Department of Environment, Land and Infrastructure Engineering

Potential Hazards of a petrochemical plant if subjected to seismic activity

by

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Abstract

The impact of natural hazards which triggers technological accidents at industrial facilities is called Natech event. Natechs have been recognized as an emerging risk for industrial facilities. Adequate preparedness, proper emergency planning, and effective response are crucial for the prevention of natechs and mitigation of the consequences. Even the largest and seemingly well-prepared facilities can be vulnerable to natechs if potential risks are not considered adequately. Risk factors, identified for a seismic activity which strikes an industrial plant, play a significant role in the seismic performance of social systems and in the emergency response after earthquake. Risk factors detection provides fundamental basis for disaster prevention systems design. Earthquake nature, limited resources, few mitigation measures, and lack of efficient communication aggravate the risk factors. Therefore, through analysis of previous occurred earthquakes, we can summarize and enumerate possible risk factors in a seismic activity. The 17 August 1999, Kocaeli earthquake, which was a devastating disaster hitting one of the most industrialized regions of Turkey, offers opportunities in this respect (Girgin, 2011).

1. Introduction

Several accidents in the industrial field in recent decades have proved that natural disasters can cause serious damage to equipment, leading to loss of containment, resulting in significant direct and secondary hazards. In the case of a seismic, the earthquake can cause simultaneous damage to different equipments, and the effect can be amplified due to the safety system failure and the domino effect. For example, Kocaeli earthquake, 1999, in Turkey; Wenchuan earthquake, 2008, in China; Tohoku earthquake and the subsequent tsunami, 2011, in Japan. Seismic loading can cause serious accidents to industrial plants as shown in past several occasions. Although the potential risks of refineries are extensive and uncalculated, it is possible to find out earthquake risk factors values through research, in order to continuously optimize the structure of the refinery and improve the ability of the refinery's overall system to resist earthquakes. Based on analysis of structural direct damage suffered by refinery during an earthquake and on secondary hazards to surrounding environment, this thesis summarizes the potential risk factors of the refinery for seismic events and provides a powerful help for future research and development.

Kocaeli Earthquake in 1999 to Tupras Izmit Refiney is a great representative example for this study. The devastating Kocaeli earthquake hit one of the most industrialized regions of Turkey, resulting in more than twenty-four industrial plants damaged. In particular, the damages to Tupras refinery were very severe; area of the plant, of tanks farm, and of landing place was totally damaged. An example of domino effect caused by a structural collapse was the breakdown of a concrete chimney that caused a big release of dangerous substances and damages to surrounding equipment (Paolacci, Giannini et al. 2012)

Industrial plants are complex systems, and because of the numerous connections, equipment and components, and operational complexity, they are particularly susceptible to earthquakes (local vulnerabilities). The chapters 2 and 3 introduce the complex characteristics of chemical plants regard the aspects of process flow and of physical units which are basic components of the refinery. The chemical processing and its corresponding facilities and equipments in the petrochemical plant are basic understanding for risk factors. The processing is mainly divided into four categories: separation, conversion, treatment, and blending. In these four main operational steps, they are further subdivided into other specific chemical units due to different division of labor by understanding the chemical processing, it is possible to figure out the physical units related to production procedures.

After understanding the refinery structure, the risk factors of the refinery system subjected to the earthquake are explained by analyzing the specific situation of the Izmit refinery, reviewing the collected studies the past few years. In general the risk factors for large chemical plant subjected to seismic activities include (a) structure design; (b) real-time monitoring; and (c) post-earthquake community behavior; The fifth Chapter of the paper provides a more detailed analysis of those risk factors. The presented lessons, learned from case study of Tupras Izmit Refinery, can be useful as well for other industrial plants located in high seismic risk areas.

2. Chemical Processing in a Petrochemical Plant

Petrochemical plant is an industrial process plant where crude oil is transformed and refined into more useful products such as liquefied petroleum gas(LPG), Naphtha, Gasoline, Jet fuel, Kerosene, Diesel Fuel, Heating Oil, Fuel Oil and Asphalt (James G,2006).

Chemical processing mainly consists of four operational steps, which are separation, conversion, treatment and blending. This chapter will briefly describe which components are in each step.

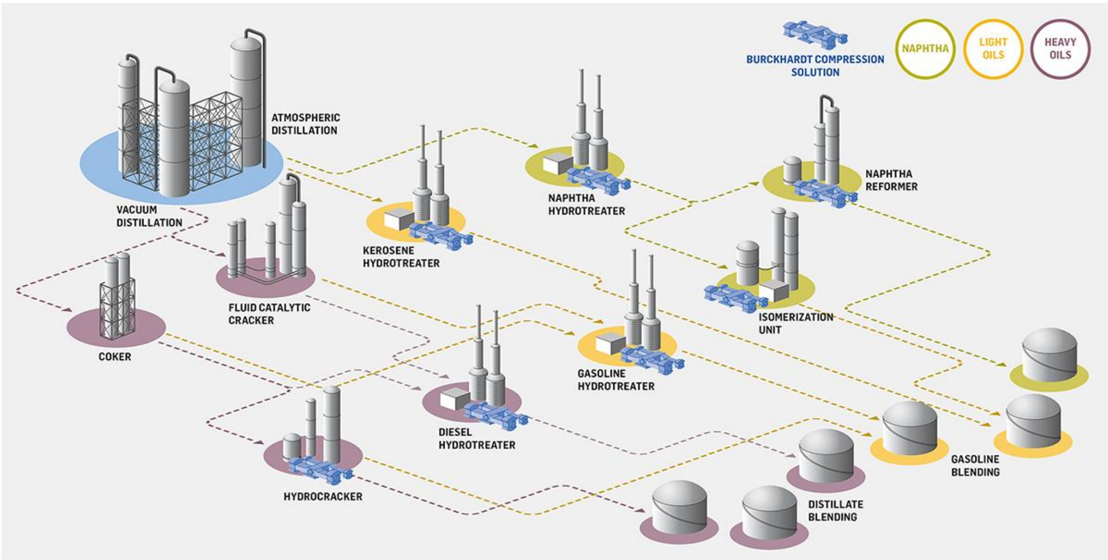

Figure 2-1 Crude oil refining process (*https://www.burckhardtcompression.com*)

2.1 Separation

Crude oil is the naturally occurring liquid form petroleum. Once raw crude oil arrives at the refinery terminal by pipeline or other transportations, they are pumped into above-ground storage tanks which are floating roof or fixed roof tanks which are floating roof or fixed roof tanks with capacities of thousands to millions of gallons.

2.1.1 Dewatering & Desalting

Petroleum is typically produced as a water-in-oil emulsion. The water must be removed (down to a level of < 1 %) in a process usually called demulsification or dehydration which consists of forcing the coalescence of water droplets and producing their separation by settling (Atta, 2013). While crude oil stored in tanks, separation naturally occurs with water collecting at the bottom of the tank below the oil. Then water was drawn off the bottom and delivered to water treatment.

Inorganic chlorides, suspended solids, and trace metals found in untreated crude must be removed by chemical or electrostatic desalting. This reduces the risk of acid corrosion, plugging, fouling and catalyst poisoning in downstream units (Magnetrol, 2018).

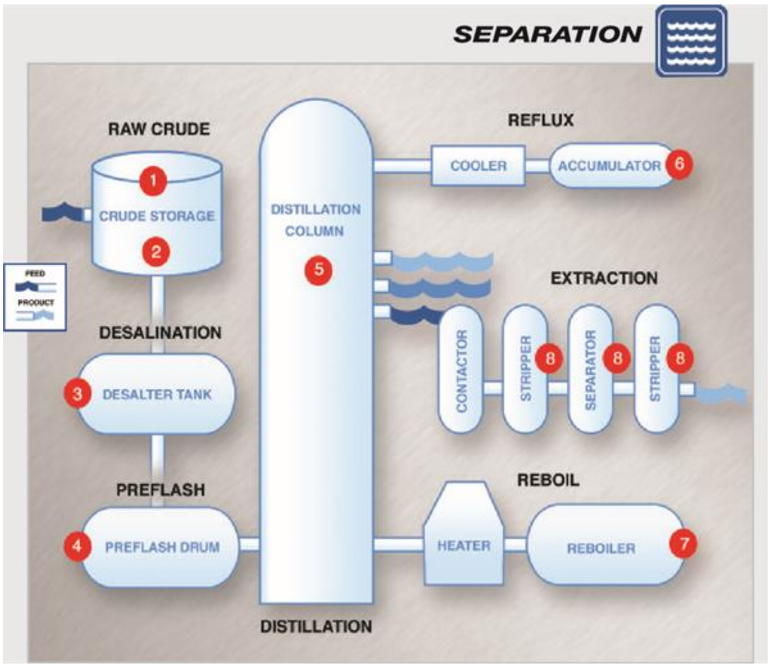

Figure 2-2, separation processing components (*www.magnetrol.com*)

2.1.2 Preflash Drum

Desalted crude oil flows to distillation columns through preflashing sections. they are used to manage crude hydraulics during grass roots crude unit designs and to increase crude capacity when revamping. (Scott W. Golden, 2005)

Preflash drum system separates the vapors generated by preheating before entering the heater or atmospheric column. This prevents higher heater firing or pressure drops and reduces vapor loading of the column to avoid flooding (Magnetrol, 2018).

2.1.3 Distillation

It is also known as crude distillation unit(CDU) and vacuum distillation unit(VDU), the crude is heated to vaporize at the column bottom with the temperature of 350°C to 400°C. The vapors rise inside the column while heavy residuals remain at the bottom which cannot be vaporizing. As the height rises inside the column, the vapors becomes more and more light and has been collected to different trays. Only gases reach the top, where the temperature dropped to 150°C.The heavy residuals left after atmospheric distillation still contains many medium density products. The residuals are transferred to the vacuum column where a second distillation is carried out to recover the middle distillate, such as heavy fuel oil and diesel.

2.1.3.1 Distillation Column

Atmospheric distillation column (ADU) and Vacuum distillation column (VDU) are the main primary separation processes and most important part of refinery, where fractional distillation separates hydrocarbons into separate streams, cuts or fractions. This process relay on the vapor pressure characteristics of liquid mixtures, and they are consist of several components, each of them is used either to transfer heat energy or reinforce material transfer.

A typical distillation contains several major components:

1. A vertical shell in which separation of liquid components
2. column internals such as trays, plates, packings, for enhance component separations;
3. a reboiler to provide the necessary vaporization for the distillation process, this improves separation by introducing more heat into the column. (M.T. Tham and R.C. Costello, 2018);
4. a condenser to cool and condense the steam leaving the top of the column;
5. An accumulator for holding condensed steam at the top of the column so that reflux can be recycled back to the column

2.1.3.2 Solvent Extraction

The heavy fraction remaining following the distillation of crudes is called petroleum residuals. A variety of solvent-extraction processes yield deasphalted oil from these residuals. These oils serve as downstream feedstocks for catalytic crackers and hydrocrackers (James G,2006).

2.2 Conversion

There are still many heavy hydrocarbon molecules remaining after the separation process. In order to achieve lighter products, the heavy molecules are "cracked" into two or more lighter ones. This process converts 75% of the heavy products into gas, gasoline and diesel, which is carried out at 500°C. (Gary, James H, 2007)

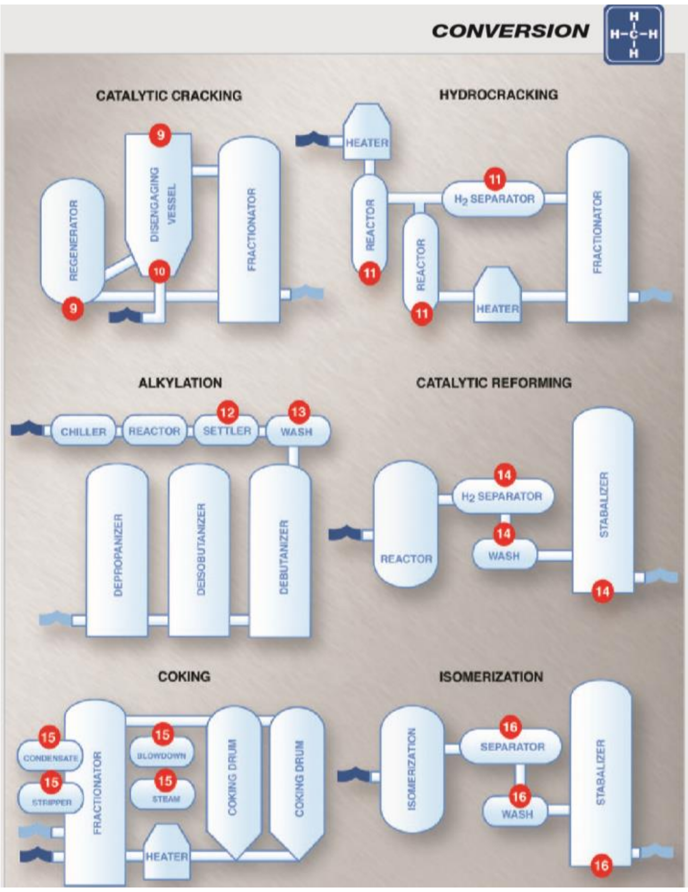

Figure 2-3, conversion operation components (*www.magnetrol.com*)

2.2.1 Catalytic Cracker

Fluid Catalytic Cracking Units (FCCUs) are a secondary conversion operation within more complex refineries, and is used to produce additional gasoline, primarily, from the gas oils produced in the atmospheric and vacuum distillation units. Its chemical process utilizes a catalyst and heat to break long-chain hydrocarbons into smaller-chain hydrocarbons. Typical products include gasoline, distillate, butane, and propane fuels.

2.2.2 Hydrocracking

Hydrocracking is an important conversion technology where heavy feedstock is cracked in the presence of hydrogen to produce high-value naphtha or distillate products from a wide range of refinery feedstocks. This process employs high pressure, high temperature, a catalyst and hydrogen.

2.2.3 Alkylation

Alkylation is a combining process that creates alkylate, a premium, high-octane blending stock. The procedure is carried out under the catalysis of a strong acid such as sulfuric acid or hydrofluoric acid. Storage and wash vessels in the alkylation unit include those for fresh and depleted acid and water, an acid analyzer settling pot, and a number of wash tanks. (Wikipedia, 2018)

2.2.4 Catalytic Reformer

Catalytic reforming is a chemical process used to convert petroleum refinery naphthas distilled into high-octane liquid products called reformates, which are premium blending stocks for high-octane gasoline. The dehydrogenation also produces significant amounts of hydrogen gas as a byproduct, which is fed into other refinery processes such as hydrocracking.

Catalytic reforming is similar to isomerization in that the hydrocarbon molecules are rearranged.

2.2.5 Coking Operations

Coking is the final means of converting the heaviest products of atmospheric and vacuum distillation which converts the residual oil from the vacuum distillation column into low molecular weight hydrocarbon gases, naphtha, light/heavy gas oils, and petroleum coke.

2.3 Treatment

Treating is the refining processes intended to remove unwanted compounds (contaminants) from and improve the properties of certain products so that they meet applicable standards. It involves removing or significantly reducing molecules that are corrosive or cause air pollution, Like Sulphur, nitrogen, oxygen, metals, etc.

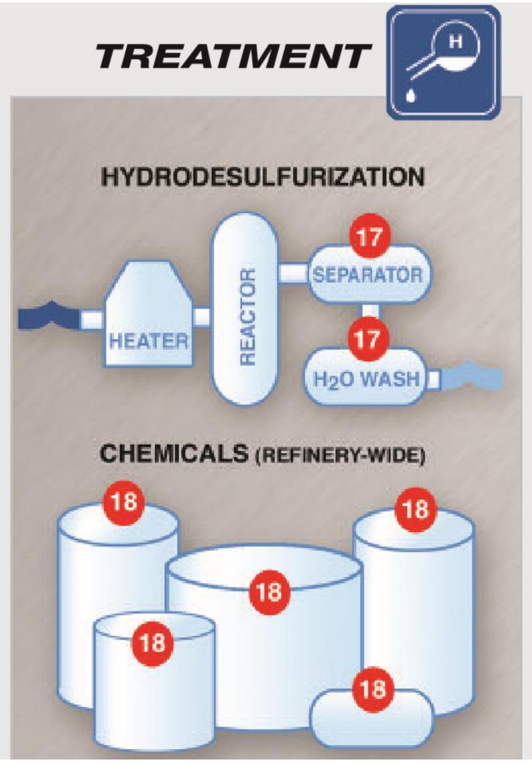

Figure 2-4, Treating operational system (*www.magnetrol.com*)

2.3.1 Hydro Desulfurization

Hydrodesulfurization (HDS) is a catalytic chemical process widely used to remove sulfur from natural gas and from refined petroleum products, such as gasoline, jet fuel, kerosene, diesel fuel, and fuel oils. The purpose of removing the sulfur, and creating products such as ultra-low-sulfur diesel, is to reduce the sulfur dioxide (SO2) emissions.

2.3.2 Chemical Storage

From acids to water treatment additives, a wide array of chemicals are stored at warehouse in vessels that range in size from plastic totes to large steel tanks. Chemicals such as sulfuric and hydrochloric acid, sodium hydroxide, liquid catalysts, blending additives and water treatment chemicals.

2.4 Blending.

Blending is mixing of HCs in certain fractions to obtain finished products with specific properties.

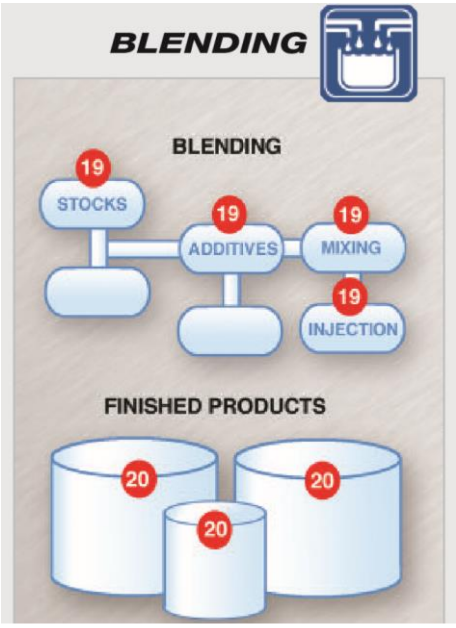

Figure 2-5, Blending component (*www.magnetrol.com*)

2.4.1 Blending Unit

A facility which has no refining capability but is either capable of producing finished motor gasoline through mechanical blending or blends oxygenates with motor gasoline. The objective of product blending is to assign all available blend components to satisfy the product demand and specifications to minimize cost and maximize overall profit. For example, typical motor gasolines may consist of straight-run naphtha from distillation, crackate (from FCC), reformate, alkylate, isomerate, and polymerate, in proportions to make the desired grades of gasoline and the specifications.

2.4.2 Finished Products and Their Uses

Finished refinery products are motor gasoline, jet fuel, diesel fuel, fuel oils, and LPG, stored in tanks with capacities that often exceed 100,000 gallons.

Each refined petroleum product obtained from crude oil has a specific use:

1. Liquefied petroleum gas (LPG), also known as butane and propane, is used as an automotive fuel or packaged in bottles and used for household purposes.
2. Gasoline and diesel are used as fuels for motor vehicles.
3. Kerosene is used as jet fuel.
4. Naphtha is a major petrochemical feedstock.
5. Heating oil is used to heat buildings.
6. Base oils are used to make lubricants.
7. Bitumen, is used to pave roads. (Planete energies, 2015).

3. Physical Units involved in the Chemical Processing

For the chemical processing phases in the previous chapter, there are specific corresponding physical units, operations require more than one physical unit to complete, while some operations are performed in the same physical unit. Therefore, the close contact between units makes the possibility of a chain reaction increase, because of complex operational system, as we can see in figure 3-1. For example, in Kocaeli earthquake, a stack collapse leads to destroy an entire crude plant.

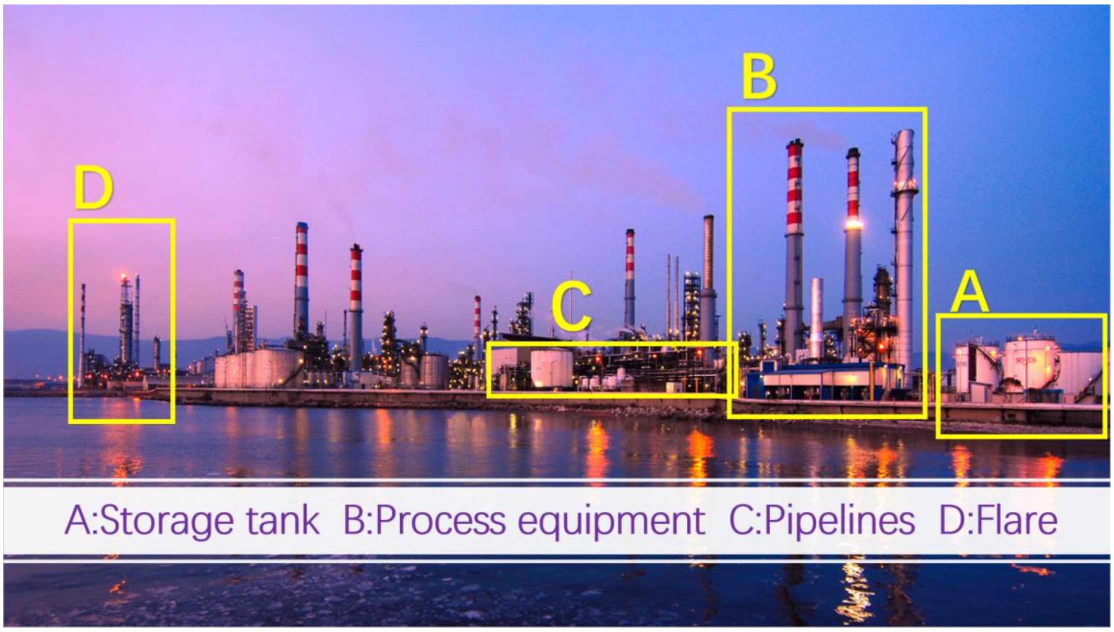

Figure 3-1, Main components of a refinery.

3.1 2D Satellite Map of Onsite Facilities in Tupras Izmit Refinery

Each refinery has its own unique arrangement and combination of refining processes largely determined by the refinery location, desired products and economic considerations. As I took Tupras Izmit Refinery as my research object and main analysis is based on the 1999 Kocaeli earthquake, I only investigated the distribution and arrangement of the Izmit refinery in this paper. Although the refinery was restored and expanded after 1999, but Tupras company information showed that the physical units of the refinery were not changed.

Tupras Izmit Refinery collect 860000-ton crude oil stored in 14 large cylindrical tanks, and also three vacuum distillation units; it has three hydrodesulphurisation (kero-diesel) units, one hydrocracker, two reformer units, two FCC units, one isomerization unit, one asphalt unit, one sulphur recovery unit, one iso-pentane unit, one naphtha sweetening unit and related utility units.(Kohei S, 2000). The final products are naphtha, gasoline, jet-oil and kerosene and other; moreover, around 840,000 ton semi-products are stored in 86 middle and small size cylindrical tanks.

Figure 3-2, is a 2D satellite view of Tupras Izmit Refinery in 2018, which is much larger than 1999, due to expansion of products output. The size of the refinery in 1999 was the part surrounded by white lines.

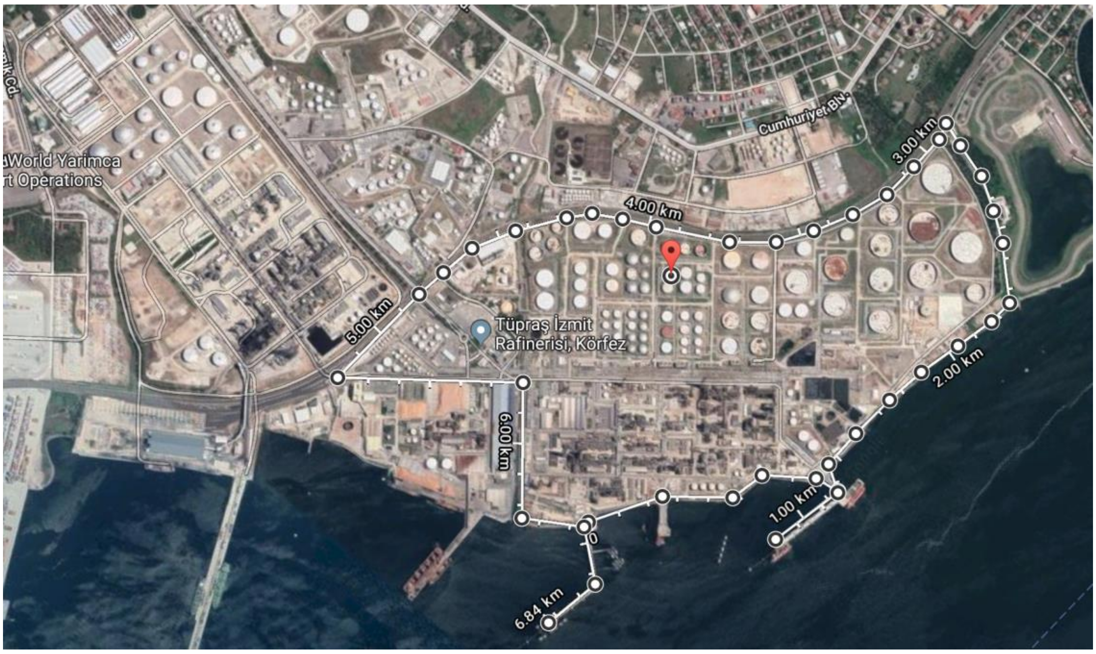

Figure 3-2, 2D satellite map view of the refinery

3.1.1 Crude Storage Tanks

Crude oil arriving at the refinery is stored in large cylindrical tanks with floating roof and fixed roof until it can be processed. In this image, five tanks are almost full, six are half-full and five are almost empty, and nine fixed roof tanks cannot tell the capacity.

Figure 3-3, 2D satellite map view of storage tanks

3.1.1.1 Floating Roof Tanks

Floating roofs are widely used to store petroleum products with high volatility. This is to prevent the product loss and to ensure safe environment around the storage tanks (Mohamed. A & Ghorab 2016). The floating top gives an indication of the volume of oil contained within the tank. They are more ideal for lay in large quantities of crude oil. Crude oil liberates volatile natural gas and also some air pollutants, vapors could cause explosions and fires, so it’s good for them to be contained in the space that is between the roof and liquids, and the vapors could be released according to the condition.

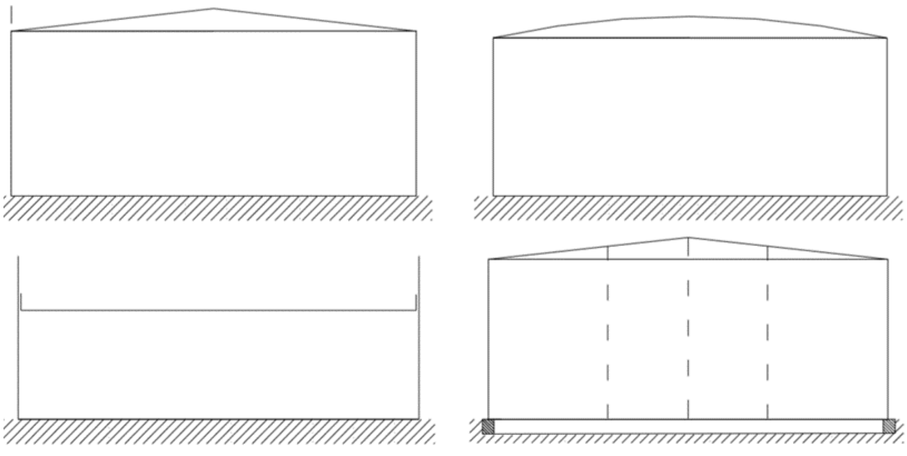

Figure 3-4, Floating roof & Fixed roof tank model (Antonio Di Carluccio, 2007)

3.1.1.2 Fixed Roof Tanks

Fixed roof tanks are suitable for liquids with very high flash points, such as water and fuel oil. Cone roofs, dome roofs and umbrella roofs are usual. These are insulated to prevent the clogging of certain materials, where in the heat is provided by steam coils within the tanks (API Standard 653, 1995).

3.1.2 Processing Area

Crude Oil is a mix of different hydrocarbons known as fractions. In the processing area these fractions are refined into a variety of products by separation/distillation, catalytic conversion, treatment and blending etc. There are four processes used in Tupras Izmit refinery to transform crude oil into a variety of useful goods and delivered by pipeline systems.

1. Fractionation of crude oil molecules by size. (Crude atmospheric & Vacuum Distillation)
2. Breaking larger molecules into smaller one. (Fluid Catalytic Cracking)
3. Combining smaller molecules into larger one. (Alkylation)
4. Changing the shapes of molecule. (Catalytic Reforming)

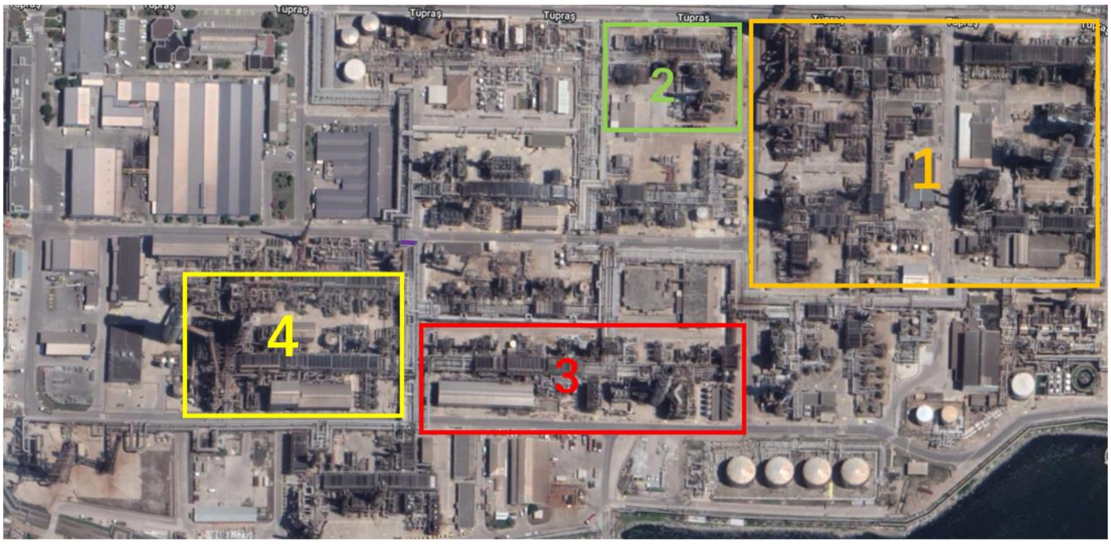

Figure 3-5, 2D satellite map view of processing area

3.1.3 Semi-refined and Refined Storage

After processing, the refined products are stored in cylindrical tanks with floating, flat, domed or peaked tops. These tanks are generally much smaller than crude oil storage tanks. Finished products are Gasoline, Jet and Heating Fuels, Liquefied Petroleum Gas, Chemicals.

Figure 3-6, 2D satellite map view of finished products tanks

3.1.4 Gas Storage Tank (spherical Storage Tanks)

Gas store is different to other refined products, stored under pressure in specially-designed spherical, spheroidal, blimp or bullet-shaped tanks. In Izmit refinery, they are designed as spherical storage tank which is built with less pieces of material and has fewer welded connection points.There are no damage happened to this kind of tank in 1999 Izmit earthquake.

Figure 3-7, 2D satellite map view of Gas tanks

3.2 2D Satellite Map of Offsite Facilities in Tupras Izmit Refinery

In addition to onsite facilities of refinery complex, there are many offsite facilities as auxiliary operations: Electric power distribution; Water supply, waste water treatment plant; Plant air systems; Fire protection systems; Flare, drain and waste containment systems; Plant communication systems; Roads and walks; Railroads.

3.2.1 Waste Water Treatment Plant

Wastewater treatment is a process used to convert wastewater into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. The plant is next to the flare stack separated by a road.

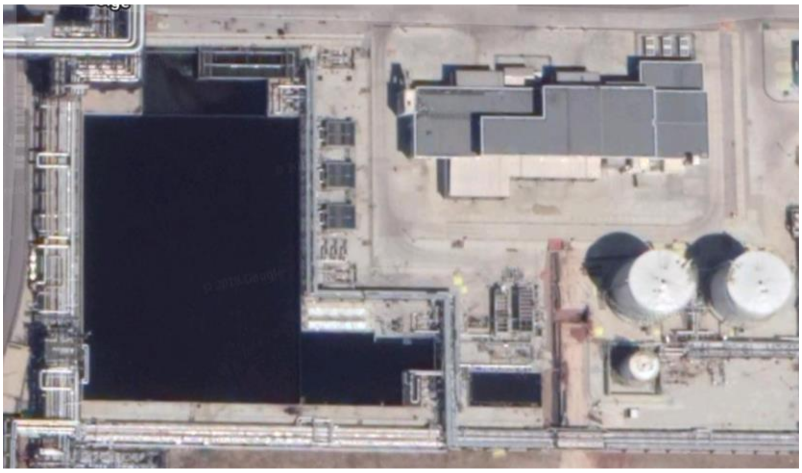

Figure 3-8, 2D satellite map view of waste water treatment

3.2.2 Energy Generation Unit (Electric power distribution)

An oil refinery uses a lot of electrical and steam power to drive pumps, compressors and control center. For this reason it requires its own power station, independent of the national grid.

Figure 3-9, 2D satellite map view of Electric power distribution

3.2.3 Flare Stack

Waste gases produced during processing are burnt off by a safety device known as a flare stack. This has a pilot light burning continuously at the top; if a flame is observed on imagery it indicates high activity within the processing area.

Figure 3-10, 2D satellite map view of flare stack

3.2.4 Distribution/Transportation

Crude petroleum oil is brought into plant, and shipped out of a refinery by a combination of methods. Crude oil normally arrives by oil tanker (a) or pipeline (b) and is pumped into storage tanks at the refinery. After production finish, different refined products will be distributed to market by oil tanker (a), pipeline (b), road tanker or rail tank cars (c).

(a)

(b)

(c)

Figure 3-11, 2D satellite map view of transportation

3.2.5 Plant Administration

Located in the center of the refinery are the administration buildings, maintenance and engineering facilities necessary for the safe operation of the plant, along with associated staff car-parking areas and storage yards.

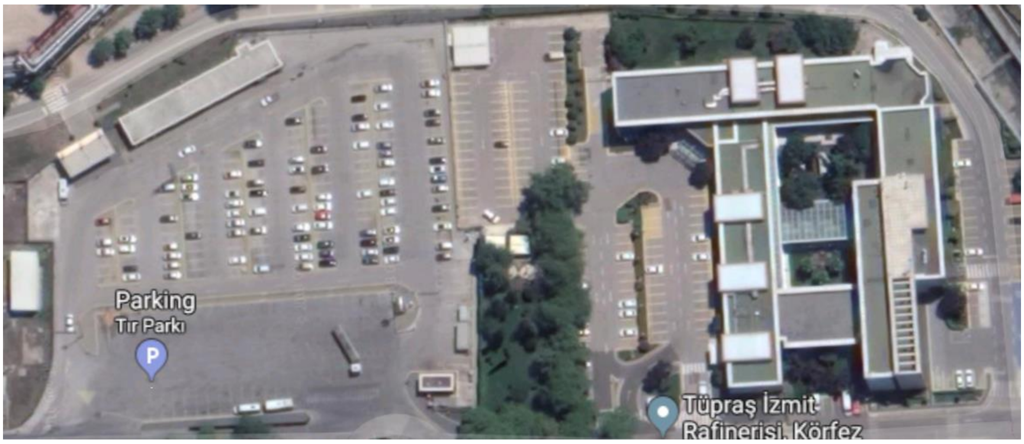

Figure 3-12,2D satellite map view of refinery headquarter

4. Kocaeli Earthquake in 1999 in Turkey

On 17th August 1999 at 3:02 am (local time), a strong earthquake of magnitude 7.4 occurred in the Izmit region of northwestern Turkey, which is the most recent of the seven major earthquakes that occurred along the northern Anatolian fault in Turkey since 1939. The earthquake occurred at the intersection of the North Anatolian fault and the western seismic zone show in figure (4-1). The earthquake caused massive surface rupture. The rupture zone extended from the east side of Izmit through the Sapaja Lake to the northeast and eastward about 180 kilometers (Gulen, L., A. Pınar, D. Kalafat, N. Ozel, G. Horasan, M. Yılmazer, and A. M. Isıkara., 2002). The rupture was mainly horizontal displacement, the maximum horizontal offset was 5 meters, and the vertical offset was 0.5-1.5 meters. The rupture zone had a maximum width of 57 meters. After the main shock, the aftershocks were frequent. The strong vibrations of the earthquake and large-scale surface ruptures caused extremely serious disasters.

The earthquake occurred in a densely populated and economically developed regions of Turkey, causing serious economic losses and casualties. In the earthquake, a total of 18,000 people were killed, more than 43,000 were disabled, more than 100,000 houses were collapsed, nearly 3 million people were left homeless, and direct economic losses exceeded $20 billion.

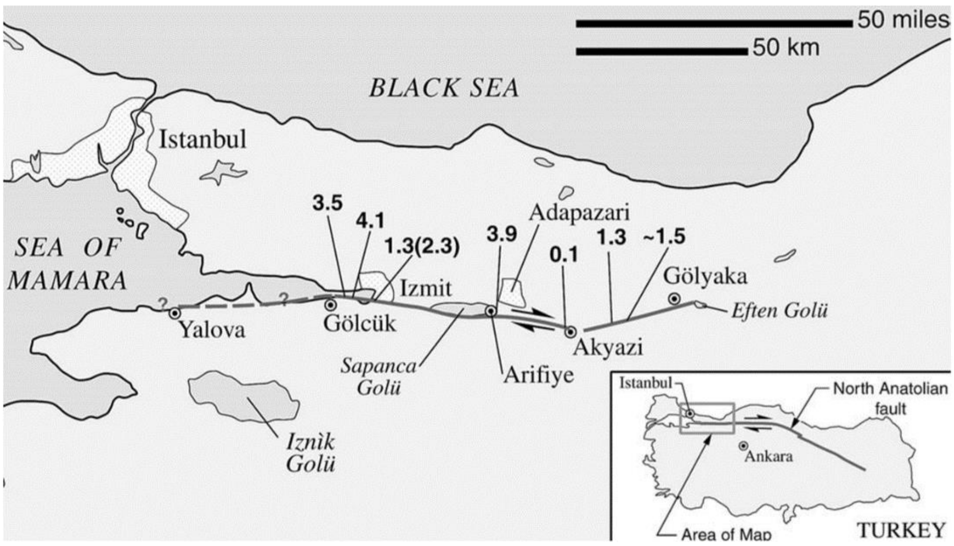

Figure 4-1, Map of affected region showing locations and size of horizontal offsets and a vertical offset (*https://www.preventionweb.net/publications/view/2589.*)

4.1 Earthquake Magnitude

The moment magnitude is based on the seismic moment of the earthquake, which is equal to the shear modulus of the rock near the fault multiplied by the average amount of slip on the fault and the size of the area that slipped (USGS, 2009). Mw is usually reported for an earthquake, which is a measure of the energy released. The typical effects corresponding to different magnitudes of earthquake defined by Mw is shown in the following table which is developed by Charles Richter and Beno Gutenberg. The values are typical only.

Magnitude	Description	Mercalli intensity	Average earthquake effects	Average frequency of occurrence (estimated)
1.0–1.9	Micro	I	Microearthquakes, not felt, or felt rarely. Recorded by seismographs.[28]	Continual/several million per year
2.0–2.9	Minor	I to II	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		III to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	VI to VII	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.	1,000 to 1,500 per year
6.0–6.9	Strong	VIII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area.	100 to 150 per year
7.0–7.9	Major	X or greater[29]	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter.	10 to 20 per year
8.0–8.9	Great		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.	One per year
9.0 and greater			At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.	One per 10 to 50 years

Figure 4-2, the typical effects of earthquakes of various magnitudes near the epicenter (USGS)

The intensity of the earthquake does not depend entirely on its magnitude size. That is, seismic event is not only based on physical principles actually, but also empirically based on observed effects.

4.2 Tupras Izmit Refinery subjected to Kocaeli Earthquake

The epicentral area in Kocaeli province was the most industrialized region of Turkey, and the most serious damage occurred at the Tupras Izmit refinery that accounted for about 33% of Turkish petroleum products consumption in Kocaeli

Province of Turkey. It started production in 1961, with a 1 million tons/year capacity of crude oil processing. As the result of significant capacity augmentation and investments over the years, its design capacity was registered at 11.0 million tons per year (Tupras, 2010). The earthquake caused a large number of structural damages and collapse of the refinery, resulting in the failure of rescue activities. And a series of chain reactions occurred in the refinery， such as tank farm fires, stack collapse, crude unit, oil spill and so on.

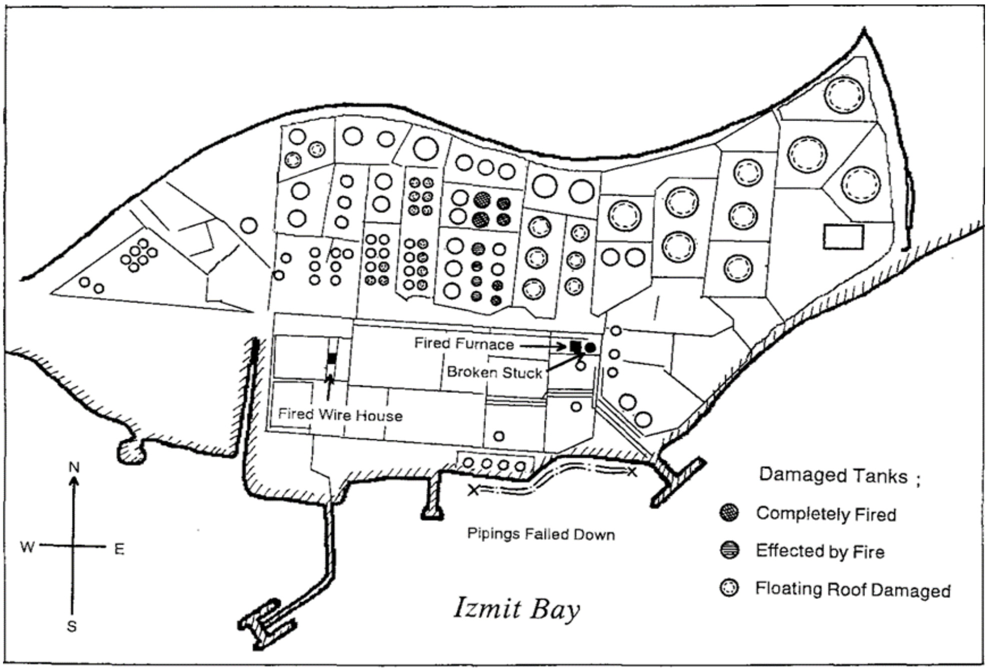

Figure 4-3, Plan view of Izmit refinery in 1999 and location of damage facilities.(Kohei Suzuki, 2000)

4.2.1 Fires Caused by Earthquake

Shortly after the earthquake, fires started simultaneously at three different locations in the refinery which are chemical warehouse fire, plant 25 fire, and the naphtha tank farm fire.

The first fire occurred in the chemical warehouse shortly after the earthquake, it was quickly extinguished due to limited size. The second fire started at the crude-oil processing plant, the fire was very fierce and finally extinguished after a dozen hours of rescue efforts. It was caused by a concrete chimney heater collapse. The third and the largest fire occurred at the naphtha tank farm, which is located approximately at the center of the tank farm area of the refinery, that you can see the tank damaged sample by fire in figure 4-6. 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. There were 46 tanks with floating roofs, most of which were built in the early 1960s according to the California Earthquake Design Code. Besides cylindrical tanks, there were also some spherical tanks for gas storage. None of these were damaged.

Although fires following the earthquake were major issues in this event, there were other kinds of hazards happened and triggered to tank farm fire, for example, tank collapses, “sinking” of floating roofs, tank elephant feet, stack collapse, water supply line breaks, oil spill, pipeline collapse, cooling tower collapse, pile damage at port.

4.2.2 Observed Damage

In the refinery, many mechanical equipment and building structures were damaged, which not only caused huge economic losses, but also caused serious damage to the environment (Kohei S,2000). There is a table below summarizes the damage.

Table 4-1, Observed damage

Component	Failure Model	Consequence of failure
Tanks *See in figure 4-5 & 4-6*	Floating roof sink/submerged	Hydrocarbon(HC) release Fire hazard Permanent failure
	Cracking of tank roof-shell wall	
	Buckling of wall & Roof	
	Elephant-foot buckling	
	Bottom rupture/unanchored	
Heater stack (115m height) *See in figure 4-7*	Collapse	Structural hazard to personnel Fire hazard to processing plant (plant-25) Structural hazard to pipe rack HC release
Cooling tower	Support failure/collapse	HC release Fire hazard
Wharf (port facilities) *See in figure 4-4*	Structure damage	Stop to load or unload materials/products
	Elevated pipeway	HC release into water Potential fire hazard
Pipe system *See in figure 4-8*	Piping support failure	Potential ignition hazard Fire hazard Hazardous chemical release
	Fracture	
	Rupture at connection to equipment	
Column *See in figure 4-9*	Buckled	HC release Structural hazard to personnel

Figure 4-4, The damage of Wharf site

Figure 4-5, The damage of Tank (Halil S and Andrew S.W,2004)

Figure 4-6, Tanks destroyed by Fire (Halil S and Andrew S.W,2004)

Figure 4-7, The damage of Heater unit (Heater stack). (Halil S and Andrew S.W,2004)

Figure 4-8, The damage of Pipeworks (Halil S and Andrew S.W,2004)

Figure 4-9, The damage of steel Column (Mohsen R. & Guy M., 2000)

As we can see from table, the most serious damage happened to storage tanks, but beyond that cooling towers and heater stacks were damaged inordinately. A total of four cooling towers, three of which were wood-based cooling towers were damaged to varying degrees; instead, reinforced concrete material towers remained intact. The processing facility is composed by three crude-oil processing units. One of the latters was destroyed by the collapse of an approximately 115-m-tall reinforced concrete heater stack (figure 4-7) in the middle of the unit. The upper two thirds of the heater stacks collapsed while the other one survived. Furthermore, due to the poor fire resistance of the steel structure, the steel column supporting the furnace was damaged under the influence of high temperature, it's show in figure 4-9. There were 63 pipelines (figure 4-8) damaged by the collapsed building, and the pipe system and its supporting structure were deformed to varying degrees under high temperature.

5. Risk Factors of a Petrochemical Plant subjected to Seismic Load

From the above seismic damage analysis, it is found that the damage caused by the earthquake to the petrochemical plant is unbearable. Moreover, the consequences of such damage are enormous, which will not only cause major economic losses to the production enterprises, endanger the safety of the workers, but also cause devastating secondary disasters (Masayoshi N and Oren L, Nakashima, M., Lavan, O., Kurata, M. et al., 2014). Therefore, in order to ensure the safety of such projects such as petrochemical plants, necessary engineering measures and monitoring program must be taken to mitigate direct and secondary disasters; as well an effective communication and a correct education to communities living surrounding petrochemical plant.

5.1 Structures Design

Earthquakes cause devastating disasters for structures. At the same time, cracks in structures and even collapse of buildings cause huge casualties and economic losses to the country. Therefore, we should continuously optimize the structural design by observing the failure mode of buildings subjected to earthquake to reduce structural damage in the future.

The main reason for the destruction of structures is that seismic waves propagate in the soil and cause strong ground motion. The damage is manifested in the destruction of ground facilities, or the failure of foundations. The damage caused by secondary effects also endanger the construction. Large-size structures such as refineries are often more devastated during earthquake. Although earthquakes are natural disasters, with the development of science and technology, effective measures can greatly reduce the losses caused by earthquakes. Since the first half of the twentieth century, seismic engineering research and development for refineries has received extensive attention, including the development of new materials, new structural designs, and so on. For example, Alloy 33 which is a new corrosion resistant austenitic material for the refinery industry and anti-seismic flexible joint are innovatively applied (2012). These valuable research presented a huge step forward in understanding earthquake hazard mitigation, which resulted in appreciable reduction of the effects of past earthquakes. The Sendai refinery in Japan officially put into operation in 1971. The refinery is located in Miyagi Prefecture, Japan, where earthquakes occur throughout the year. Since its establishment, the refinery has always emphasized safety first and has good safety measures. The refinery absorbed the lessons of the Great Hanshin Earthquake in 1995 and continuously optimized the design of the structure, attaching great importance to the seismic design, material selection and construction of new equipment. The post-construction structure is based on the new national seismic standards of Japan, which improves the seismic requirements and basically withstands the test of the earthquake. Especially in 2003, a magnitude 7 earthquake occurred in Sendai City, and the refinery did not suffer damage. Moreover, from the above damage analysis of Tupras Izmit Refinery, if structural damage is reduced, damages caused by the earthquake are greatly reduced. For example, if the floating roof and walls of the storage tanks use dissipative spacers to reduce the collision between them, the damage of the storage tank will be reduced and the fire will not develop rapidly. In the end, the destruction of this refinery will not be so serious. Therefore, it also proves that structural seismic design is an important measure to reduce earthquake disasters.

5.1.1 Storage Tank

Seismic provision of all types of structures integrating the petrochemical plant is of paramount importance in regions subjected to medium and high seismic hazard. This is especially true for steel storage tanks, which typically contain toxic, flammable and explosive materials. Moreover，special attention should be paid to the seismic design of steel storage tanks, because these structures are very specific and have certain features that make their behavior particularly different from that of a building. Storage facilities are presented by a variety of members whose size, shape, operating pressure and temperature, functional requirements and characteristics vary. Each type has its own analysis, design and detail criterion . In addition, steel storage tanks are part of special facilities related to national security and defence. In the 1960s, US contractors built the Tupras refinery in accordance with US standards, and the storage tanks were designed according to UBC which is called API650 in nowadays. In recent years, with the development of science and technology, API650 has been continuously revised to meet the seismic needs of oil storage tank structures. Many historical earthquakes indicate that oil storage tanks are the most severely affected equipment in petrochemical equipment. Incidents with storage facilities around the world as a result of seismic activity are not uncommon. Some of the most severe cases happened in Chile in 1960, USA: Alaska 1964; Japan: Niigata 1964 and Tokachi in 2003. Lighter incidents are more common, will not make the statistics in this paper.

There are several types of earthquake disasters in oil storage tanks: damage to the pipe wall, damage to the roof of the tank and instability of the upper tank wall, joints of the structure and damage of the weld seam, and uneven settlement of the foundation. At present, there are many methods for reducing the earthquake damage of oil storage tanks. For example, as shown in Figure 5-1, for structural buckling failure of the tank wall, structural engineers optimized the structural design by placing steel bars on the outside of the tank to withstand greater bending moments after the Kocaeli earthquake. In response to the severely damaged floating roof storage tanks, not only new construction forms, but also sufficient fire-fighting equipment are provided. Moreover, typical observed damages (failure of wall-bottom plate welding, elephant foot buckling, elastic buckling of wall, settlements of the ground under the tank) can be eliminated using base isolation technique (Paolacci, 2012). Other accidents and possible damages due to sloshing motion in presence of floating roof, are neither amplified nor reduced by the isolation. A possible solution to reduce the effects of the impact between floating roof and tank wall can be represented by spacers placed between roof and wall or by inserting a TMD system into the roof (Paolacci, 2012).

However, in order to reduce the damage caused by the earthquake to the oil storage tank, we still have a lot of work to do in the future, mainly including the following aspects. First of all, we should use materials with high strength, toughness and good seismic performance and high-fire resistance. Secondly, improve the construction and design method of the structure to ensure the strength and rigidity of the structure and increase the plastic deformation of the oil storage tank under the action of cyclic loading; thirdly, the necessary energy-consuming devices and reinforcement methods should be used so that structural bearing capacity is improved and the response under earthquake is reduced.

Figure 5-1, Retrofitting on the naphtha tank TK-202 burned during the fire.(Girgin 2011)

5.1.2 Other Structures

From the perspective of the damage of the cooling tower, it is not difficult to find that the seismic performance of reinforced concrete structure is higher than that of the wood. Moreover, in the event of a fire, reinforced concrete has strong fire resistance. Therefore, in order to improve the performance of the structure, the cooling tower should be made of reinforced concrete. By above mentioned earthquake scenes, we can see that the impact of stack collapse is also huge. The fall of heavy concrete causes irreparable damage to the surrounding equipment, especially the damage of the pipeline system, causing leakage of toxic liquids, contributing to the spread of the fire, and posing great obstacles to rescue operations. For structures with large slenderness ratio, under the action of earthquakes, large displacements occur in the upper part of the structure or overturning damage occurs in the whole structure, which leads to failure of the flange connection or yielding of the anchoring steel at the bottom of the structure. In this case, the most appropriate passive control technique appears to be dissipation coupling between blood vessels and adjacent structures (Paolacci, 2012). Taking corresponding measures, the damage of pipe system, attached to the stack, will be reducted and the fire will not be so fierce.

It can be seen that studying the seismic design of structures is very important. Firstly, for such a major structure, we should carry out a rigorous structural design to resist the horizontal forces generated by the earthquake. Secondly, high performance materials and energy absorbing devices can be used to mitigate the effects of earthquakes on the structure. Moreover, supervision should be carried out during the construction process to ensure the quality of the structure. Finally, it is important to have appropriate fire protection measures for the structure.

5.1.3 Equipment

In the Tupras Izmit refinery, pipes of various calibers and materials connect thousands of units to complete the transportation of the medium. These pipes are crisscrossed and versatile. In a medium-sized refinery, the cumulative length of various pipelines can reach thousands of miles, so the pipeline is the key to the normal operation of the refinery. The design of these pipelines not only affects economics, rationality and aesthetics, but also relates to the construction, production and maintenance of the entire refinery.

However, from the damage of Tupras Izmit Refinery, we found that due to the action of the earthquake, the pipe will vibrate and tilt, which will cause damage to the pipe joint and collapse of the pipe itself. In particular, the metallurgical pipes themselves are not particularly vulnerable to seismic actions, but they can suffer the effects of differential displacements, which may not be compatible with the permitted deformations. Moreover, such damage may magnify the hazards of the earthquake and cause toxic liquid leakage. Moreover, the inclination and vibration of the pipe will cause bending moment in the pipe support structure triggering out large-scale collapse of the pipe.

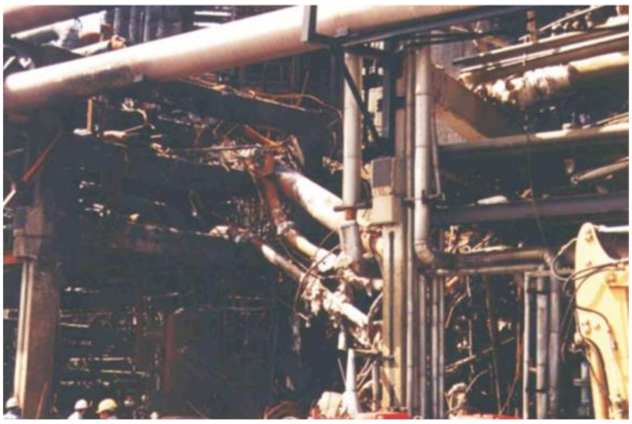

Figure 5-2,The damage of pipeworks by stack collapse (Mohsen R. & Guy M., 2000)

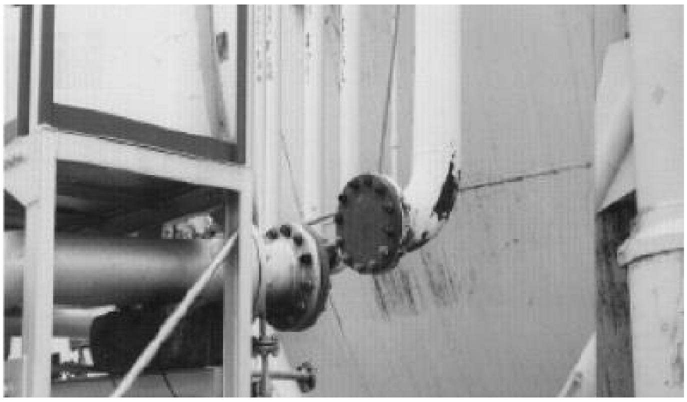

Figure 5-3, The damage of joints (Paolacci, 2012)

Therefore, in order to prevent the overflow of toxic liquids happening, the piping system should have good resistance to deformation, and uniform, high fire resistance materials should be used. In addition, fireproof coatings can also be used to protect them. In particular, the joints of the pipes should be constructed in a more ductile manner to resist deformation of different pipes. At the same time, in the process of structural design, in order to prevent continuous damage, the seismic performance and stability of the supporting structure are firstly ensured, and necessary reinforcement measures are taken.

5.2 Real-time Monitoring

Although the occurrence of an earthquake is inevitable, an efficient and rapid real-time monitoring system is fundamental to reducing the loss of human lives and leading the rescue teams quickly to the right place. In the Tupras Izmit refinery, although earthquakes and fires caused huge damage to the building structure, and caused incalculable damage to the surrounding natural environment. Fortunately, the accident did not cause casualties, mainly due to the good real-time monitoring system. In addition, a 7.3-magnitude earthquake occurred in Haicheng, Liaoning Province, China in 1975. Haicheng is an industrially concentrated and densely populated area. According to previous seismic data analysis, if the earthquake is not successfully predicted, the number of casualties will reach 150,000 or more. Due to accurate real-time monitoring, the government organized the mass to prevent which reduced the number of casualties was greatly, resulting in a total of 18,308 casualties. In 2008, a 7.2-magnitude earthquake struck Iwate Prefecture, Japan, killing only 7 people and injuring more than 100 people. At the time of the earthquake, Japan’s real-time monitoring system played an important role in effectively reducing casualties and losses. Therefore, in order to reduce the damage caused by earthquakes to the refinery in the future, we should adopt a more perfect real-time monitoring system. In particular, real-time prediction and real-time prevention are effective in reducing the damage caused by earthquakes, and taking corresponding actions quickly, and have important significance for post-earthquake recovery work. For this purpose, more advanced sensing and monitoring technologies as well as theory for an immediate condition assessment and structural health evaluation are essential.

5.2.1 Real-time Prediction

So-called real-time prediction: sensing the event parameters of an earthquake and predicting the impact of the earthquake. Before the earthquake occurs, the detailed information of the earthquake will be predicted in a short time, and appropriate measures can be taken to minimize the impact of the disaster. In addition, real-time forecasting can exercise the system's crisis management capabilities. Therefore, real-time prediction is very important and is the basis for real-time prevention and crisis management. When a disaster occurs, real-time forecasting can convey the latest news to the government, company, organization, etc., which is conducive to better overall planning. Moreover, for individuals, obtaining real-time seismic information facilitates action and reduces the number of casualties caused by the earthquake.

Prediction of ground motions and the corresponding structural response is a crucial step in preparedness and response. Based on the seismic response acceleration spectrum, the maximum force on the structure is derived. Accurately predicting the time, location and magnitude of earthquake by seismic devices, like accelograms in Figure 5-4, and conducting short-term earthquake predictions is also the most economical way to mitigate earthquake disasters and is the goal of seismologists around the world. For example, real-time prediction system also played a role in the 2011 East China Sea earthquake, which enabled 27 pairs of Shinkansen trains running between the Tohoku region and Tokyo to stop braking and avoid further losses. At present, countries around the world are aware of the importance of real-time prediction systems and are constantly innovating in this field. For example, the self-developed ICL earthquake early warning technology system in China has accurately predicted 18 destructive earthquakes and reduced huge losses.

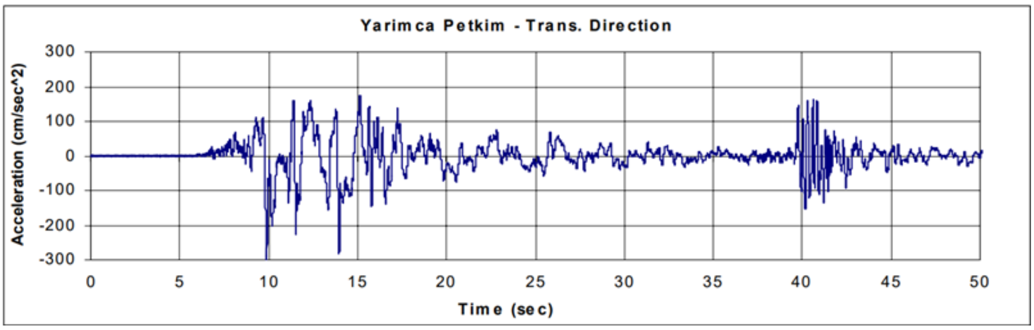

Figure 5-4, Seismic accelerogram (Sezen and Whittaker 2006)

5.2.2 Real-time Prevention

With real time prediction at hand, real time prevention could be made possible. Real time prevention refers here to early warning systems as well as shut down systems for functions where damage may endanger a large population (e.g., nuclear power plants, plants working with hazardous materials, etc.). After an immediate feedback warning system, an advanced emergency system technology is capable of remotely shutting down operation of every single unit in the event. And also an accurate emergency security response could be supported by an emergency operations support system promptly. After years of study seismic activity to lifelines, there are many real-time prevention methods for reduce the disaster caused by earthquakes. For example, SUPREME by company Tokyo Gas which is a ultrahigh density real-time earthquake disaster prevention system for the prevention of secondary disasters related to gas leakage when a major earthquake occurs, this system is capable of utilizing data collected to estimate damage to gas pipeline networks in about 10 minute span following the occurrence of an earthquake. And the earthquake data collected by SUPREME system is sent to employees' mobile phone within minutes of an earthquake, is used to confirm the safety (Tokyo Gas Site, 2018). With the continuous occurrence of the earthquake disaster in the chemical industry in recent years, engineers have designed and developed many prevention systems. Although these systems have greatly reduced disasters, it is still difficult to be close to zero disasters due to the difficult to predictive of earthquakes.

5.3 Post-earthquake Environment

Based on the previous description and analysis, we know that the damage caused by the earthquake to the refinery is devastating.

5.3.1 Post-earthquake Buildings State Evaluation

The main tasks of the post-earthquake building emergency assessment include: assessing important buildings, seeing whether there is a risk of collapse for buildings that have not collapsed, other hidden dangers, and the evacuation of the building and its surroundings.

In the face of natech-events, such as earthquakes, people are often caught off guard. Earthquake prediction and assessment work is particularly important, but because of the current science and technology, it is often impossible to effectively inform people of the earthquake in advance, so that people can prepare in advance. So in order to avoid as much as possible the losses suffered by people after the earthquake, the importance of post-earthquake assessment work at this time is highlighted. The assessment of the post-earthquake building is an important part of the post-earthquake assessment work, so in order to build a safe and comfortable living environment for people in the earthquake-stricken areas, engineers should do this significant work.

5.3.2 Environment Pollution

In order to make Tupras Izmit Refinery return to normal use after the earthquake, Tupras company need to do a lot of difficult and complicated work. After the earthquake, a large number of oil pipelines broke, causing a large amount of oil to be discharged into the sea. Also, an oil-filled ship sank to the bottom of the sea (Johnson et al., 2000). But this is not the main cause of marine pollution. The key is that the fire protection work is not perfect. Since the earthquake, the rescue team's attention was to deal with the fire, and a large amount of oily water entered the drainage system, causing the sewage treatment plant to be damaged, and then the oily water entered the bay. Three days after earthquake, a special response team from the Oil Spill Response Limited (OSRL) arrived at the refinery to undertake oil spill response and clean-up activities. Over 500 m^3 oil was collected from the separator of the wastewater treatment plant. About 400 m^3 emulsified oil that had been reported at two harbours located west of the refinery, Tavsancil and Karamursel, was recovered during a 6-day clean-up operation. An additional 32 m^3 material was recovered from the beach adjacent to the refinery (Harmer, 2001). Okay et al. (2001) reported that polycyclic aromatic hydrocarbon (PAH) concentrations in the seawater, sediment and mussels had increased in Izmit Bay after the incident.

Since the disaster response process, the management department has learned a lot of experience, so in order to improve the ability to respond to disasters, the management department formulated relevant regulations in 2000. and the mitigation of consequences. A membership agreement was signed with OSRL for quick response to oil spills, both on land and offshore (Gorgun, 2007). Table 1 summarizes the measures taken by the refinery after the earthquake and their causes.

Table 5-1, Selected safety and fire-fighting system improvements at the refinery (S. Girgin, 2011)

Problem	Precautionary measure
Insufficient preparedness for natechs	Revised emergency response plan taking natechs into consideration
Inadequate response to the natechs	Disaster management plan with scenarios: – Fire events at four different locations – Fire at the largest storage tank with minimal water supply
Deficiencies in coordination and management of response activities	Bimonthly emergency response practices based on probable scenarios including natechs with participation of all refinery personnel
Inadequate fire water supply	Increased fire water capacity (5 folds)
Ineffective use of sea water	Portable diesel water pump (900 m3/h), monitor and 600 hose (2 km); Sea water connection to fire water system
Lack of sprinkler and foaming systems	Water sprinkler and foaming systems at all tanks; Gas and flame sensors
Insufficient fire fighting equipment	Upgrade of the fire water network; Upgrade of fire fighting vehicles; Water canons (50 fixed and 10 portable)
Insufficient oil spill response	Increased oil barrier stock (3 km) OSRL membership

Moreover, the company reconstructed and reinforced the damaged building structure in the earthquake. These measures not only consume a lot of resources, but also affect the operation of the refinery. The majority of the units, which were out of service due to the earthquake and fire damage, were put into operation within 3 months after the earthquake when the refinery became functional again. The refinery's total cost of repairing damaged buildings, equipment, and the environment was $57.8 million, about half of the initial estimate of $115 million. But the refinery was out of service for a year. 95% of this loss was covered by the insurance (Danis and Gorgun, 2005). The operational loss of the refinery can be seen in Figure 5-5, which shows the amount of crude-oil processed by TUPRAS refineries between 1996-2003. The refinery's loss of production due to the earthquake is evident from the sharp decrease in the processing, while the other refineries have a steady trend (TUPRAS company operates 4 refineries in Izmit, Izmir, Kirikkale and Batman). The loss is roughly equivalent to 6 months (Hurriyet, 1999) of production loss.

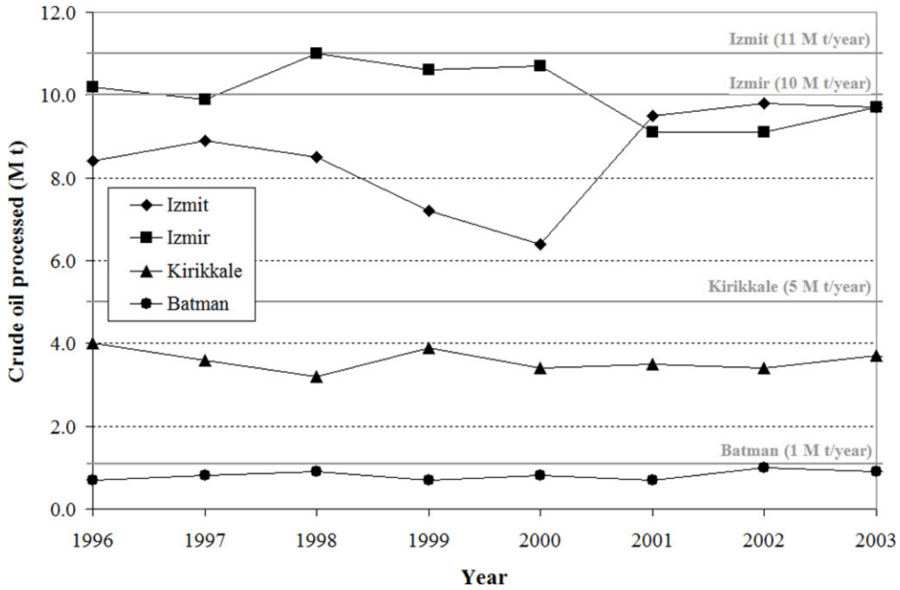

Figure 5-5, Yearly distribution of crude-oil processed by Tupras refinery (Girgin 2011)

5.3.3 Social and Economic Impact

From the events of the refinery, we found that earthquake is a natech event and the starting point of a disaster chain. Not only will the earthquake itself cause various disasters, but also various secondary disasters, such as sand liquefaction, fires and reservoir breaks. Among them, environmental disasters caused by earthquakes are very important, but they are often overlooked. Earthquake secondary disasters at the social level, such as road damage caused by traffic smashes, fires caused by gas pipeline rupture, pollution of drinking water sources due to damage to sewers, communication disruption caused by destruction of telecommunications facilities, plague epidemics, factory toxic gas pollution, hospital bacterial contamination or radioactive pollution. Historical experience shows that the casualties and losses caused by secondary disasters are sometimes greater than direct disasters. Moreover, the treatment after the earthquake is complicated and lengthy. Therefore, the impact of earthquake disasters on the community should be highly valued.

In addition, when the earthquake occurs, we must not only consider a single building, we need to form a complete urban system, which is the construction of urban seismic recovery. The purpose of urban seismic resilience construction is to enable cities to face the impact of different levels of earthquake disasters, and finally form a disaster prevention system with multiple lines of defense to ensure that the main functions of the city after the disaster are effective enough to minimize the loss of life, property and economy. At present, the theory and practice of building earthquake-resistant recover ability in cities is still in the exploratory stage, and long-term research and summary are needed. The keyword "Resiliency" has been used by many researchers in the context of earthquake engineering and in many ways (e.g., Bruneau et al., 2003; Bruneau and Reinhorn, 2007; Cimellaro et al., 2009, and references therein). The earthquake-resistant and disaster-resistant resilience is also an important part of the construction of resilient cities.

6. Conclusion

The work done of this thesis is inserted within a research activity interdisciplinary which figures out the refinery's potential risks, among possible external events, attention has been paid to the seismic event. The aim of this study is based on the "potential dangers of petrochemical plants affected by seismic activity", according to the damage caused by the Kocaeli earthquake to the Tupras Izmit petrochemical plant, the potential risk factors existing inside the petrochemical plant are summarized.

In the refinery, components own intrinsic hazard due to the fact that very often contain hazardous materials. Structural and seismic design analysis of the damaged components are necessary for improve earthquake resistance. The advanced real-time monitoring technology makes the emergency response more timely, and can greatly control the damage within the resilience recovery capability of the community. In additional to the dangers of specific structures, the potential hazards include post-earthquake environment and economical loss due to equipment recovery and operation. As we can seen from earthquake events history, the post-disaster environment is a primarily problem for system recovery.

The risk factors discussed in view of Izmit refinery can be used as a reference for other refineries. Industrial plants located in different regions can improve the facilities structural design and seismic design based on their own condition, thus achieving the mitigation of caused damages.

In additional, as the refinery damage did not cause casualties, the post-earthquake community response did not allow any analysis of the people actively. But if we consider in a larger community range, in realistic, the social stability after the earthquake is very prominent, people lost their family, are homeless to live in temporary tents; lifeline systems are struck, people's emotion will be easily out of control, resulting in social community problem. So citizens response can also be considered as another potential risk factor.

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