SEISMIC ISOLATION MEASURE FOR OIL STORAGE TANKS

AKARYAKIT DEPOLAMA TANKLARINDA SİSMİK YALITIM ÖNLEMİ

Lee Li * Wengen Liao **

ABSTRACT

Oil storage tanks are critical lifeline facilities. In large earthquakes, oil storage tank may break and leak. Base isolation measures can mitigate this earthquake hazards. In this paper, a new base isolation technique is suggested for oil storage tanks using pneumatic air to float the storage tank, thereby isolating it from any ground motion. This technique can be applied to retrofitting existing oil storage tanks as well.

INTRODUCTION

Oil storage tanks are critical structures for developed industrial countries, both for those countries that do not have natural petroleum resources and use these tanks to store imported oil, and for those petroleum producing countries which need them for storing petroleum prior to sale. In the past, several large earthquakes have resulted in these tanks breaking and leaking large amount of oil. For example, in the Niigata earthquake of 1964 in Japan, millions of gallons of oil were lost and enviroment was seriously polluted .[1] In addition, the leak caused a huge fire which raged for three days which could not be extinguished. (Photo 1)

Obviously, there is a great need for adequately protecting these storage tanks from large earthquakes. Many paper have been published on the analysis of dynamic fluid pressure on the wall of cylindrical storage tanks in order to design a stronger tank wall which would survive large earthquakes .[2, 3, 4] These papers use mostly the Bessel functions to calculate the fluid pressure act on the wall of the tank based on the ideal fluid assumptions: incompressibility and non-viscous fluid,

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and wrote the unique equation of the displacements of the tank wall and the fuild motion near the tank wall. These solutions are not only difficult to calculate but inaccurate due to the unreasonable assumptions and the Bessel function series approximation. For those tanks which have floating covers on the surface of the oil, the analysis is even more complicated. For retrofitting existing oil storage tanks, to fasten the tanks on the ground tightly ,[6] will be more shaked by the ground, and will be damaged more severely.

Photo 1

Currently, seismic isolation measures are becoming more and more accepted by the structural engineering community. Base-isolated buildings are performing well in earthquakes. Most of these buildings using some sort of laminated rubber bearings which isolates the building from large earthquakes .[5] Unfortunately, laminated rubber bearings are not practical to use under oil storage tanks constructed using thin steel plates, which in addition to their size, and weight, renders them very flexible. The diameters of these tanks are 20 - 80 meters, and 10 - 30 meters in height, but the thickness of the steel wall and bottom plate are only 3 - 4 centimeters. If rubber bearings were used to support the tank and considering the allowable sag of the bottom plate, the space between isolators should be less than the thirty times the thickness of the bottom plate, i.e., thousand of rubber bearings would be needed for a medium-sized storage tank. This is not only prohibitively expensive but it may produce high stress in the bottom plate. Also, it would be impossible to insert so many bearings under a large, heavy, flexible existing tank in an attempt to retrofit it.

From the point of view of dynamic analysis, rubber bearing elongate the period of an isolated building to reduce the responses of this building during large earthquakes. But for large storage tanks, the original vibrational periods are very long and therefore do not need their periods to be elongated. Obviously, laminated rubber bearings are not a viable isolation solution in protecting oil storage tanks from large earthquakes. Therefore, let us look at other types of seismic isolation approaches which might be prove feasible with the following criteria :

(1) It should be effective against large earthquakes;

(2) It should not hinder the regular use of the structure;

(3) It should be inexpensive;

(4) It should be simple to install;

(5) It should be durable over a long period of time.

SEISMIC ISOLATION MEASURE FOR OIL STORAGE TANKS

Generally, oil storage tanks are shallow cylindrical tanks composed of thin steel plates. They are very large, very heavy and very flexible structures. During earthquakes, these storage tanks may break and leak, they may be damaged due to vertical impact force which forces the tanks to lift up on one side and then fall down back to the ground, or the bottom plate of the tank may split. All of these response to ground motion will cause the oil to leak and potentially ignite if sparking is produced by the impact of the floating cover against the tank wall, or electricity is produced by the friction the oil. To address these hazards, a base isolation approach should be developed for this kind of structure. Using the pneumatic air to make the whole tank float above the ground (Fig. 1) would protect the tank from ground vibration, mitigate the

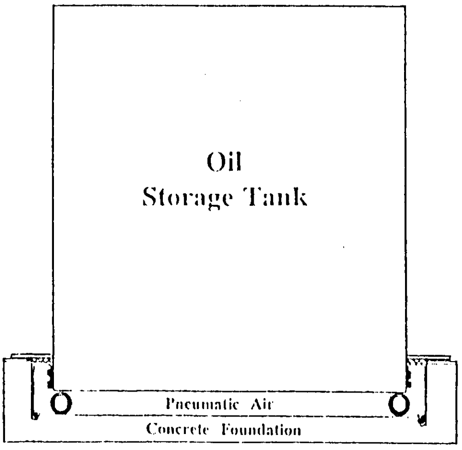

Fig. 1

sloshing of the oil in the tank, stop the floating cover from connecting to the tank wall, and isolate the tank bottom plate from any cracks in the ground. All the potential hazardous scenarios that these tanks might experience in a large earthquake are addressed.

Floating Measure for Oil Storage Tanks

As shown in Fig. 1, the whole tank is floating on an air-tight chamber supported by pneumatic air which frees the tanks from ground shaking. This air-tight chamber is constructed by first building a circular concrete foundation plate with a concrete parapet around the rim of the plate. The diameter of the circular foundation is 150 cm larger than the diameter of the tank. The height of the parapet is 120 cm above the foundation. (Fig. 2) The concrete is made impermiable by spray a layer

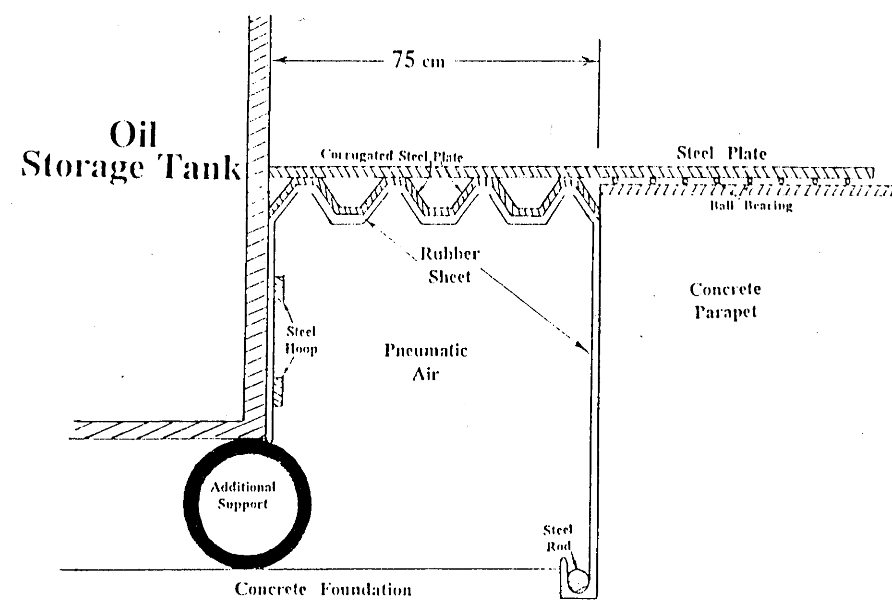

Fig. 2

of air-tight coating on the concrete or by lining the concrete plate, the inner side of the parapet with a rubber sheet. This rubber sheet may be fastened by steel hoops to form an air- tight chamber under the tank. When pneumatic air is pumped into this chamber, the tank will float and will be isolated from the ground shaking. The shearing resistance of the air is equal to zero, and the shearing resistance of the rubber sheet is almost neglegible. Under vertical vibration, the air chamber works as a spring, and the natural vertical vibration period T :

$$T - \sqrt{\frac{W}{g \cdot K}}$$

Here : W ---- Total weight of the tank, (kg)
A ---- Base area of the tank, (cm^2)
K ---- Spring constant of the air chamber, (kg/ cm^2)
h ---- Height of the air chamber. (cm)

For example : W = 20000 Tons, A = 2000 m^2 , h = 50 cm,
$K = \frac{(W + A \cdot 10.3)}{h} = 800000$ kg/cm, and T = 1 sec.

It is long enough to avoid resonance under vertical ground excitation. The vertical response of the tank will be very small. Therefore the air chamber is an effective isolator for both vertical and horizontal ground motion, and the tanks will be perfectly isolated.

Design of Parapet

The air pressure (nominal pressure) in the chamber is p (kg/ cm^2). It makes a large hoop tension P in the parapet.

$$P - \frac{p \cdot D \cdot h}{2}$$

Here : D ---- Diameter of the parapet, (cm)
h ---- Height of the parapet. (cm)

For example : p = 1 kg/ cm^2 ; D = 5000 cm ; h = 120 cm .
Then the total hoop tension $P = \frac{1 \cdot 5000 \cdot 120}{2} = 300000$ kg = 300 tons.
That is to say, 300 cm^2 steel reinforcement required.

If there is tamped soil at the back to the parapet, its passive soil pressure may save the need for some of the steel reinforcing. At the very least, the passive soil pressure may give a safe garranttee for the parapet.

Anti-Tilting Support

To protect the floating tank from tilting, many air-inflated rubber round balls are placed under the tank near the edge of the bottom plate.(Fig.2) These balls carry the weight of the steel wall of the tank. Therefore there will be no bending stress on the bottom plate of the tank because the air pressure is supporting the weight of the oil and the bottom plate. The pressure and load are uniformly distributed. If there is any unbalance in the oil load and air pressure, then some strain gauge sensors under the bottom plate send a signal to a controller to adjust the air pressure in the chamber to maintain the equilibrium of these two pressures. This insures that the round balls under the bottom plate near the edge of the tank will support only the weight of the steel wall. This makes the design of the steel tank simpler than before since there is no bending stress in the tank plate, allowing the designer to use thinner steel plates.

A detail design of the fabrication method of the chamber and a man hole to enter the air chamber to inspect the air-tight rubber sheet and to ensure that the balls are in their correct positions is mandatory. It would be optimum if a robot could run in the corridor around the tank to inspect and adjust the positions of the balls instead of a diver, as the pneumaic pressure in the chamber may be as high as 2 -- 3 atmospheric pressure.

Wind Protection.

There are two ways to keep floating tanks from moving during wind storms :

(1) Build a masonry wall around the tank to protect the tank from any wind laod. Or erecting many precast reinforced concrete buttresses around the tank to make a round wall to protect the tank from wind load. In China, masonry work is very popular and inexpensive and many large storage tanks are surrounded by brick walls. It does not only to protect the tank against wind load, but also to protect the tanks against other attacks.

(2) Lock the floated tank onto the foundation by electro-megnetic locks (Fig. 3) around the tank. The electric megnetic lock is composed of a a saw-tooth plate under an electric megnet. During periods of non-seismicity, the megnet draws up the saw-tooth plate and fix the position of the tank on the ground. At the begining of an earthquake, a signal coming from earthquake sensors will cut-off the electricity, the saw-tooth plate will deactivate and the floating tank will be isolated from the ground shaking.

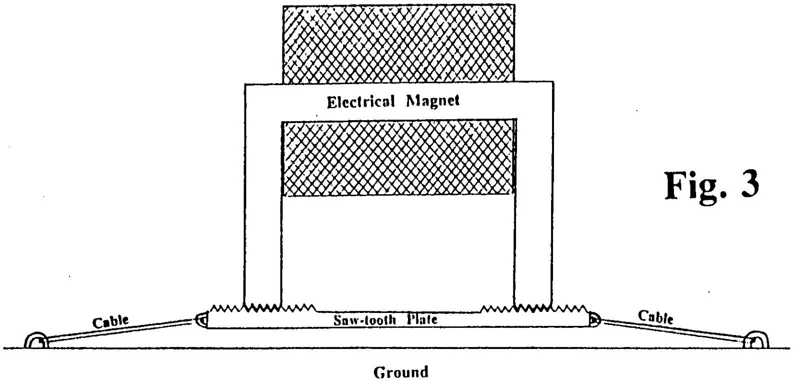

Fig. 3

In the past, there is no wind during earthquakes. It concern the relations that the atmospheric pressure may induce earthquakes .[7] But in this suggestion, it should be pay most attention that there might be a fire caused by an electric sparkling. So that, all of the electric facilities should be insulated perfectly.

Application for Existing Oil Storage Tanks

The only problem for using this type of isolation technique to existing oil storage tanks is the construction of the air-tight chamber under the tanks. Because

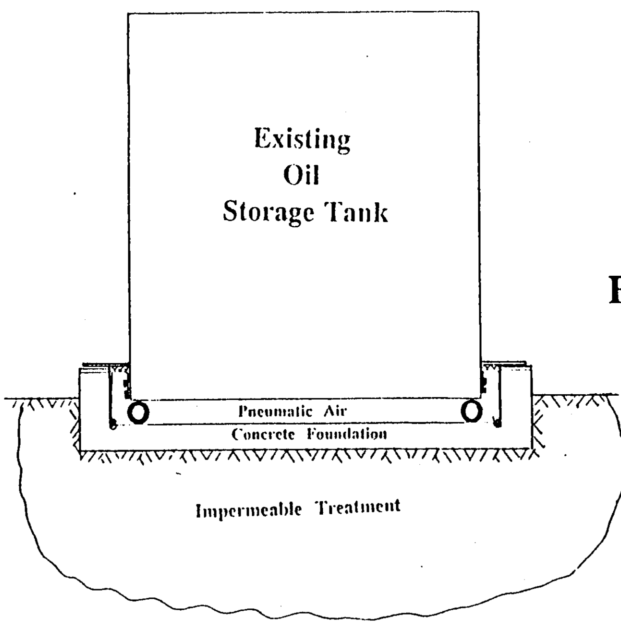

Fig. 4

the foundations of the tanks have already been constructed, a layer of air-tight coating or paving the foundation with a rubber sheet is not possible. But the soil bed under the concrete foundation may be made impermeable. This can be done by grouting chemical solutions into the soil bed as shown in Fig. 4. The area of the impermeable soil bed should be larger than the area of the tank foundation. The concrete foundation plate should then be extended 75 cm outward and a concrete parapet constructed as shown in Fig. 4. The inner surface of the extended concrete foundation and the parapet is sprayed with the impermeable coating, and paved with rubber sheet to make this big-ring space air-tight by fastening the rubber sheet to the tank wall. Then the air is pumped into this space to float the tank and the anti-tilting balls are inserted under the bottom of the tank near its edge. This is the way to seismically isolate existing storage tanks. It is very impotant when applying this method to ensure that the soil bed under the tank foundation be impermeable.

CONCLUSION

Oil storage tanks are especially vulnerable to earthquakes. During large earthquakes, many of them break and leak oil, causing large fires and polluting the enviroment. Strengthening these tanks is expensive, and not yet proven to be effective against large earthquakes. By using a floating seismic isolation technique, oil storage tanks may be successfully isolated from ground motion. This is a relative inexpensive technique because designers may use thinner steel plates to build these tanks because of a lack of bending stresses. This method is simple to construct, is durable over a long period of time, and does not hinder the regular use of the floating tanks. All of our design criteria have been met.

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AKARYAKIT DEPOLAMA TANKLARINDA SİSMİK YALITIM ÖNLEMİ

Lee Lİ - Wengen LİAO

Petrol tankları yaşamsal önemi yüksek yapılardır. Petrol tankları şiddetli depremlerde hasar görerek sızmalara neden olabilir. Pek çok mühendis petrolün tank çeperine yaptığı dinamik basınç konusunda yayın yapmış ve çelik silindirik tankın stabilitesini tartışmıştır. Ancak şiddetli depreme dayanacak petrol tanklarını boyutlamak güçtür.

Depreme karşı temel yalıtımı riski azaltır. Fakat ince cidarlı çelik tankların altına bazı ayrık deprem yalıtıcıları yerleştirmek tankın temel plağında büyük eğilmelere neden olacaktır. Bu nedenle depremden böylesi bir yalıtım uygun sayılmaz. Özellikle ağır ve yumuşak olan mevcut tankların altına yalıtım elemanlarını yerleştirmek mümkün değildir.

Burada petrol depolama tanklarının deprem etkilerinden yalıtımı amacıyla yeni bir yol önerilmektedir. Bu amaçla sızdırmayan temel, tankın çevresinde hava kaçırmayan bir detay ve tankın dibinde oluşturulacak bir kapalı hacme gerek vardır. Bu hacme düşey petrol basıncına eşit olana dek hava pompalanır. Eşitliğin sağlandığı anda tank hava yastığının üzerinde yüzer. Bu yol yatay yer hareketini en iyi biçimde sistemden ayırır, deprem sırasında tankın içinde çalkantı olmaz, tanka düşey deprem hareketinin sadece küçük bir yüzdesi aktarılır.

Yana yatmaları önlemek üzere tankın altına ek hava yastıkları yerleştirilmelidir.

Mevcut ağır ve yumuşak petrol tanklarının altına sızdırmaz beton temel inşaı mümkün değildir. Bu durumlarda zemin bazı kimyasal bileşenler yardımıyla geçirimsiz hale getirilir ve tankın çevresine bir beton parapet yapılarak hava yastığı için bir sınır oluşturulur. Bundan sonra tank çevresine bir lastik conta oturtulur.