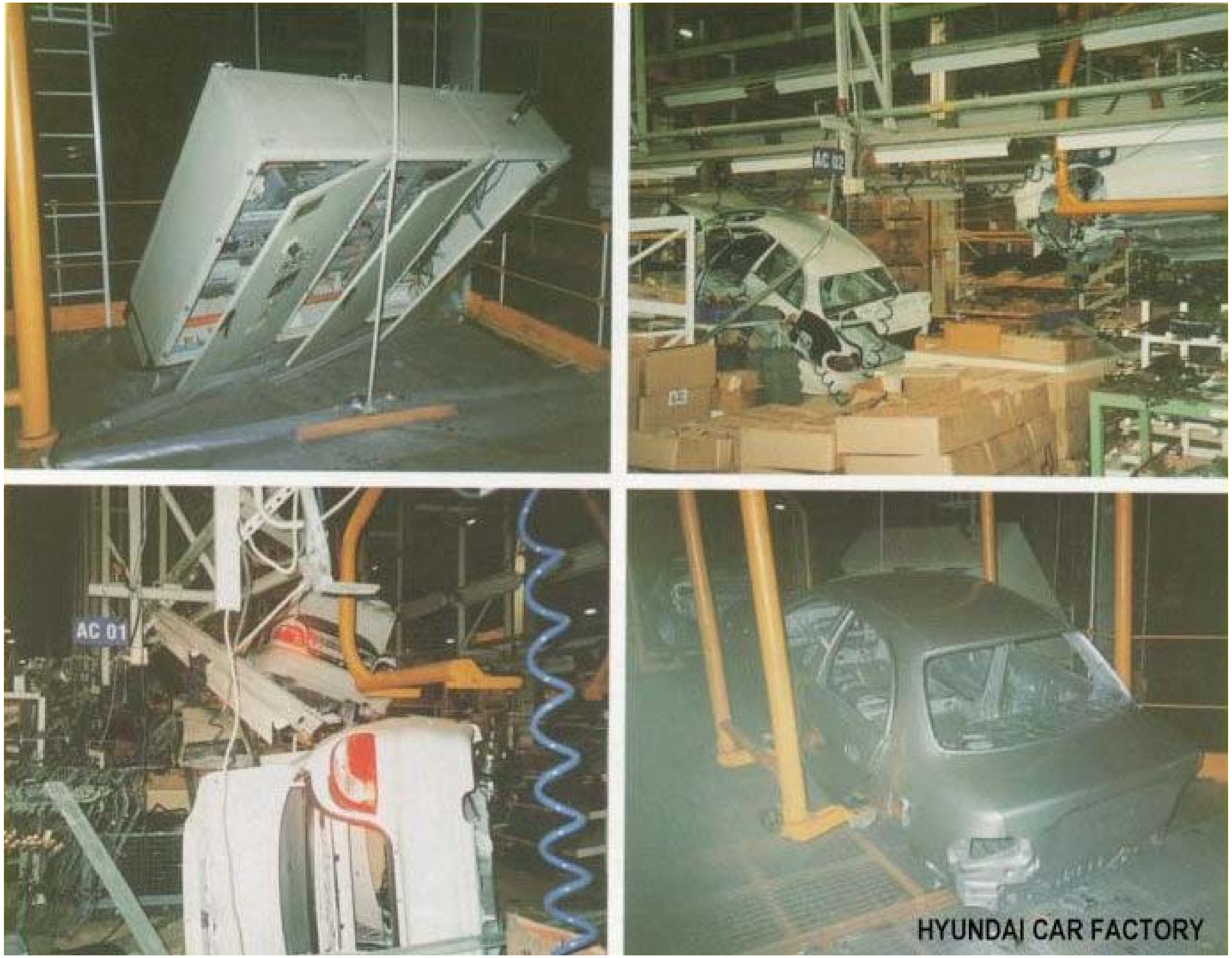


Figure 4.34. Equipment damage at Hyundai-Assan car factory (after Milli-Re).

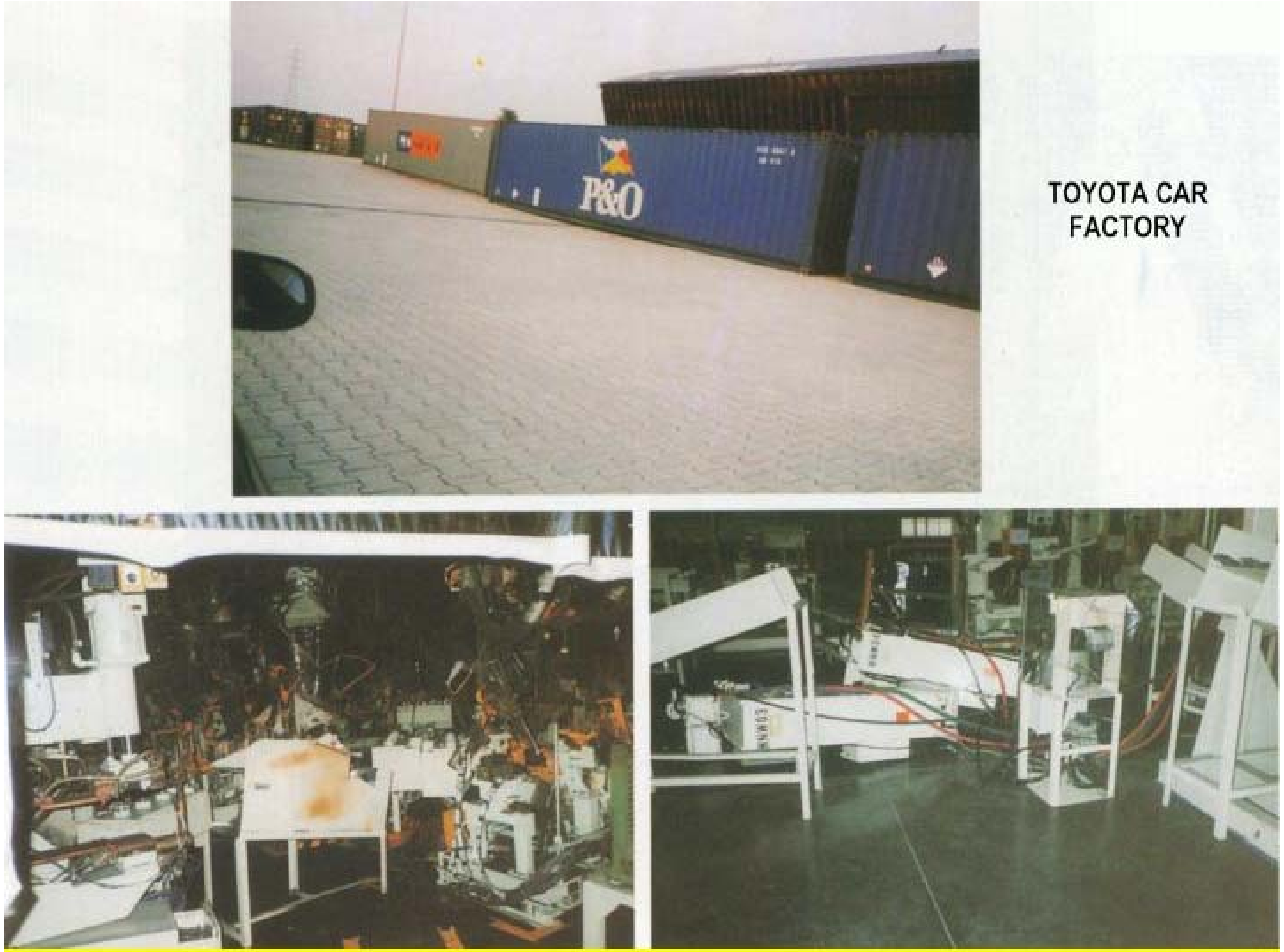


Figure 4.35. Equipment and storage damage at Toyota Car Factory (Afte Milli-Re).

Figure 4.36. Damage at TUVASAŞ Rail Car Factory (after Milli-Re).

Figure 4.37. Damage at Toprak Pharmaceutical Company (after Milli-Re)

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake.

Name of Facility	Type of facility	Year of Construction	No of employees	Downtime estimated	Intensity	PGA estimated	Estimated Loss (% of insured value	Damage	Reference
Tüpras	Refinery	1960-	1350	6 months-1 year	IX	0.32g		Tank farm fires water supply lines break floating roofs sank pile damage at port stack collapse Oil spill pipeway collapse collapsed tanks Structural Damage Level 5 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
Petkim	Petrochemical	1967-1975	2500	2 months	IX	0.32g		cooling tower collapse water supply lines break pipeway collapse port failure Structural Damage Level 5 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
IGSAS	Fertilizer	1977		2-6 months	IX	0.3g		cranes off rails pipeway damage building damage reactor support structure damaged	MCEER, 2000
BP	Gas Terminal	1980-		<1 week	IX	0.3g		buckling of tank roofs damage to tank walkways	MCEER, 2000

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)

BP	Gas Tanker Filling Plant	1974		<1 week	IX	0.3g		minor vessel movement	MCEER, 2000
Hyundai	Car Manufacturing	1997	850	1-2 months	IX			lost connection bolts on steel frame air handler duct failure unzipped cable tray runs Structural Damage Level 4 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
ToyotaSa	Car Manufacturing	1994		2 weeks	IX	0.4g		collapsed storage racks movement of cars on line and unanchored items transformer jumped Structural Damage Level 1 *Nonstructural Damage Level 2*	MCEER, 2000 PEER, 2001
Ford	Car Manufacturing	under construction		not in operation	X	0.4g		large building displacement building damage Structural Damage Level 3	MCEER, 2000 PEER, 2001
Pirelli	Tire Manufacturing	1960's	900	several weeks	IX	0.3g		building collapse Structural Damage Level 4 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
Goodyear	Tire Manufacturing	1963	500	2-3 weeks	IX	0.3g		fire protection lines broken minor structural damage	MCEER, 2000 PEER, 2001

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)

								Structural Damage Level 2 *Nonstructural Damage Level 3*	
BriSa	Tire Manufacturing	1976, 1989		2-3 weeks	IX	0.3g		severe structural damage control room damage transformer damage Structural Damage Level 4 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
KordSa	Steel Cord for Tires	1976	1100	few weeks	IX	0.3g		building damage Structural Damage Level 3 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
DuSa	Tire Cord Fabric	1987		6 months-1year	IX	0.3g		severe building damage process equipment moved pipes blocked instrument cables cut Structural Damage Level 1	MCEER, 2000 PEER, 2001
EnerjiSa	Power	1997	50	few days	IX	0.3g		boiler moved structural damage to HRSG transformer bushings broke Structural Damage Level 2 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
BekSa	Steel Cord for Tires	1987	240	few weeks	IX	0.3g		building collapse windows broke Structural Damage Level 4	MCEER, 2000 PEER, 2001

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)

								Nonstructural Damage Level 3	
NUH	Cement Plant	1968-1973		few days	IX	0.3g		minor structural damage falling monitors in control room settlement at port	MCEER, 2000
Lafarge-Aslan	Cement Plant			few days	VIII	0.2g		minor structural damage settlement at port	
Mannesmann	Steel Pipe Manufacturing	1955	200	few weeks	IX	0.3g		building damage crane collapse Structural Damage Level 3 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
Seka	Paper Mill	1936-1960		2 weeks-2 months	IX	0.3g		complete port collapse silo collapse transformer damage multiple partial roof collapses water supply lines break Structural Damage Level 4 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
Pakmaya	Food Processing	1976	300	2 months	X-IX	0.3g		shifting of reactor vessels vessel piping and support damage steel frame structural damage steel frame building damage fallen walls Structural Damage Level 4 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)

Philips	Incandescent Bulb Factory	1964	77	1-2 weeks	IX	0.3g		minor building damage water tower base cracked minor movement of items	MCEER, 2000
Habas	Liquefied Gas Plant	1995		few weeks	IX	0.3g		liquid oxygen tanks collapsed Structural Damage Level 5 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
Citi	Glass Vial Manufacturing			few weeks	IX	0.3g		minor structural damage minor equipment movement Structural Damage Level 3 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001
Toprak Ilaç	Pharmaceutical	1990	240	2 months	IX	0.3g		storage rack collapse Structural Damage Level 2 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
Toprak Saglik	Paper Products	1993	170	few months	IX	0.3g		product fell unanchored cabinet stand air tanks fell some structural damahe Structural Damage Level 3 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
Çamlica	Soft Drinks	1999 under construction		not in operation	IX	0.3g		partial roof and wall failures Structural Damage Level 4 *Nonstructural Damage Level 3*	MCEER, 2000 PEER, 2001

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)

Çap	Textiles	1997	650	may be permanently shut down	IX	0.3g		building collapse Structural Damage Level 5 *Nonstructural Damage Level 4*	MCEER, 2000 PEER, 2001
	Pharmaceutical, packaging and storage			2 weeks		0.15g soft rock	structures <5% equipment < 5% stock < 5%	tank bases cracked minor cracks in masonry walls 10 mm racking of RC frames	Moat et al, 2000
	Textiles, manufacturing			1 month reduced capacity for 2-3 months		0.25g alluvial deposits	structures 25% equipment 30% stock 20%	cracks in RC columsn floor damage, cracks in masonry walls widespread equipment damage	Moat et al, 2000
	Chemical, storage			2 weeks 25% cap. for 3 months full cap. in 6 months		0.25g alluvial deposits	structures 20% equipment >50% stock 80%	cracks in masonry structures concrete tank supports failed	Moat et al, 2000
	Power, manufacturing			none		0.15g soft rock	structures <5% equipment < 5%	minor damage broken windows	Moat et al, 2000
	Manufacturing,			1 month		0.35g	structures 25%	fallen concrete parapets 50 mm racking of RC frames column cracking HVAC collapse	Moat et al, 2000

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)									
	production and storage			reduced capacity for 6 months		alluvial deposits	equipment 35% stock 20%	damage to equipment damage to cranes	
	Petrochemical, refining and storage			1 week full capacity in 1 month		0.25g alluvial deposits	structures 10% equipment 15% stock 10%	RC elements cracked steel tank roof damage silo movement pipe joints damaged	Moat et al, 2000
	Naval, manufacturing			6-9 months repairs		0.35g alluvial deposits	structures 10% equipment 15%	X baces buckled base anchor bolts elongated crane damage ground subsidence	Moat et al, 2000
	Automotive, manufacturing			loss of production 6-12 months		0.30g alluvial deposits	structures 40% equipment 25% stock 10%	structural collapse and cracking steel connections damaged widespread equipment damage	Moat et al, 2000
	Packaging, manufaturing and storage			1 week full capacity after 1 month		0.35g alluvial deposits	structures 15% equipment < 10% stock 50%	racking of steel frames failure of brace connections widespread toppling of stacked product collapse of masonry fire wall	Moat et al, 2000
	Petrochemical, refining and storage			60% capacity for 12 months		0.35g alluvial deposits	structures 10% equipment 15% stock 30%	RC stack collapsed piping ruptured tank movement and damage+I37 fire extensive equipment damage	Moat et al, 2000

Table 4.5.1. Damage to Industrial Facilities during the 1999 Kocaeli Earthquake (cont.)									
Bastas	Flourescent Tubes	1960's			X-IX	0.3g		*Structural Damage Level 1*	PEER, 2001
								Nonstructural Damage Level 4	
Adapazari Substation	Power				X-IX	04g		*Structural Damage Level 1*	PEER, 2001

Table 4.5.2. Structural Damage Classification (Reproduced from PEER, 2000).

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 I 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, gross distortion of steel frames, large permanent drifts

Table 4.5.3. Nonstructural Classification, (Reproduced from PEER, 2000).

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	

4.5.2. Questionnaires

A form was prepared to aid in gathering data on industrial facilities, which experienced Kocaeli earthquake. The form consisted of parts on general information about the facility, on direct damages, damages due to business interruption and on the details of damages sustained by each building in the facility and its contents. A typical form can be seen in Appendix #.

The forms were sent out to about 100 firms altogether. We received substantial support from Marsh-Istanbul in this task. Marsh Mc contacted 26 of its customers. In addition to that, they have contacted 36 firms, which are known to have damage due to the Kocaeli earthquake. In particular we would like to acknowledge the assistance of Mr Mert Yucesan (CEO) and Mr. Serkan Cimilli of Marsch Sigorta ve Reasürans Brokerliği A.Ş., Istanbul.

We received totally or partially completed forms from 43 firms. The compilation of this information can be seen in Table 4.5.4. Fully completed forms were received from only 11 firms. The information, which the majority avoided to provide was the total replacement values of building, machine and equipment, and stock. Indeed, this information was the crucial one in the assessment of percent losses. Still, returned forms provided significant data, details of which are shown below.

The percent losses sustained by facilities regardless of industrial sector can be seen in Figure 4.38 against intensity. In the figure we have also used the data provided by Moat et al (2000) on percent losses for a series of industrial facilities. Losses to buildings, machine and equipment and stock as a percentage of their total replacement value are provided in Figure 4.38. The majority of information available is from intensity zone IX. The sectoral breakdown of losses for intensity zone IX is presented in Figure 4.39.

Business interruption losses as a percentage of the annual turnover are summarized in Figure 4.40 against intensity regardless of the sector. Time required for an industrial facility to return back to normal operation can be seen in Figure 4.41 with respect to intensity.

Losses due to business interruption for intensity zones for all intensity zones, that is VIII and IX, are shown in Figure 4.42, along with business losses in zone VIII only and zone IX only displayed separately. Time to normal operation is displayed in Figure 4.43 for facilities in intensity zones VIII, IX and X. The same information is given in Figure 4.44 for zone VIII and IX in two separate subfigures.

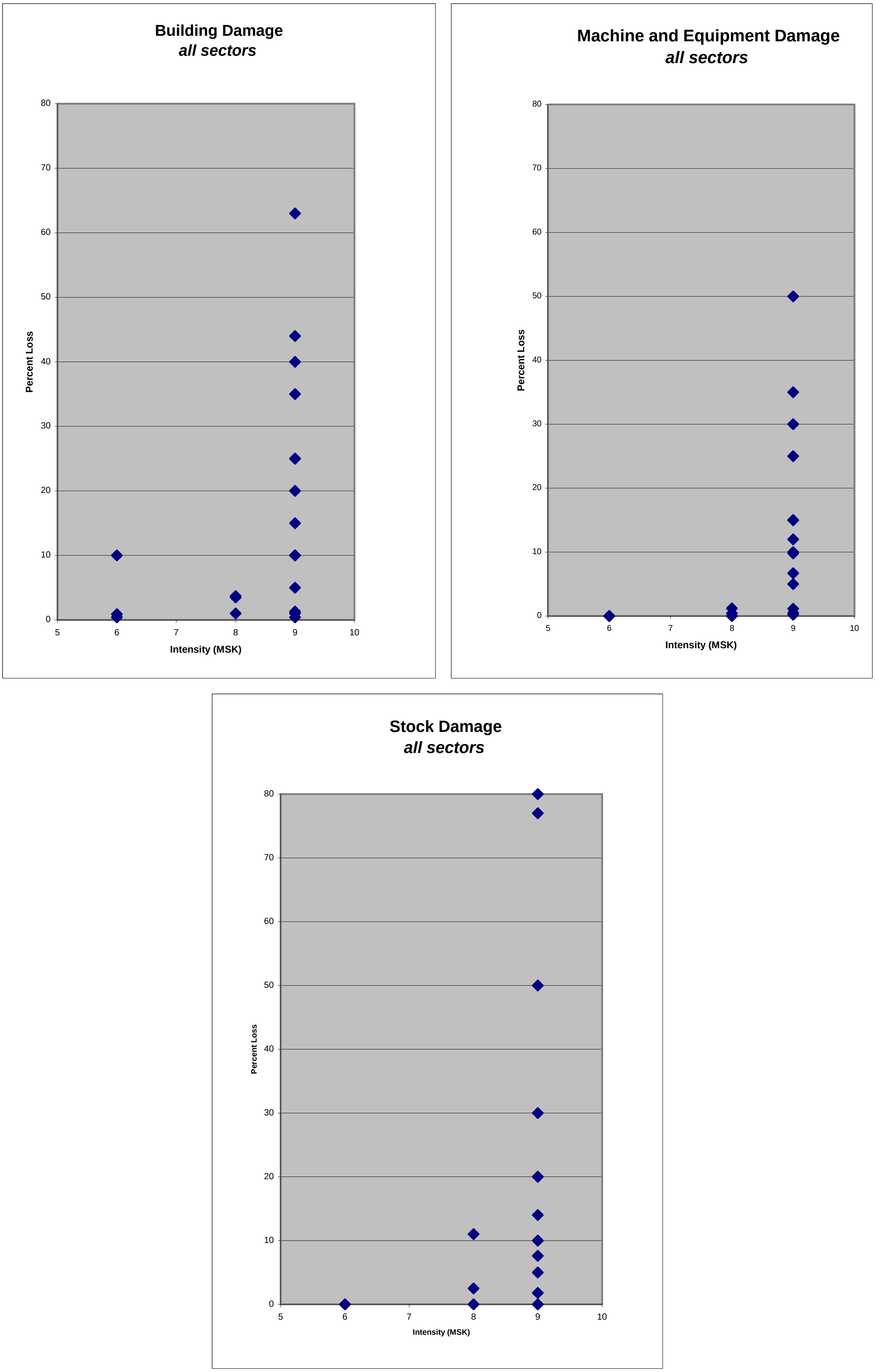
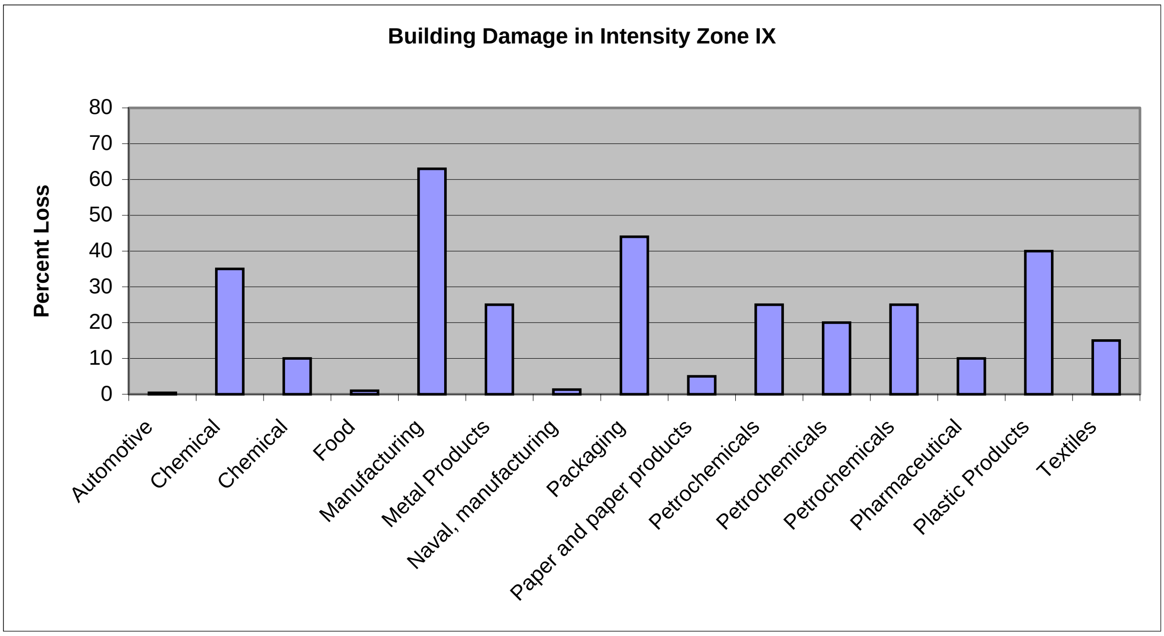
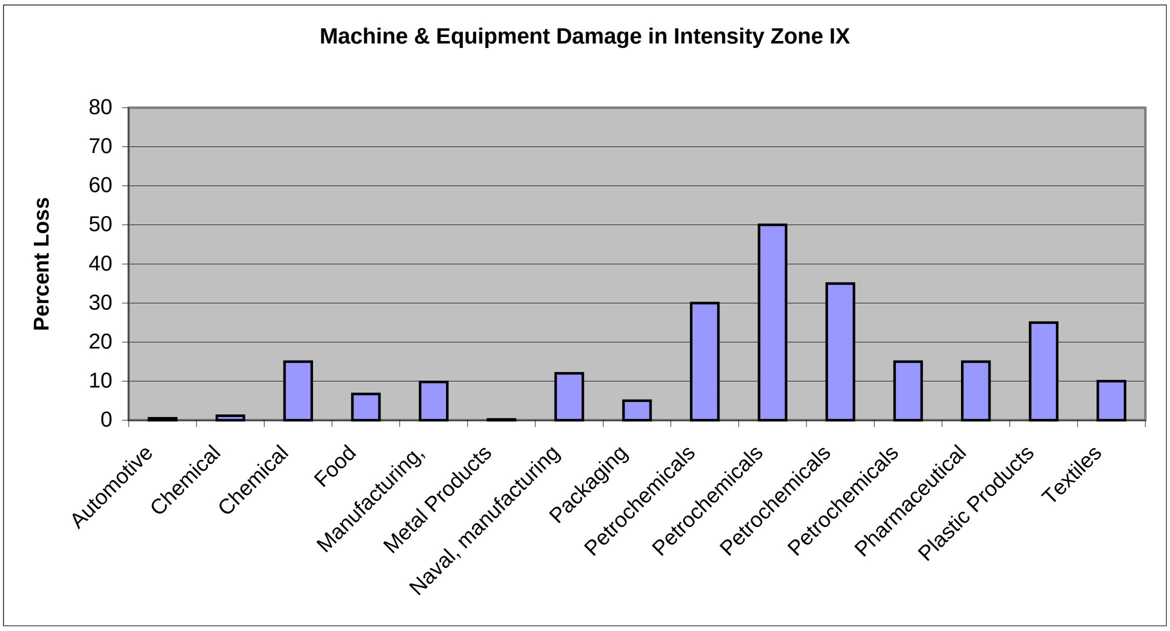


Figure 4.38. Percent losses to industrial facilities during the 1999 Kocaeli earthquake; building, machine & equipment, stock.





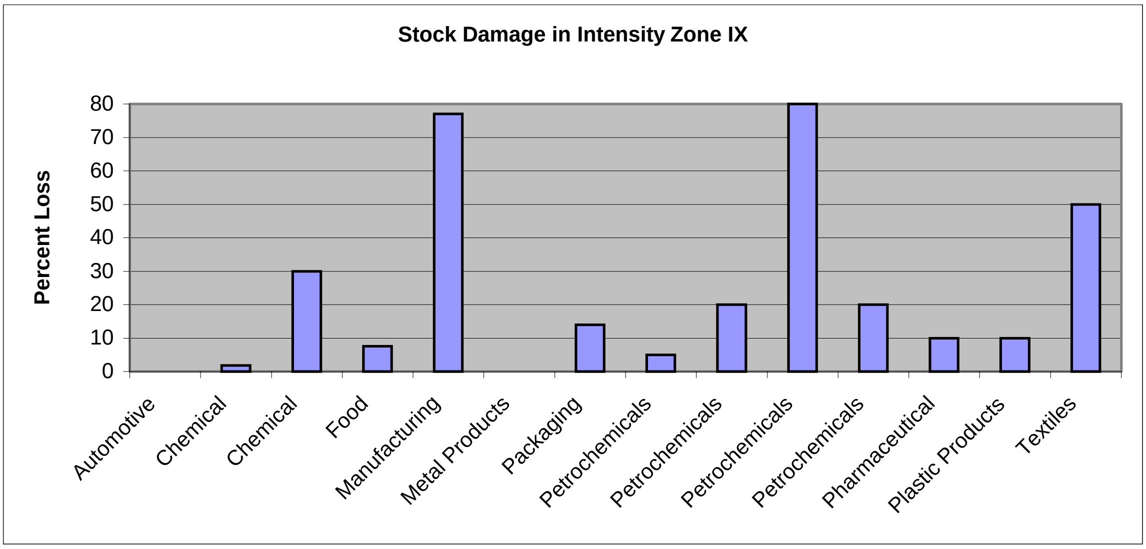


Figure 4.39. Earthquake losses in intensity zone IX on sectoral basis

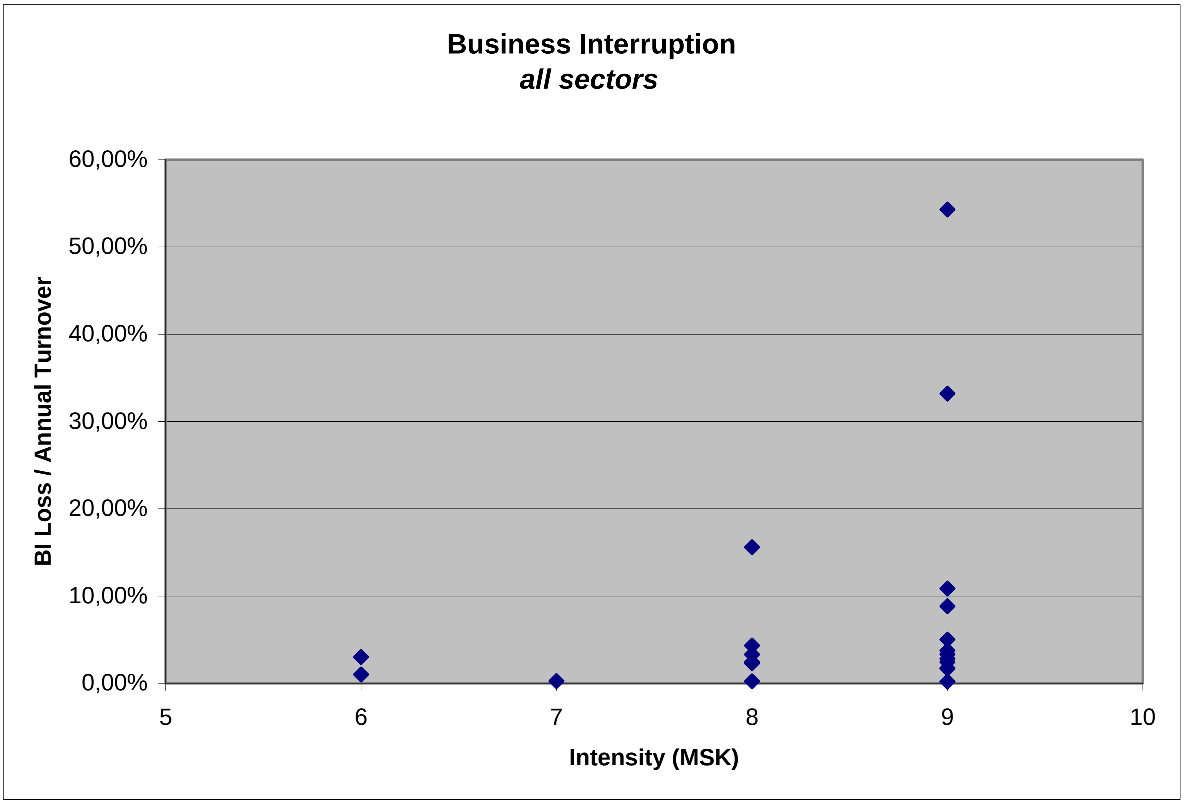


Figure 4.40. Business interruption losses in terms of BI Loss / Annual Turnover, all sectors

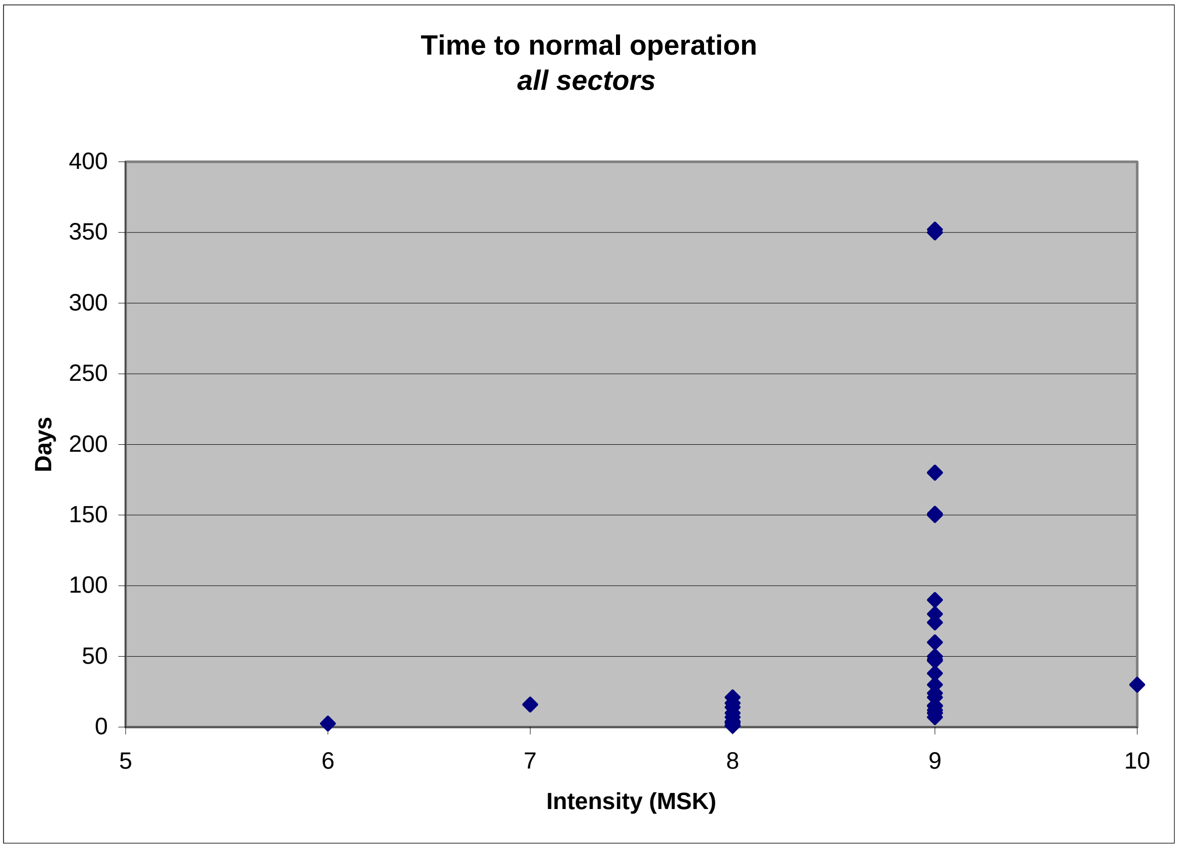


Figure 4.41. Time to normal operation, all sectors.

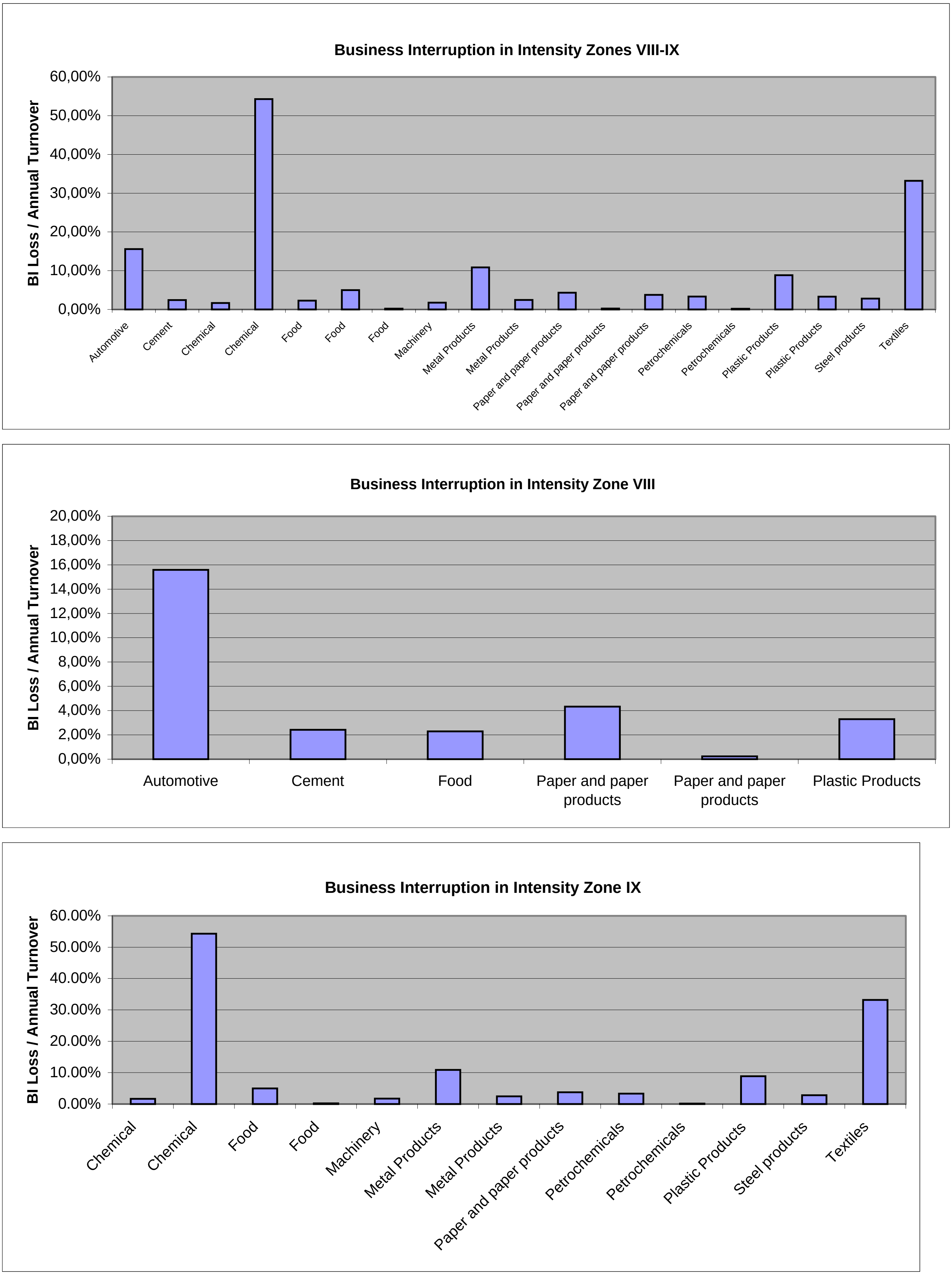


Figure 4.42. Business interruption losses on a sectoral basis for intensity zone VIII-IX (top), VIII (middle) and IX (bottom)

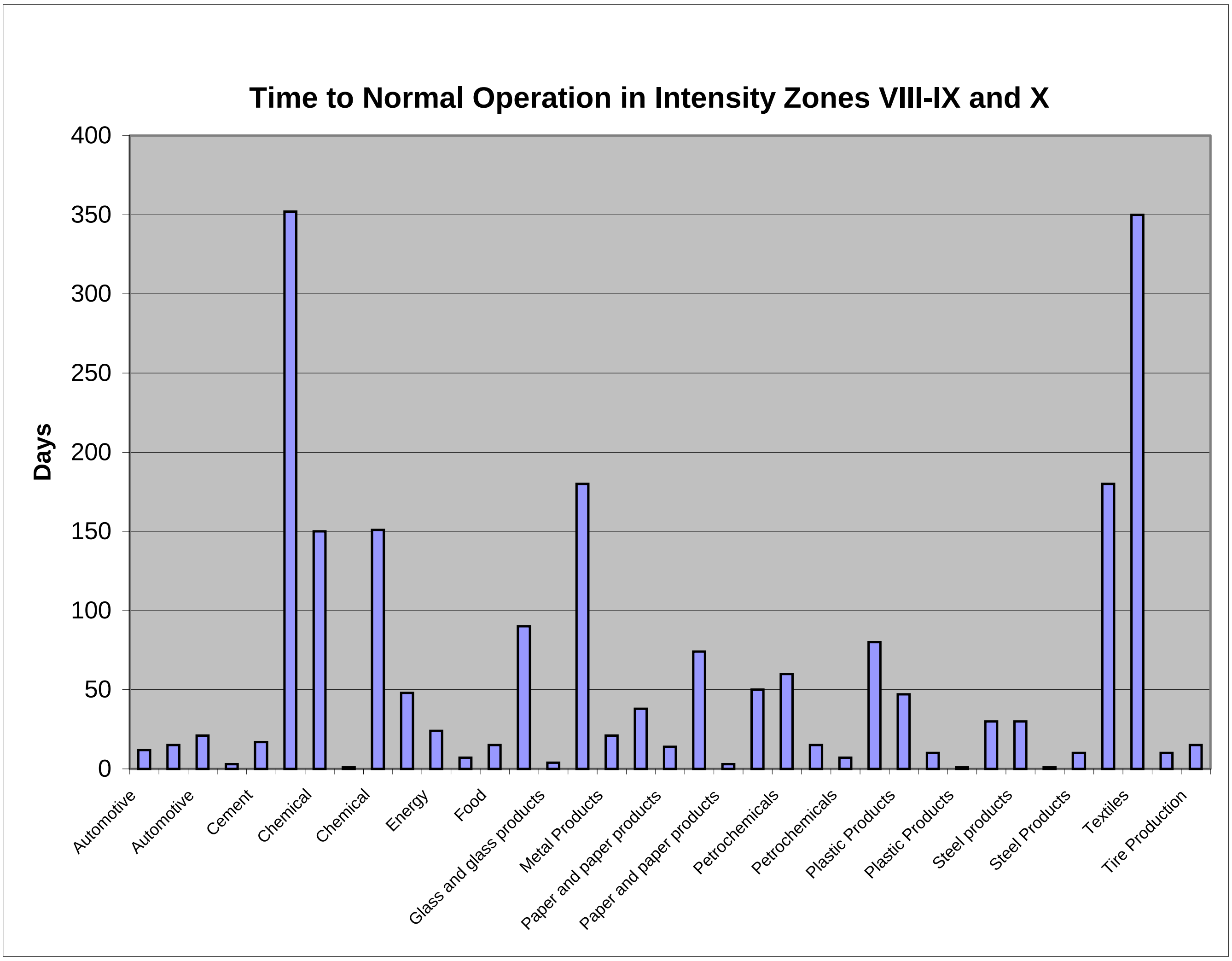
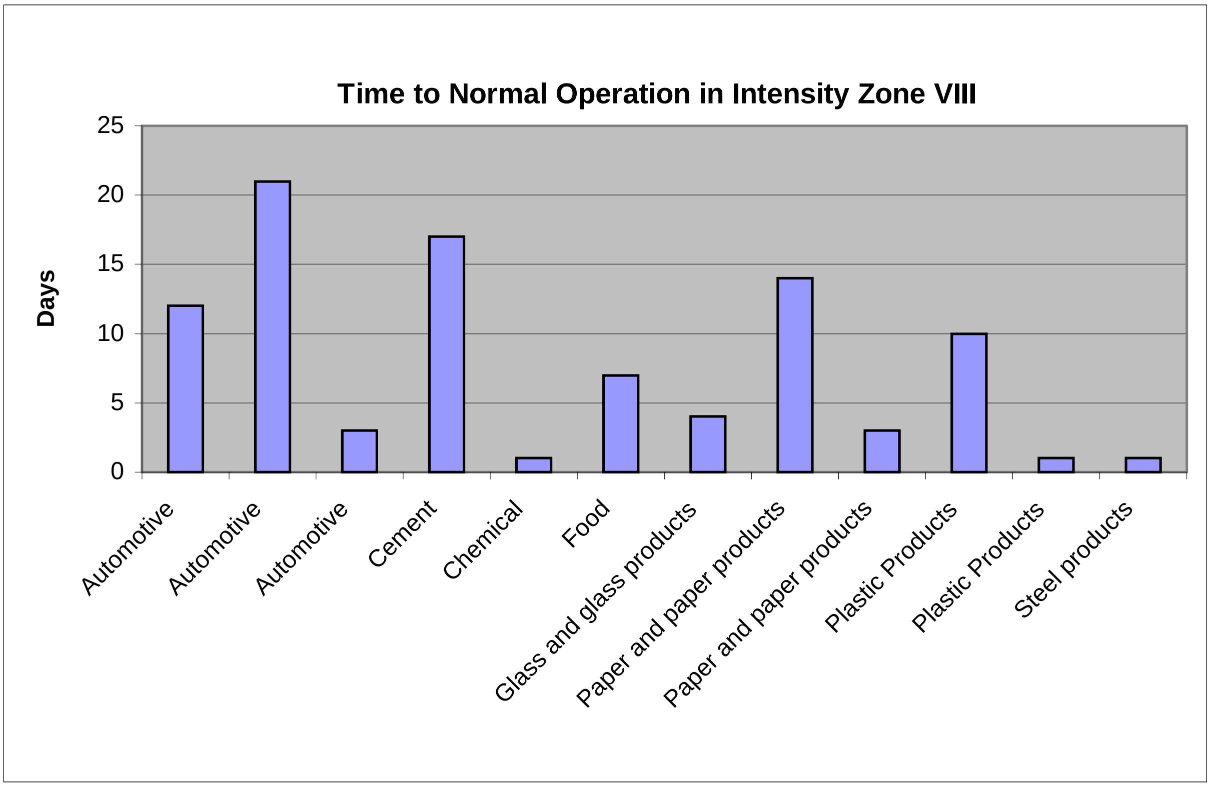


Figure 4.43. Time to normal operation in intensity zones VIII, IX and X on sectoral basis.



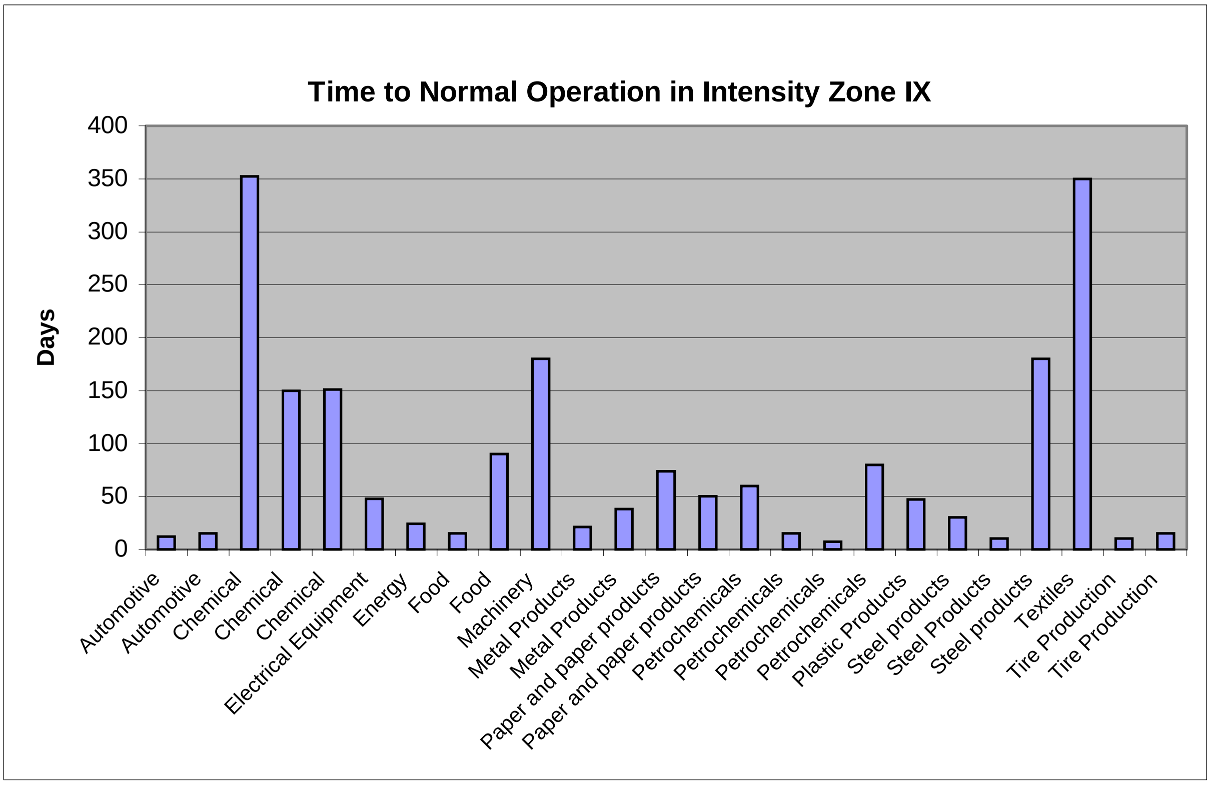


Figure 4.44. Time to normal operation in intensity zones VIII (top) and IX (bottom) on sectoral basis.

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