Fire of Petroleum Tank, etc. by Niigata Earthquake

June 16th, 1964, Niigata, Niigata pref.

AKATSUKA, Hirotaka (High Pressure Gas Safety Institute of Japan)
KOBAYASHI, Hideo (Tokyo Institute of Technology)

(Summary)

The Niigata earthquake on June 16th, 1964, had a magnitude of 7.5, and a seismic scale of 6. The earthquake caused an urban bridge to fall down, apartment buildings constructed with steel reinforced concrete to be overturned, and fires to break out in petroleum tanks. These incidents caused a different type of damage compared with past incidents, and they attracted notice as new types of urbane disasters. The Niigata earthquake was also the first seismic disaster in Japan where the liquefaction of the ground attracted notice. Among the disaster incidents caused by the earthquake, five crude oil storage tanks in a refinery caught fire and continued burning for two weeks, spreading into the surrounding area and burning down a total of 286 adjacent houses. One of them was a 30,000kL floating roof type tank, 51,500mm in diameter, and 14,555mm in height, which was fully stocked with oil. The cause of the fire was ignition by sparks generated by the collision of the floating roof with the side wall, which in turn was caused by the movement of the crude oil by the sloshing phenomenon. The fire also spread to two spherical tanks for LPG made of 70 kg/mm^2 (700MPa) class high tensile steel, 1,200m^3 in volume, 13,240mm in inner diameter, and 25mm in thickness, resulted in the splitting and buckling of a supporting leg. Furthermore, all of the equipment in the refinery, including horizontal set tanks and freight tanks, were damaged. The Niigata earthquake was also one of the most serious seismic disasters to affect chemical plants, and it brought about many precepts such as the increased perception of the liquefaction phenomena of the sandy ground, the importance of investigations into earthquake-proof designs for tanks, and the importance of the application of fire-proof concrete coating to supporting structures.

1. Event

Each tank in the refinery was shaken by the earthquake in the north and south direction, coinciding with the direction to the seismic center (Figures 1 and 2). The floating roofs of five crude oil storage tanks shocked, and shaking motion of one of them was complicated by its inclination to the west, which was caused by subsidence of the ground that was associated with the soil liquefaction phenomenon. "Sloshing" is defined as the phenomenon of vibration induced on the free surface of a liquid contained in a vessel by the shaking of the vessel itself (Figure 3). In the sloshing of large vessels such as petroleum tanks, the force of impact to the top and the negative pressure to the side wall are serious problems. As a result of the shaking of the floating roof, the crude oil flowed out of the top of the tank, fell down along the side wall, and was ignited by the sparks generated by the collision between the floating roof and the side wall. The crude oil storage tank yard was located adjacent to the main plant area. That is, the tank was within 40m of the plant area, and 48m away from the nearest equipment. A part of the crude oil flowed into the main plant area and caused fires in the catalytic conversion plants including the reactor, a part of the heating furnace, the heat exchangers, the gas separator, and a part of the compressor.

Various damages occurred as a result of the liquefaction of the ground. The "liquefaction of the ground" occurs when seismic vibration causes sandy ground saturated with underground water to become a liquid. Buildings that had been supported by the ground lose their support and become tilted or sink into the ground. On the other hand, structures that had been buried underground are lifted out of the ground (Figures 4 and 5). The ground liquefaction phenomenon caused uneven settlement to the tanks, which resulted in the deformation and failure of the pipes (Figure 6). The oil fence cracked to expose the reinforced steel bars, which in turn suffered from thermal expansion by the fire, causing the fence to lose its strength and collapse. Underground water rose up to the surface by the ground liquefaction, filling the campus together with the sea water that had come in with the earthquake induced tidal wave (Tsunami). Oil flowed out through cracks in the tanks and pipes and was spread by the flood water, causing the fire to spread at an accelerated rate.

As a result of the fire, one of the leg poles supporting a spherical tank for LPG split and buckled due to inner pressure from heated rain water that had been sealed in the pole during the construction work. Because a part of the refinery campus was at sea level, the flow of underground water and sea water caused fire to spread extensively. The surrounding houses to which the fire spread were divided into four areas. Houses in one of the areas located more than 200m from the refinery caught fire because the ground level of the area was lower so the burning oil was carried by the flow of water. Houses in another area located at a distance of 30 to 50m lee side of the yard containing the small size tanks (ca. 10m in diameter) in the refinery caught fire immediately after the outbreak of the fire at the plant. The other two areas were very close to the refinery, with a part of the houses located at a distance less than the length of the diameter of the tanks. The ground level in those areas was also low enough that the sea water carrying the burning oil flowed into the area, causing the fire zone to expand rapidly.

2. Course

The Niigata earthquake that occurred at 13:02, June 16th, 1964 had a magnitude of 7.5, and a seismic scale of 6. The earthquake caused five crude oil storage tanks in refinery to catch fire. The fire spread over the tanks and the tank yard. The fire was remarkably difficult to extinguish, one of the tanks continued to burn until 17:00 on June 29th, and another four tanks burned until 10:00 on June 24th. The burning crude oil that flowed out during the fire caused fires to extend to the integrated plant containing the heating furnace, the heat recovery boiler, the reactor of the catalytic conversion process, the hydrolysis treatment equipment, and the bottom of the hydrolysis reactor for the desulphurization process. A part of the high voltage electric substation was also burned down by the oil that flowed out of the tanks.

3. Cause

(1) Sloshing phenomenon

The floating roof type tank is considered to be safer than the cone roof type tank because the floating roof minimized vaporization loss of the stocked oil by eliminating the vapor phase. However, the danger associated with the sloshing phenomenon is greater for the floating roof than for the cone roof. This disaster happened as a result of the following process; the floating roof was shaken vigorously by the earthquake together with the uneven settlement of the tank caused by the ground liquefaction, which resulted in ignition of the oil by sparks generated by the collision between the floating roof and the side wall. The sparks were generated by the metal touch sealing between the floating roof and the side wall. Recently, soft touch sealing composed of synthetic rubbers or urethane foams has been used instead of the metal touch sealing.

(2) Insufficient earthquake-proof design

Insufficient improvement of the basic foundation for heavy structures as tanks and insufficient flexibility of the pipe line against the subsidence of the ground resulted in the amplification of the damages, especially in the areas of ground liquefaction and of zero ground level ground into which sea water could easily flow. In fact, some of tanks that were located on the improved basic foundation suffered little damages from the uneven settlement. At the initial stage, the oil fence helped to prevent expansion of the fire, however, later it collapsed because of insufficient earthquake-proof design.

4. Immediate Action

When an earthquake occurs, operators must shut the valves of pipes in order to prevent oil from flowing out, and they must stop boilers and furnaces to eliminate possible sources of ignition. A large scale refinery fire is tremendously difficult to extinguish. Therefore, measures preventing the expansion of refinery fire, such as early detection of outflowing oil or spreading fire, are very important.

5. Countermeasure

In response to the accident, the following countermeasures have been taken;

(1) Application of the vibroflotation method in order to improve the basic foundation.

The vibroflotation is a method for consolidating and tightening loose and soft ground as follows; the vivroflot (vibrator with water jet) is slowly lowered while vibrating to the bottom of soil layer, and then it gradually withdrawn while feeding sand into the area.

(2) Improvement of the floating roof type tank.

The metallic seal mechanism was eliminated entirely and the side wall was heightened to prevent the outflow of oil.

(3) Protection of the supporting legs of poles for stock tanks.

The regulation requiring that the legs be covered with fire-proof concrete of more than 50mm in thickness was introduced.

(4) Increase of earthquake-proof considerations for the piping.

Design such as the spring support and the flexible joint have been adopted depending on the kind of piping. Moving underground piping above ground has made it easier to find defective parts during ordinary operation and to take necessary actions quickly in the case of an emergency.

(5) Increase of the earthquake-proof performance for the oil fence.

Applying a flexible structure to the joints of the oil fence and introducing redundancy of the oil fence have increased its earthquake-proof performance. If the inner fence is broken, the outer fence prevents the oil from flowing to the outside.

6. Knowledge

○Never skimp on consolidation of the ground foundation.

Refinery and petrochemical complexes are usually constructed near the coast, where the ground is often loose and soft. If improvement of the ground foundation is insufficient, then uneven settlement can easily occur for tanks as a result of an earthquake. Also, other accidents such as [Heavy oil flowed out by break of tank at Mizushima on 1974] can occur.

○Consider all of the dynamic situations that occur as a result of an earthquake.

Piping and its related parts will fail as a result of an earthquake if the tank, the emergency shut valve, and the piping are not set on the same foundation. Disasters like [Leak of LP gas from piping of the low temperature stock tank at South Hyogo pref. earthquake on 1995] can also occur as a result of an earthquake.

7. Discussion

Fires and other disasters resulting from failures of petroleum tanks as a result of earthquakes around the world that are comparable to this accident are as follows;

(1) 1933, Long beach earthquake, California, USA, Magnitude 6.3.
(2) 1960, Chile earthquake, Chile, Magnitude 7.8.
(3) 1964, Alaska earthquake, Alaska, USA, Magnitude 8.4.
(4) 1978, Miyagi prefecture offshore earthquake, Japan, Magnitude 7.4.
(5) 2003, Tokachi offshore earthquake, Japan, Magnitude 8.0.

In the Tokachi offshore earthquake that occurred on September 26th, 2003, a total fire of a naphtha storage tank occurred. A total fire is a fire that covers the total surface of top of the tank. This kind of fire occurs after the floating roof sinks down, and it is different from the ring fire that occurs as a result of leaked oil around the perimeter of the tank. The cause of the ignition of that fire is still unknown. The floating roof was thought to have sunk because it was broken after the sloshing phenomenon continued for a long period. The weakness of the floating roof type storage tanks against the sloshing phenomenon was pointed out in this case as well. Many tanks that did not catch fire and a part of the piping were still damaged by this earthquake, which showed that the countermeasures adopted against earthquakes were still insufficient.

8. Information Source

(1) Report of Field Investigation on Niigata Earthquake, September 14, 1964, Mining Department, MITI.

9. Primary Scenario

01. Insufficient Analysis or Research
02. Insufficient Environment Study
03. Lacked Research for Foundation of Ground
04. Production
05. Hardware Production
06. Engineering Work
07. Insufficient Ground Improvement
08. Failure
09. Deformation
10. Liquefaction Phenomena
11. Bad Event
12. Thermo-Fluid Event
13. Petroleum Tank
14. Sloshing Phenomena
15. Bad Event
16. Chemical Phenomenon
17. Spark Generation
18. Ignition
19. Firing
20. Secondary Damage
21. External Damage
22. Extended Fire
23. Burned Down of Houses

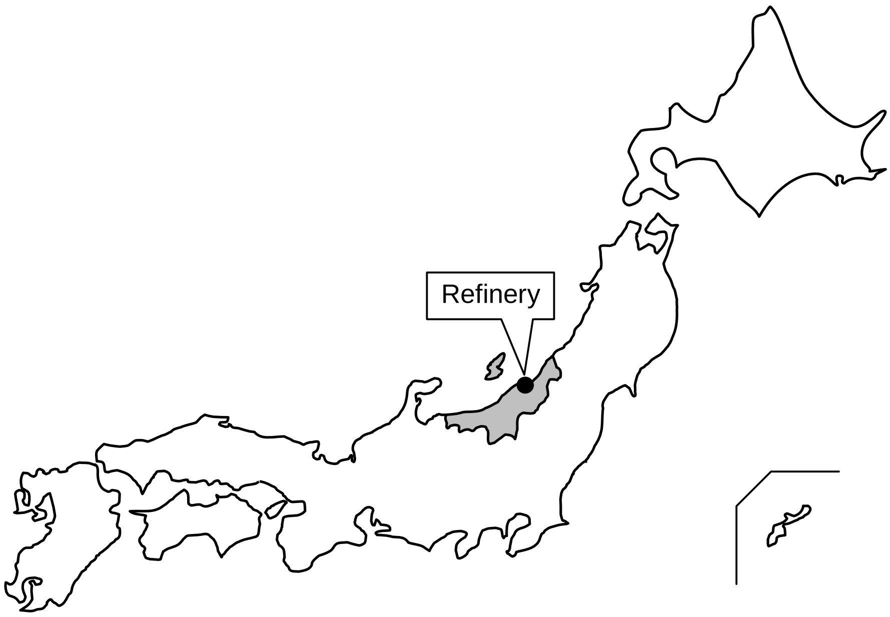

Fig. 1 Site of refinery.

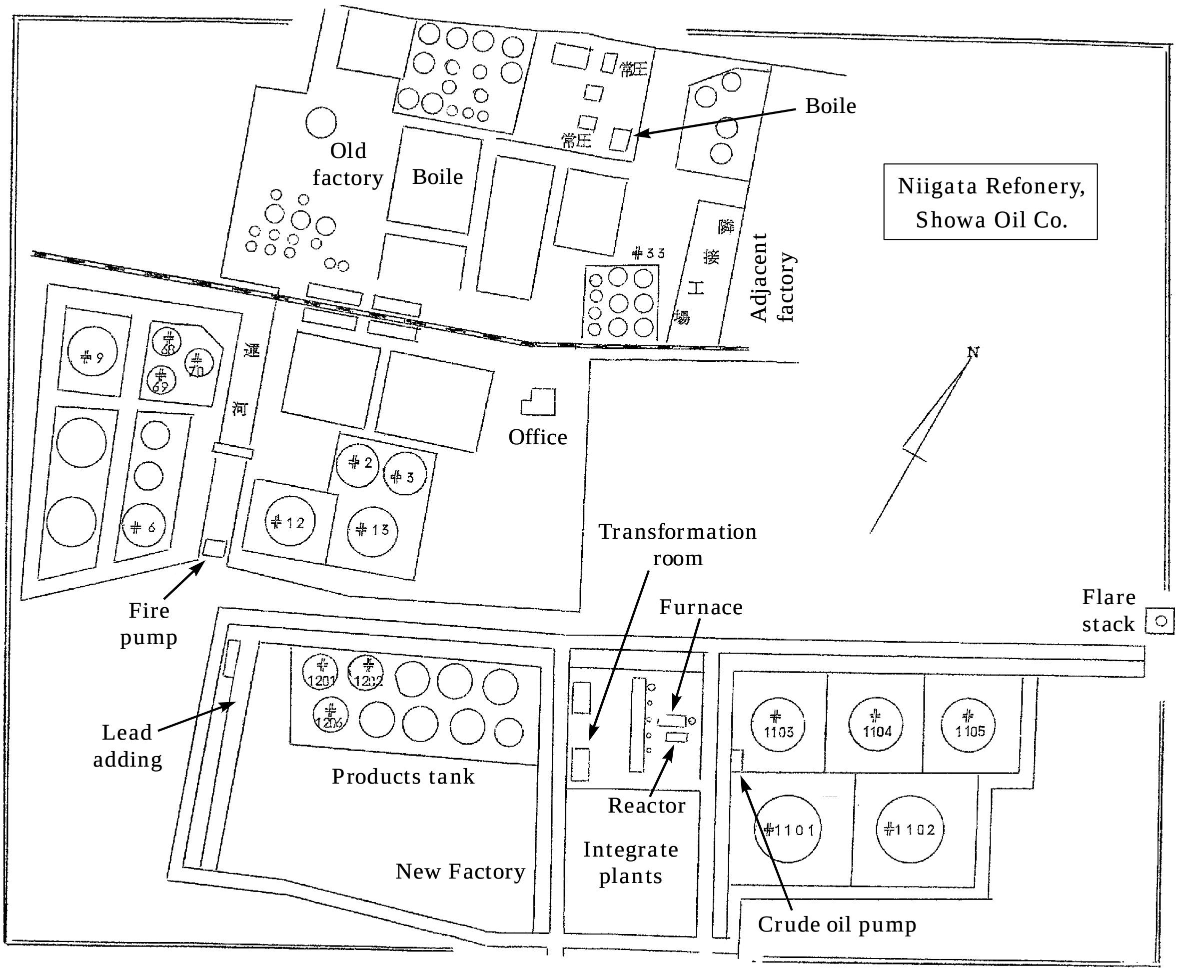

Fig. 2 Damaged part of refinery.

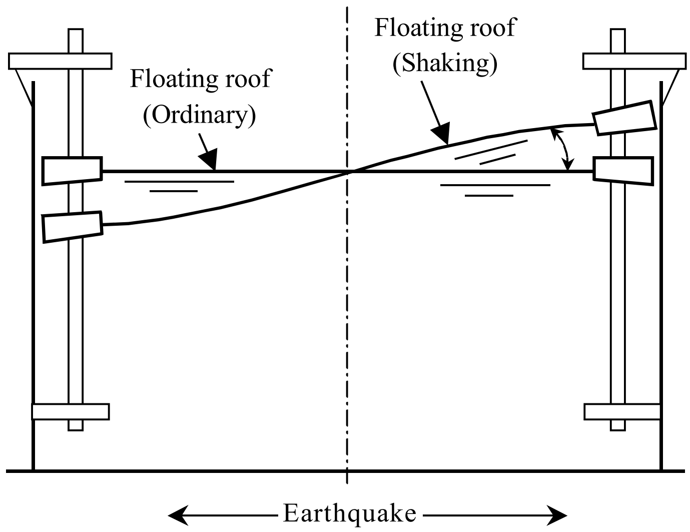

Fig. 3 Sloshing phenomenon.

http://www.jecc.co.jp/tech/bumon_head/frame_kanbo.html)

Fig. 4　Liquefaction of ground (Kawagishi-cho).

(http://www.jecc.co.jp/tech/bumon_head/frame_kanbo.html)

Fig. 5 Uplifted manhole by liquefaction (Near girder bridge of Echigo-line).

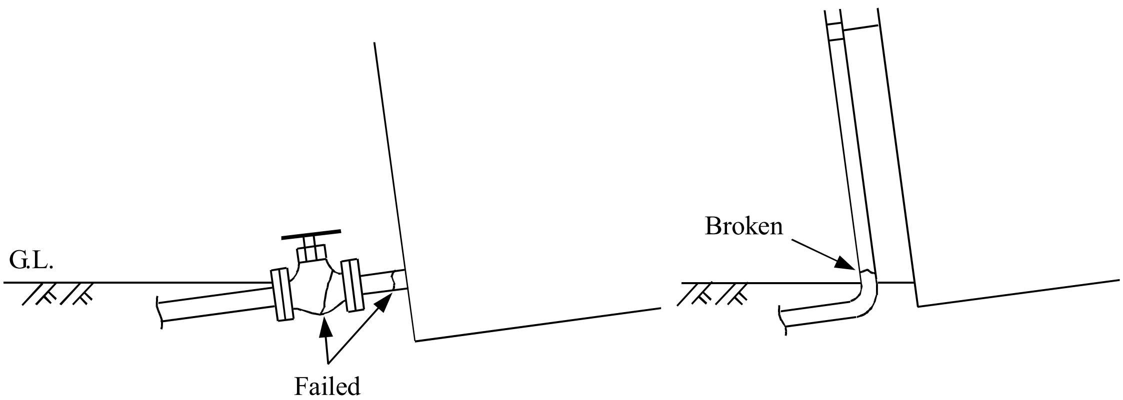

Fig. 6 Damage of tank attachment piping.