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Report on Damage of Industrial Facilities in the 1999 Kocaeli Earthquake, Turkey

Kohei Suzuki*

Abstract

The author got a chance to visit Turkey for investigating the damage of industrial facilities in the 1999 Kocaeli Earthquake which occurred on 17, August 1999 in the Kocaeli province of Turkey.

This report provides a brief investigation obtained through the seismic damage survey, particularly, focused on the damages to industrial facilities. The epicentral area in the Kocaeli province is the most industrial region of Turkey. Severe excitation attacked this region and industrial plants and structures got more or less damages. Since the author could only visit a few sites, the report mainly describes the damages of two plants; TÜPRAS oil refinery where big fire occurred and TOYOTA–SA car manufacturing factory where no significant damage appeared.

1. Introduction

A great earthquake with a magnitude of Mw=7.4 occurred at 3:02 a.m. on 17, August 1999 in the Kocaeli Province of Turkey. Fig.1 shows an attacked area around the epicenter. This area is called "Marmara Region" from the name of Marmara Sea. A part of the right-lateral strike slipped along the North-Anatolian Fault in east-west direction for about 100 km. This earthquake is officially called Kocaeli Earthquake. The earthquake caused disastrous damage to a huge number of buildings resulting in significant casualties in the provinces such as Istanbul, Kocaeli, Sakarya, Bolu, Bursa and Yalova. According to a preliminary report, the earthquake caused the loss of more than 17,000 lives and injured more than 30,000 people and collapsed about 34,000 buildings and houses totally. Also, this earthquake caused significant structural damages in Gölcük, Izmit, Gebze, Yalova, Adapazari and the suburbs of Istanbul, whose location are shown in Fig.1. Estimated economic lost due to only structural damages is about 6 billion US dollars.

The joint investigation mission organized by 3 teams from Japan Society of Civil Engineers (JSCE), Architectural Institute of Japan (AIJ) and Japan Geotechnical Society (JGS)

* Graduate School of Engineering, Tokyo Metropolitan University

conducted a field investigation in the damage area from September 5 to 12. The author joined the JSCE team as a special participant from Japan Society of Mechanical Engineers (JSME).

This report provides a preliminary investigation obtained through the damage survey, particularly, focused on the damages to industrial facilities. The epicentral area in the Kocaeli province is the most industrialized region of Turkey and industrial facilities include petrochemical plants, pharmaceutical firms, car manufactures, tire companies, paper mills, steel fabrication plants and so on. Although these plants or firms got more or less damages to some of facilities, the author could only visit a few sites including TÜPRAS oil refinery and TOYOTA–SA car manufacturing factory. Therefore, this report mainly describes the damages to both plants and gives a brief survey on the damage to other industrial facilities.

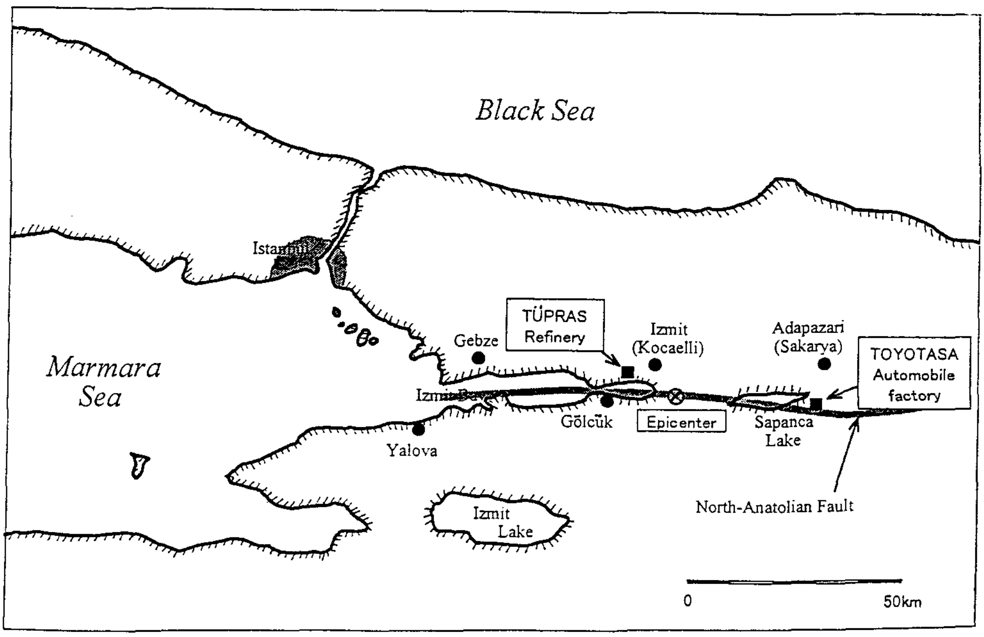


Fig.1 Damaged Area in Marmara Region

2. Damage to TÜPRAS Refinery

The most widely publicised and spectacular damage occurred at the massive TÜPRAS refinery in Yarymca. This refinery is the largest one accounting for about 1/3 of Turkey's oil, and is a major supplier to much of the industry in the area. The annual refined petroleum is 270,000 m^3 and it is the 7th largest plant in Europe. The plant was designed and constructed in 1961 by the US firm called CALTEX (now defunct). Fig.2 shows an aerial view of the refinery.

The refinery is located along the shore at Tütünçiftlik of the western Kocaeli province as shown in Fig.1. The ground was firm and no significant ground failure occurred except some liquefaction at re-claimed land during the earthquake.

The refinery has three crude oil- and three vacuum distillation units, three hydrodesulphurisation (kero-diesel) units, one hydrocracker, two unifer/reformer units, two FCC units, one isomerization unit, one asphalt unit, one sulphur recovery unit, one isopentane

Fig.2 Aerial View of TÜPRAS Izmit Refinery

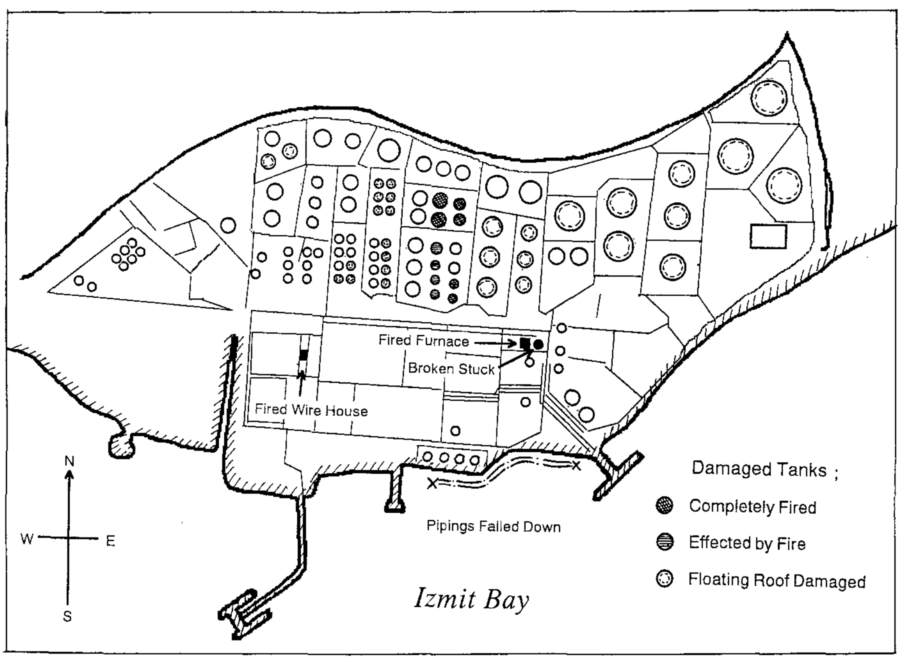


Fig.3 Plan View of Izmit Refinery and Location of Damaged Facilities

unit, one naphtha sweetening unit and related utility units. The products are naphtha, gasoline, jet-oil and kerosene and others. The 860,000-ton crude oil is stored in 14 large cylindrical tanks and 840,000-ton semi-products are stored in 86 middle and small size cylindrical tanks. Fig.3 shows an outline of the refinery in which location of the fired and damaged tanks are described.

2. 1 Damage State of Refinery

(1) Fire at Tanks with Floating Roofs

6 cylindrical tanks having floating roofs caught fire immediately after the earthquake. Out of 6 tanks, 4 middle size tanks has a diameter of 20-25 *m* and 2 small size tanks has a diameter of about 10 *m*. Naphtha in the middle size tanks were completely burned. Tanks were damaged as a result of thermal deformation. The estimated naphtha is about 36,000 ton. Fig.4 and 5 show the deformed state of burned tanks.

The fire in a naphtha tank farm was considered to be initiated by sparks created by bouncing of the floating roof against the inner walls of the tank during the earthquake. Sparks ignited the naphtha. There were 46 tanks with floating roofs and among them those of 30 tanks were damaged independent of the size of tanks. Most of tanks were constructed in the early 1960s according to the earthquake design code of California for a Level 4 ground shaking. In addition to cylindrical tanks, there were some spherical tanks in the plant. None of these was damaged. As seen in Fig.6, the piers and bracing of these spherical tanks shows no visible damage. Therefore, they should have had enough resistance strength against the ground shaking during the earthquake.

As seen in Fig.7, the upper part of a tank with a fixed roof near a burned tank was deformed as a result of thermal pressure caused by fire rather than sloshing.

The fire at the tank farm was completely extinguished on August 20, 4 days after the earthquake.

(2) Fire due to Collapsed Stack

The collapse of one of stacks in the crude oil distillation unit caused fire also just after the earthquake. One of the collapsed stack parts directly hit an upper super heater unit having high temperature of more than 500 ℃ . The height of 5 stacks which were built in 1981 ranges from 90 *m* to 115 *m*. Fig.8 shows a collapsed stack together with undamaged stacks. Crumbled stack shown as Fig.9 was initially 105 *m* high. However, it is difficult to estimate that the main cause of the collapse of the stack is only resonant response to ground shaking since other stacks having similar height were undamaged. Investigators at TÜPRAS explained the main reason of collapse might be associated with material degradation of inner wall of the stuck as a result of corrosion due to alkali gases such as hydrogen sulfide gas. Fig.10 shows fired heater unit by getting the hit of collapsed stack. The fire of this unit extinguished at the night of August 17. While extinguishing the fire at this unit, the fire in the tank farm became very strong and unmanageable. Another part of collapsed stack hit the pipe-rack which was arranged near the damaged unit. Fig.11 demonstrates the damaged pipe and pipe-rack.

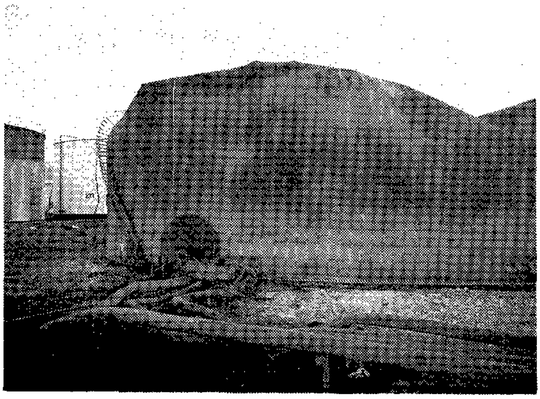


Fig.4 Burned Cylindrical Tank (1)

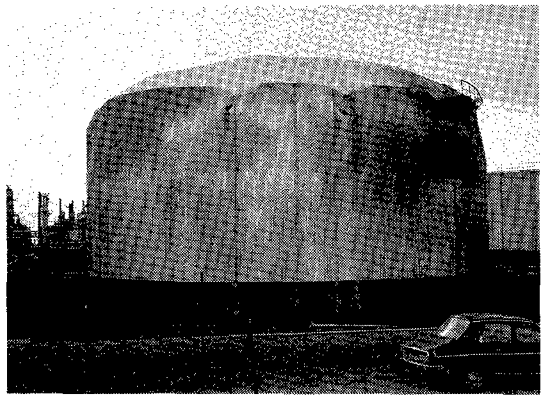


Fig.7 Deformation of Cylindrical Tank with Fixed Roof

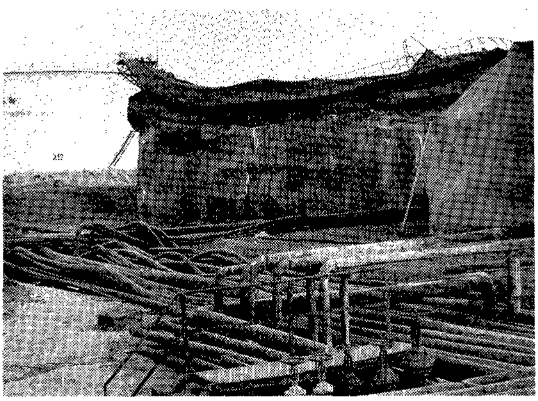


Fig.5 Burned Cylindrical Tank (2)

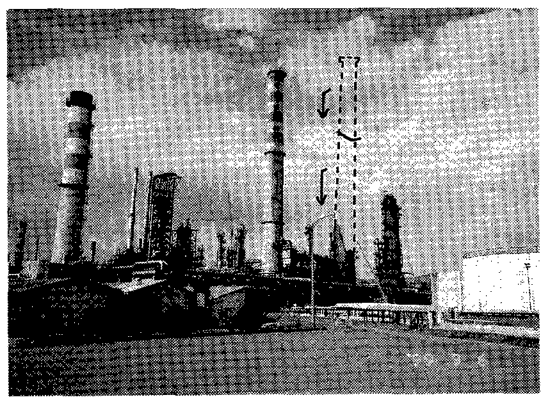


Fig.8 Collapsed Stack and Undamaged Stacks

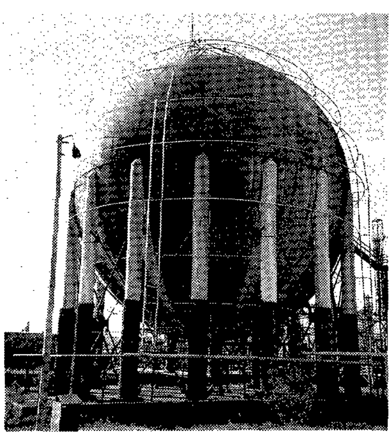


Fig.6 Undamaged Spherical Tank

Fig.9 Crumbled Stack

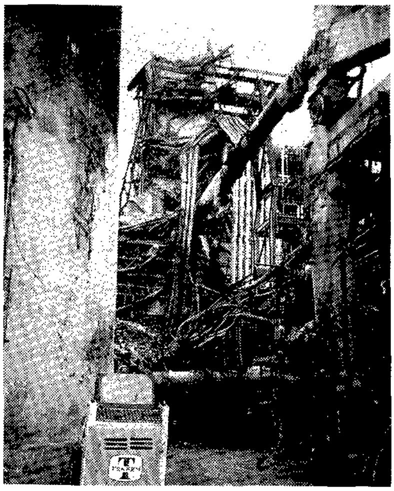


Fig.10 Damaged Oil Furnace Hit by the Collapsed Stack Part

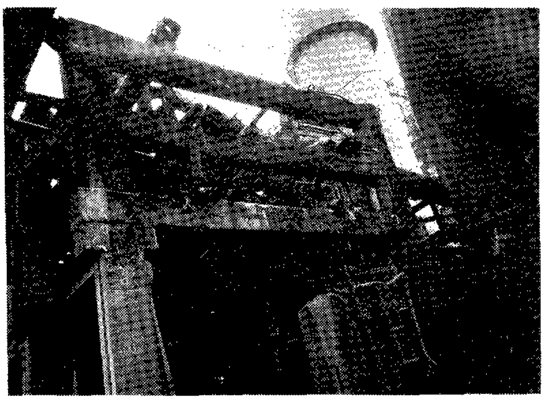


Fig.11 Damaged Piping and Pipe-support Structures Hit by the Collapsed Stack Part

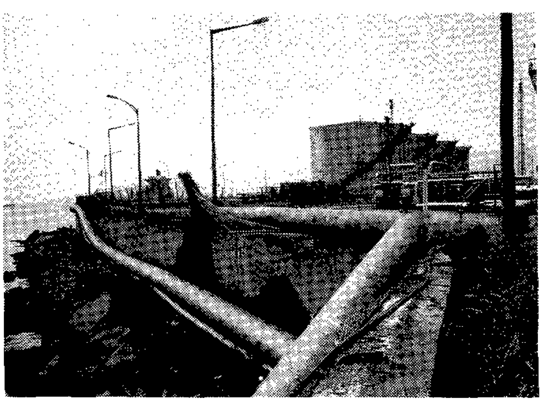


Fig.12 Piping Falling from the Embankment Wall

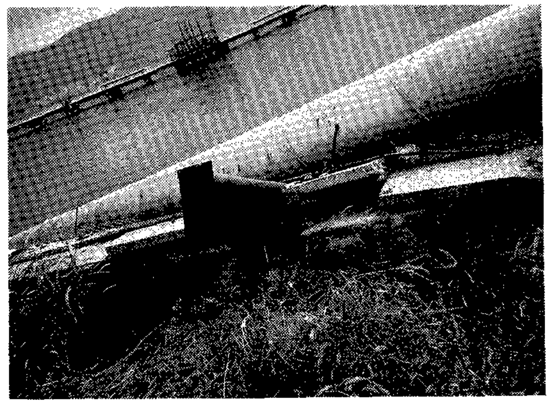


Fig.13 Tilted Pipe Support on the Embankment Wall

Fig.14 Damaged Pipings by the Tank Fire

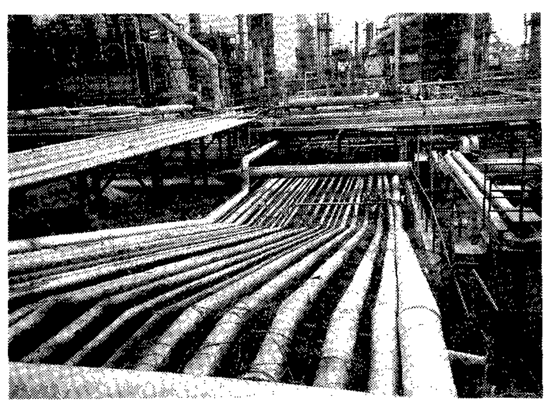


Fig.15 Completely Undamaged Pipings

(3) Other Damages

Another fire started at the tele-communication room. However, this fire was quickly extinguished. Several concrete pipe supporting structures were broken. However, piping had no damage and the damaged concrete structures were reinforced by steel elements.

The pipes having a diameter of about 700 *mm* installed over a concrete embankment were fallen towards the sea-side as seen in Fig.12 for a length of 150 *m* due to the tilting of supporting device as in Fig.13. Nevertheless, the pipes got no serious failure such as breakage and rupture. As shown in Fig.14, there was no severe damage to pipings around the area near oil refineries except to those damaged by the fire shown as in Fig.15. However, some failures were observed at pipe joints in the area of sea side where the supporting structure somehow moved due to the earthquake as shown in Fig.16.

The officials of the TÜPRAS stated that the total damage was about 500 million US dollars. Within one year, it was said that the plant would fully recover.

2. 2 A Back Analysis of Tank Fire

As explained in 2.1, the fire in a tank was presumed to be resulted from an ignition of naphtha caused by sparking as a result of bouncing of the floating roof with the inner side of the tank wall. The fire occurred in tanks having a diameter of about 20 *m* while no fire occurred in tanks having a long diameter like 100 *m*.

The natural period of first mode of sloshing can be caluculated referring to the liquid height H and tank diameter D by the following formula

$$T=2\pi\sqrt{\frac{D}{g}\frac{1}{3.68}\coth\left(\frac{3.68H}{D}\right)} \qquad \text{......(1)}$$

The units of D and H are m and the unit of gravitational acceleration g is m/s^2. This formula is used in No.515(1981) earthquake design code of Japan Ministry of International Trade and Industry (MITI) for high pressurized gas facilities to estimate the sloshing natural periods of cylindrical tanks during seismic excitations (The code was revised after the Kobe Earthquake (1995) as No.143 which include design code for piping.).

Table 1 shows the fundamental sloshing periods of tanks whose diameter ranges between 10 *m* to 100 *m*. The sloshing period of the tanks with a diameter of 20 *m* is about 4~5 seconds. Fig.17 shows the acceleration record at Izmit site and integrated velocity and displacement of NS component. Fig.18 shows computed acceleration, velocity and displacement response spectra of the record. In the displacement response spectra, dominant peaks can be observed between 3~5 seconds. Therefore, the tanks with a diameter of about 20 *m* are the most likely ones to be subjected to violent sloshing.

Fig.19 shows a rough description of cross section of cylindrical tank with floating roof. Some kinds of sealing devices are installed between outer edge of the floating roof and inner wall of the tank. In Fig.20, typical examples of metallic seal and rubber envelope seal are illustrated. Currently, for almost all tanks rubber envelope type of sealing are introduced in

Table 1 Sloshing Periods of Cylindrical Tank Calculated by eq.(1)

Diameter (m)	Liquid Height (m)	Period T	Diameter (m)	Liquid Height (m)	Period T
10.0	3.0	3.69	50.0	10.0	9.34
	5.0	3.39		20.0	7.80
	8.0	3.32		30.0	7.49
	10.0	3.31			
20.0	5.0	5.49	100.0	20.0	13.22
	10.0	4.80		30.0	11.68
	15.0	4.70		50.0	10.73
	20.0	4.68			

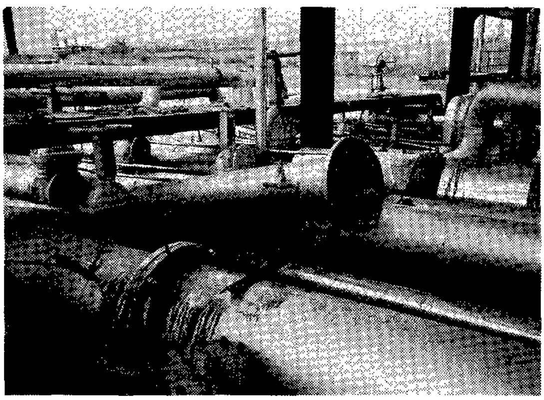


Fig.16 Damaged Pipe Joint due to the Axial Movement

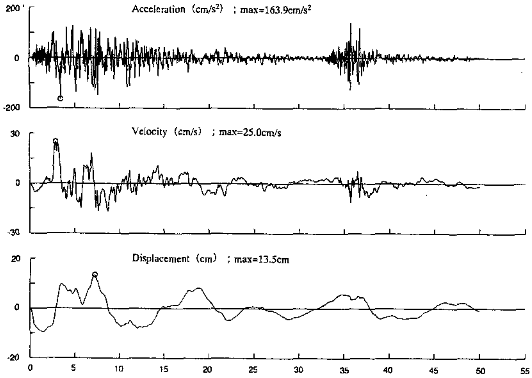


Fig.17 Acceleration Record at Izmit and Integrated Velocity and Displacement of NS Component (Courtesy of Dr. S. Horikoshi, Kajima Construction Co.)

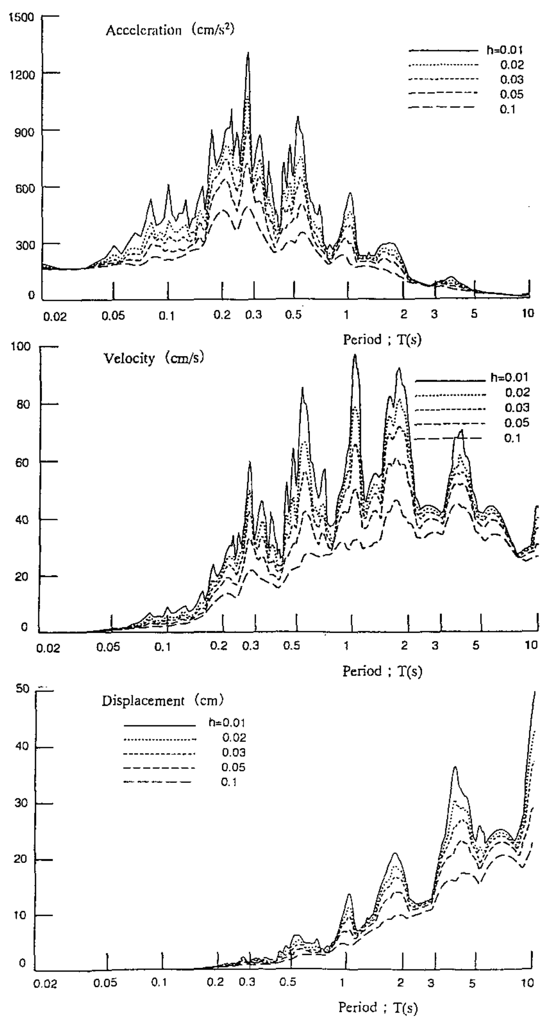


Fig.18 Computed Acceleration-, Velocity- and Displacement Response Spectra of Izmit Record (Courtesy of Dr. S. Horikoshi)

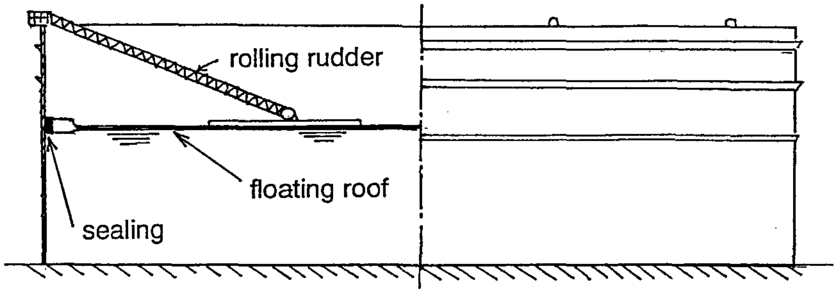
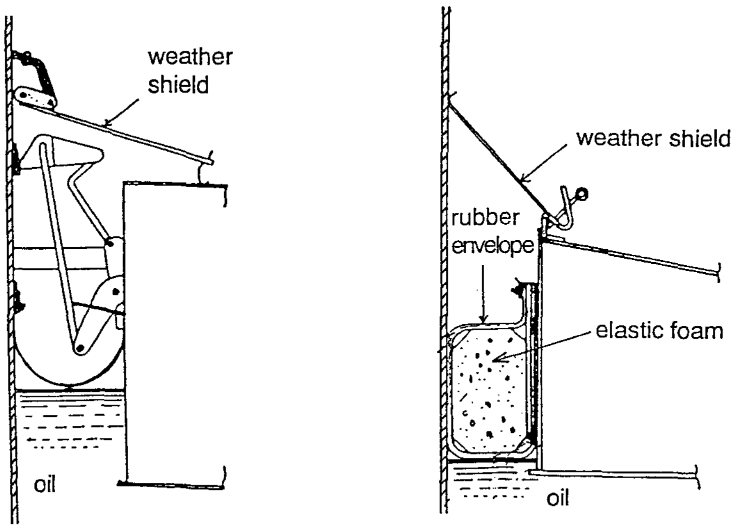


Fig.19 Cross Section of Cylindrical Tank with Floating Roof



(1) metallic seal (2) rubber envelope seal

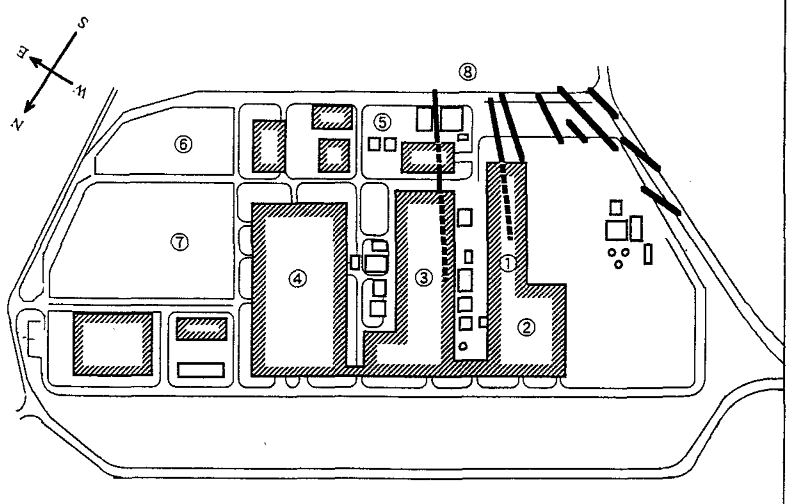
Fig.20 Mechanism of Metallic Seal and Rubber Envelope Seal

order to avoid the spark due to the roof bouncing against the tank wall. However, in 1960s when the tanks in the Izmit firm were constructed, metallic sealings were still introduced. Therefore, it is expected that big sloshing behavior could ignite the naphtha by sparks resulting from the bouncing of the roofs against the walls caused by the seismic excitation.

3. Damages to TOYOTA–SA Car Manufacturing Factory

The name TOYOTA-SA is a combination of the Japanese car maker TOYOTA and Turkish SABANCI Holding, which is a big financial group in Turkey. This factory was constructed in 1994 at the south of Adapazari city and it is close to the Sakarya-Kocaeli province boundary.

Initially, the factory was considered to be built at Gebze where a maximum horizontal seismic acceleration of 264 Gal was recorded at the earthquake. Since 1,000,000 m^2 space was necessary, the plant was eventually moved to the present site. The plant is close to the collapsed Arifiye overpass and the fault crosses the plant site. The maximum acceleration at this plant should be larger than 400 Gal. Although it is not certain, it seems that the fault bifurcates and several ground breaks were observed in the north-east corner of the plant. The plan of the plant locations are shown in Fig.21. In southern area ground breaks appeared described as thick lines. The top 12 *m* layer of the site consists of soft and hard silty sediments. This layer is underlaid by a gravelly layer (SPT value is greater than 50) and silt layer (SPT value is more than 18). The buildings were designed by considering a M 8 class earthquake with a base shear of 0.4g. The allowed displacement was set to 10 *mm*. This value is considered to be vertical relative displacement between adjacent columns. The buildings were founded on piles. The number of 14 *m* long RC precast piles with a square cross section was 3800. Each column is supported by 4 piles and each pile has a H type pure steel column. The flange thickness ranges between 50 *mm* to 125 *mm*. The layout of pipes were designed to have a truss type structure.



① Press Shop ② Welding Shop ③ Paint Shop ④ Assembly Shop
⑤ Switch Yard ⑥ Container Yard ⑦ Car Pool Yard ⑧Pipe Buried Area

Fig.21 Plan View of TOYATA-SA Automobile Factory

3. 1 Damage State

(1) Damage to Building and Piping

Since the ground breaks due to faulting pass through the north-east part of the plant, the floor and side-walls of press shop and welding shop ① in Fig.21, and welding shop ② were deformed. Nevertheless, this damage could not cause any obstruction to the production. Pipes for water, electricity and fire extinguishing were broken or damaged as a result of ground breaks. Water pipes had a diameter of 400 *mm* and made of concrete. Fire extinguishing pipes are steel and had a diameter of 200 *mm*. The pipes were ruptured at connections or valves in the area ⑧. Fig.22 and 23 show a mended pipe connection and damaged valves, respectively. The boiler for car drying after painting uses natural gas. No damage to the natural gas pipeline was reported. Among 30 buildings, two buildings with concrete roofs were only damaged. The damage was concentrated at the bottom and top connections of the columns. The roof was displaced about 10 *cm*. The side-walls of the factory is made of poly-uretan sheets and no brick clad walls are used. Some of windows in roof were fallen and plastering in walls were peeled off. In addition, some slight damage to steel structures was observed.

(2) Damage to Facilities and Machinery

Out of 2 transformers located in ⑤, one transformer was fallen as a result of the failure of its supports. Another one was not fallen, however, damaged at the leg as seen in Fig.24. Both transformers are put on rails. Anchors were used to restrain the movements of transformers during ground shaking. These anchors were pulled out of their concrete foundations and the transformers were displaced. 3 cylindrical tanks put horizontally were undamaged. On the

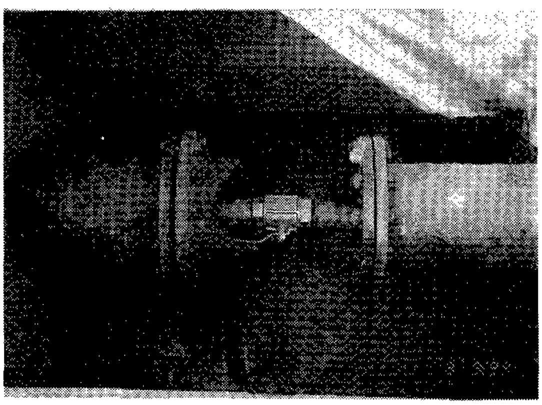


Fig.22 Repaired Embedded Piping Damaged at the Joint

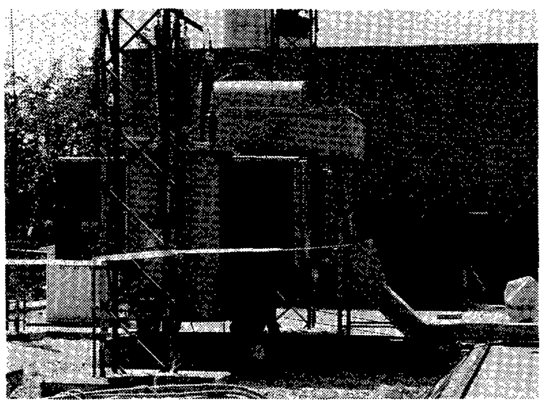


Fig.24 Damaged Transformer (Another one fallen off the supporting rail)

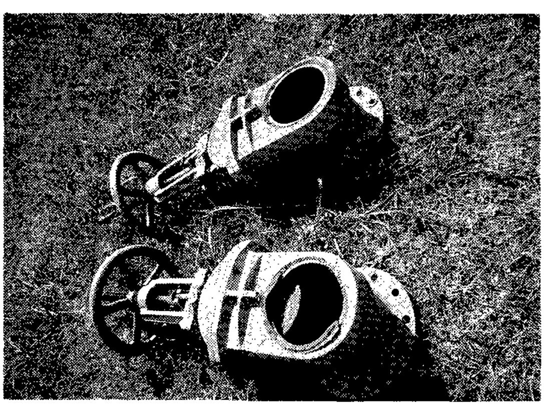


Fig.23 Broken Valves

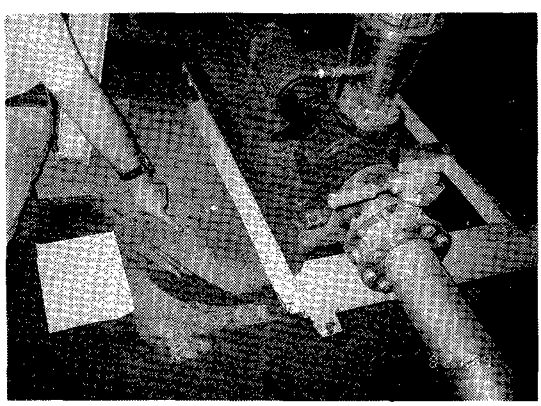


Fig.25 Sliding of Pump and Pipe

other hand, the cooling water tank installed horizontally slided 1 *m* and pipe connections were broken. Also, small pump with piping slided as shown in Fig.25. The ventilator (8 *ton*) in a 9 *m* high building ③ was fallen as a result of breakage of the pin of vibration-proof coilsprings as seen in Fig.26. The guide-rails of roof cranes (10~30 *ton*) with a 20 *m* span become 1~2 *cm* narrower. The parts on the racks were fallen. In addition, the hen-machine was displaced from its rails. In welding shop, the robot for welding was not damaged. However, some kinds of auto-manufacturing machines got tilting as shown in Fig.27.

(3) Other Damages

Since the TOYOTA-SA factory was on summer holiday at the time of the earthquake, the farm was not in operation. Furthermore, no car was suspended during the earthquake. About 80 % of the 658 workers were living in Adapazari and the rest in Izmit. The houses of 139 workers were completely collapsed. The houses of 110 workers were damaged. It was expected that the plant would be in operation at the end of October, 1999 due to the check-up of machineries, control units and finished products. About 1,000 cars in the car-pool yard ⑦ were slightly damaged as a result of bumper-collisions.

4. Damages to Other Industrial Facilities

The author got a chance to visit a petro-chemical plant, PETKIM, which is located at the western side of TÜPRAS. This plant was constructed in 1965 and it produces petro-chemical products such as plastics of various kind, high-polymer fibers, LP gas and benzen. Fortunately, the damage to the plant is said to be very limited. Distinctive damages could be summarized as follows;

(1) Wooden cooling tower structure was totally collapsed and several structure parts of the reinforced concrete cooling towers were damaged.

(2) The jetty of loading-unloading facility of this plant was damaged due to the movement of wharf.

(3) Embedded pipes along the seashore were damaged.

Fig.28 shows the damaged state of wooden cooling tower. Fig.29 shows the damaged columns of the reinforced concrete cooling tower. Pipes suspended to the jetty were fallen for several centimeters. However, they were already repaired at the time of the visit. The officials of this plant said they were more concerned with the housing of their workers since the damage to the plant was quite limited.

In Kosekoi near Izmit, a liquefied gas supplying company called HABAS is located. In this plant, there were cylindrical tanks for liquefied oxigen and nitrogen. These tanks were supported by reinforced concrete columns. Out of three tanks, the columns of the two tanks were collapsed due to earthquake and the tanks sank and inclined. These tanks were storing great amount of liquefied gas while the undamaged one was almost empty at the time of excitation. Fig.30 and 31 show the damaged state of the tanks.

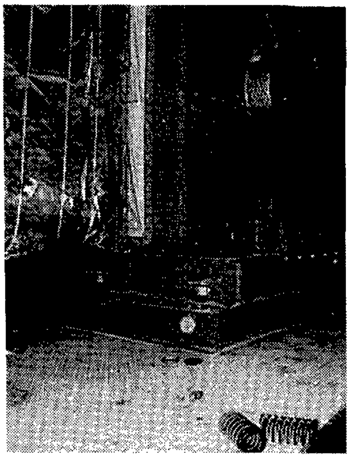


Fig.26 Fall of Large Blower due to the Breakage of Vibration-proof Springs

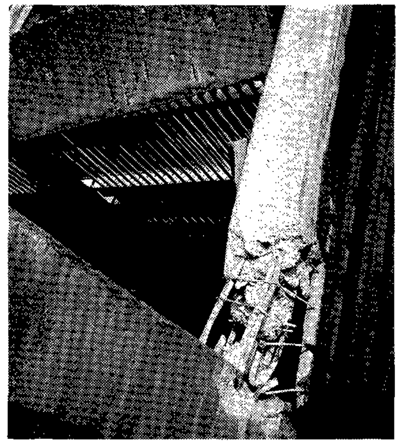


Fig.29 Damaged Support Column of Reinforced Concrete Structure for Colllimg Towers

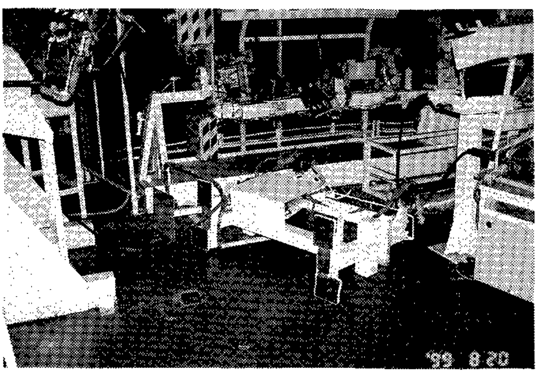


Fig.27 Tilting of Auto-manufacturing Machine

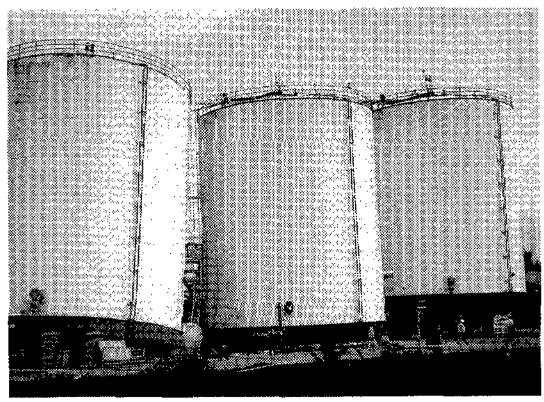


Fig.30 Damaged Liquefied Gas Tanks(left and middle) and Undamaged Tank(right)

Fig.28 Collapsed Wooden Cooling Tower Structure

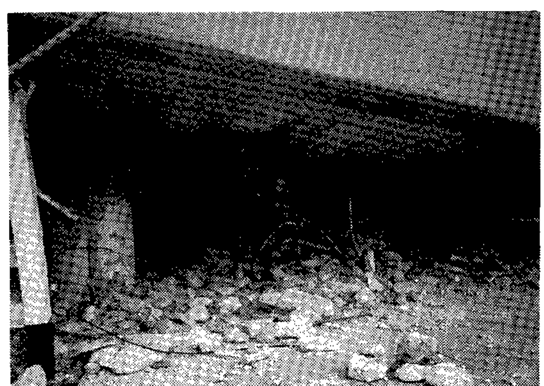


Fig.31 Close-up View of Broken Support Columns of Vertical Tank

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He also acknowledges Dr. Omer Aydan who kindly translated my part into English in the ASCE report relating to the Kocaeli Earthquake. Finally, he appreciates Dr. S. Horikoshi and Dr. Nihat Aksu, for their help in the preparation of this report.

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Key Words（キー・ワード）

1999 Kocaeli Earthquake, Turkey（1999年 トルコ コジャエリ地震）, Oil Refinery（石油精製工場）, Fire（火事）, Seismic Design（耐震設計）, Sloshing（スロッシング）, Oil Tank（石油タンク）, Car Manufacturing Factory（自動車工場）

1999年トルコ・コジャエリ地震における産業施設の被害

鈴木　浩平

東京都立大学大学院工学研究科

総合都市研究　第72号　2000　p.23-37

1999年トルコ・コジャエリ地震は、トルコにおいて最も工業施設や生産プラントが多いIzmit地域を襲った。いくつかの工場やプラントが多大の被害を受けたがその詳細は明らかではない。

著者は、土木学会の被害調査団に加わり、代表的な施設の被害状況を調べることができたのでその概要を報告する。

まず、Izmitにある TÜPRAS という、国営の石油精製プラントで大規模なタンク火災が生じたのでその概要を述べる。火災は3ケ所で生じたが直径が20m規模の中型平底円筒タンクが数基、ほぼ完全に燃焼した。浮屋根のスロッシングによる振動により、タンク内壁と衝突して、着火したとされている。また、硫化水素ガス等により、材料劣化していた煙突が破断し、高温の反応炉を打撃したことによる火災も生じた。

一方、トヨタ自動車との合併会社である TOYOTA-SA 工場は、震源近傍の地域に建設されていたがレベルの高い耐震設計、耐震工法が採られていたため、被害を最小限に止めることができた。

本報告では、多くの写真や図を用いて、産業施設の被害状況と、その事後考察を英文で説明している。