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BEHAVIOR OF STEEL OIL TANKS DUE TO NEAR-FAULT GROUND MOTION

Mehran SEYED RAZZAGHI[1], **Sassan ESHGHI**[2]

SUMMARY

The damages undergone by steel tanks during past earthquakes, such as the 1964 Anchorage (Alaska) and 1999 Izmit (Turkey) events showed that these structures are seismically vulnerable. Response of structures to near-fault earthquakes can be substantially different to response to the far-fault earthquakes , because of the special characteristics of near-fault ground motions. The objective of this study was to evaluate the response of various steel tanks to the available near-fault ground motion records. Numerical Analysis carried out to investigate the behavior of steel tanks due to near- and far-fault ground motions in different cases of tank geometry. Based on this limited case study it was found that there is an obvious difference between the behavior of steel oil tanks due to near- and far-fault ground motions.

INTRODUCTION

The behavior of structures due to 1995 Kobe (Japan), 1999 Chi-Chi (Taiwan) and 2003 Bam (Iran) earthquakes showed that there is an obvious difference between the behavior of structures under the effect of the far- and near-fault excitations. These differences are related to special specifications of near-fault earthquakes such as directivity, long period pulse in acceleration history ,etc.

Several research were conducted in order to investigate the response of framed structures to near-fault excitations. Mazza and Vulcano [1] investigated the response of medium to high-rise RC buildings designed according to EC.8 and showed that the aforesaid structures are vulnerable under the effect of near-fault ground motions. Eshghi and Razzaghi [2] , reported the same results for low-rise to medium symmetric RC framed structures designed according to Iranian seismic code. There are only a few documents about the seismic behavior of special structures during near-fault excitations.

Steel oil tanks sustained severe damage during major earthquake events such as Alaska (1964) Turkey (1999) and Iran (2003) and it shows that they are vulnerable to the earthquake.

The major failure modes of these tanks are elephant foot buckling of the tank shell because of the tank uplift and bending type action of the shell, leakage of contains from the tank due to sloshing of the liquid and/or rupture of the wall nearby the connection of tank to pipes or non-ductile action of welded junctions.

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[1] PhD Candidate , International Institute of Earthquake Engineering and Seismology , Iran , mehran@dena.iiees.ac.ir

[2] Assistant Professor , International Institute of Earthquake Engineering and Seismology , Iran , s.eshghi@dena.iiees.ac.ir

SEISMIC PERFORMANCE OF STEEL OIL TANKS

Large capacity steel on-grade tanks in refineries and petrochemical plants are used to store crude oil ,oil , gasoline ,etc. Damages imposed to oil tanks following the intense earthquakes , may lead to loss of valuable contains and environmental impact .

Seismic damage to steel tanks may take several forms such as elephant foot buckling , damage to shell and leakage of contains due to sloshing and hydrodynamic pressure , failure of rigid piping ,etc. Elephant foot buckling of the tank shell occurs under the effect of large compressive stress of the tank wall . Hydrodynamic pressure and long-period sloshing of fluid can damage upper shell of the tank wall and/or roof or cause the leakage of contains due to fracture of the connections . Most tanks whether anchored or unanchored , experiences base uplift during strong shaking [3] . uplifting the tank , may cause stress concentration in the vicinity of base anchors and rigid piping connections and impose rupture in these locations . furthermore rupture of the base plate shell junction and settlement or fracture of foundation ring may occur due to the base uplift .

Several parameters such as liquid table level , base flexibility , etc. can affect the dynamic performance of liquid storage tanks . Base flexibility may increase foundation deformation. Base uplift , reduces the hydrodynamic forces and increases the compressive stresses in the tank wall [3] .

RESPONSE OF TANKS TO PAST EARTHQUAKES

During the recent decades, strong earthquake events has caused serious damages to ground supported cylindrical steel tanks [4] . In general tanks , especially unanchored tanks , are particularly susceptible to damage during large earthquakes . The reason for this vulnerability is that the contains and the relatively flexible tank shell and bottom plate can not transfer the shear which is induced by the earthquake to the foundation. Thus all of the mass contributes to the overturning moment; but a small portion of mass contributes to the overturning resistance [5] . The failure of storage tanks can brought about disastrous consequences. Fire causing extensive damage to oil refineries in the 1964 Niigata event and the pollution of waterways due to 1978 Sendai earthquake are some examples of disastrous situations [5] .

Several damages undergone by steel tanks during an intense earthquake of magnitude Ms=8.5 which happened in Alaska (1964). Following the 1979 Imperial Valley event of magnitude Ms=6.9 , four out of 18 steel tanks of a tank farm experienced an elephant-foot buckling . The aspect ratio (H/D) of all of the tanks were less than 1.5 . Four large steel tanks with floating roof designed according to API650 ;damaged due to the 1983 Coalinga near-fault ground shaking [6] . The distance of aforementioned tanks to the epicenter of earthquake was 5 Km . Also base uplift and failure of containment discharge system occurred in tanks due to the earthquake . Leakage of fluid from the floating roofs in over 50 tanks and fire of numerous oil tanks in Tupras refinery occurred during the 1999 Izmit near-fault ground motion of magnitude Ms=7.4 [7] . Following the December 27 , 2003 Bam near-source earthquake (Mw=6.5) , failure of rigid piping and loss of contains took place in an steel gasoline tank in a site with a distance of less than 5 Km from the fissure of the faulting (Figure 1) . Also the foundation ring damaged because of the base uplift of the tank .

Figure 1- Failure of Rigid Piping Due To The Bam Near-fault Earthquake

NUMERICAL ANALYSIS

FEM Models

In order to investigate the dynamic behavior of steel tanks two series of models are considered. Anchored tanks with different aspect ratios of H/D =1,2 representing broad and tall tanks respectively , categorized In class "A" and unanchored tanks with aspect ratios of H/D= 1, 2 categorized in class "B" . Shell thickness remained constant in each case. Aforesaid models are summarized in table 1 .

Table 1-Description Of Tank Models

CLASS	H/D=1	H/D=2
A	A-1	A-2
B	B-1	B-2

The dynamic characteristics of each model were studied using the finite element program [6] . Finite element models of class "A" is indicated in figure 3 .

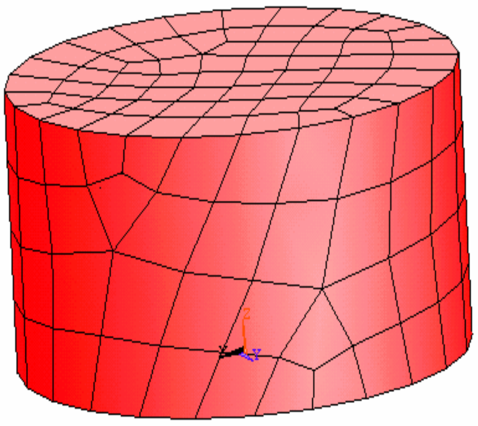

Figure 3-FEM Model of The Tank

The free board level of liquid contains in all cases remained constant at 70% of total height of each tank .

Ground Motion

Several earthquake parameters such as PGA , duration and frequency content are effective in the dynamic performance of the structures . On the other hand the behavior of structures due to a given earthquake varies depending on source , site and path conditions , such as distance between site and source , type of fault rupture subsoil conditions , etc.

In order to compare the behavior of the cylindrical steel tanks due to near- and far-fault ground excitations two real near-fault records (Kobe 1995 and Izmit 1999) and two far-fault records (Manjil and El-Centro) selected . All earthquake records scaled to 0.4g (Figure 4) . No attempted was made to cover the effect of directivity and the angle of source-to-site path with faulting direction . Also the effect of vertical component of the earthquake was neglected .

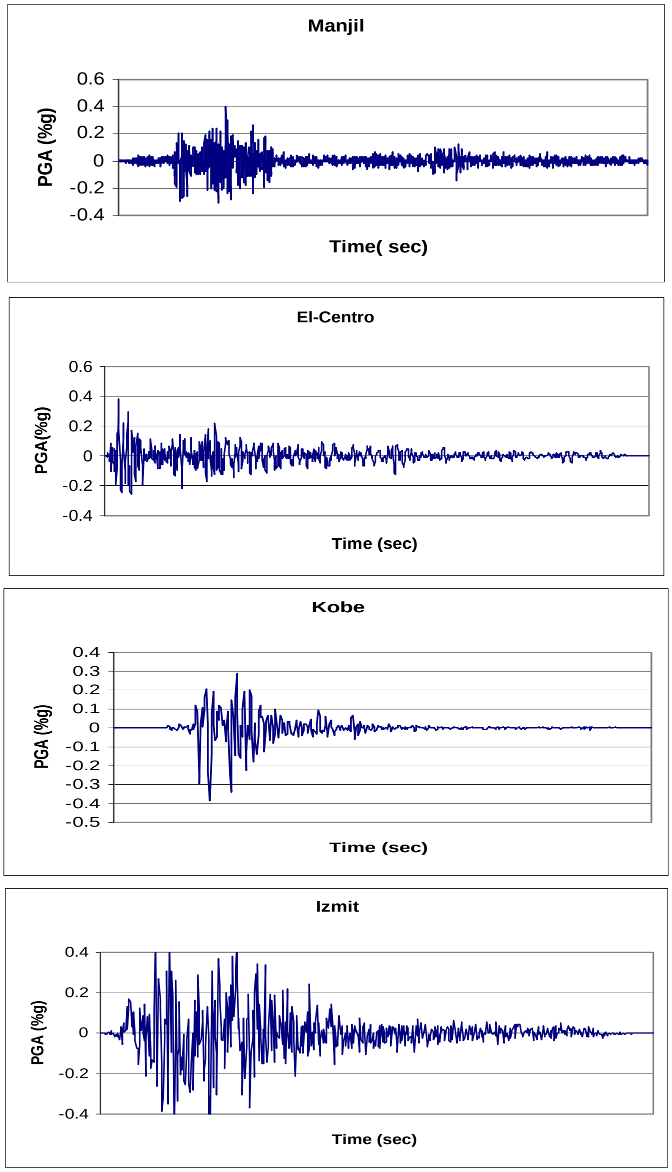

Figure 4-Time-History of Selected Earthquake Records

Numerical Results

Nonlinear time-history analysis conducted by using a finite element software . Results shows that the stress concentration near the base anchor , in anchored tanks is much higher due to near-fault excitations in both “A-1” and “A-2” models . As mentioned before , the stress concentration in this region may cause the rupture of wall shell in poorly detailed tanks . As indicated in figures 5 and 6 the base uplift in a tall anchored tank (model “B-2”) is much higher due to near-fault excitation than far-fault ground shaking . But base uplifting of model “B-1” is not susceptible to the source-to-site distance .

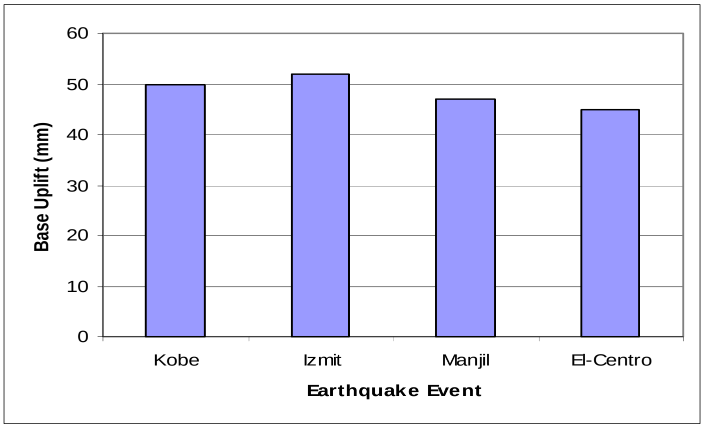

Figure 5-Maximum Base Uplift Of Model “B-1”

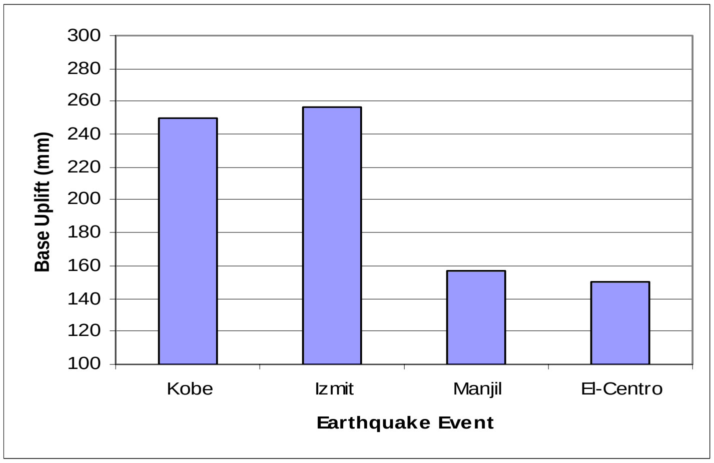

Figure 6-Maximum Base Uplift Of Model “B-2”

It is eminent that the base uplift of model “B-2” is higher than the base uplift of model “B-1” ; under the effect of a given earthquake .

CONCLUSIONS

Nonlinear time history analysis carried out in order to investigate the behavior of steel oil tank due to near-fault strong ground motion . Results shows that there is an obvious difference between the performance of anchored and unanchored tanks due to near-and far-fault earthquakes.

The stress concentration in the vicinity of base anchor is higher due to near-fault ground motion in compare to far-fault excitation. This means that poorly detailed steel tanks are more vulnerable when they experience the near-fault ground shaking comparing to those which experience far-fault .

Base uplift of the tall tanks due to near-fault earthquake is higher than the base uplift under the effect of far-fault ground shaking .The base uplift of broad cylindrical tanks are almost similar whether they subjected to the far- or near-fault ground motion.

REFERENCES

1. Mazza F. , Vulcano A.; “ Effects of Near-fault Ground Motions on The Response of RC Framed Structures Designed According To Eurocode 8 “ ; 12th ECEE ;England ; Paper No. 705 ; 2002
2. Eshghi S. , Seyed Razzaghi M. ; “ Behavior of RC Framed Structures Designed According To Iranian Seismic Code Due To Near-Fault Earthquakes “ ; 4th International Conference of Earthquake Engineering And Seismology ; IIEES ; Tehran ; Iran ; Paper No. BS.56 ; 2003
3. Malhotra p. ; ” Practical Nonlinear Analysis of Tanks “ ; Earthquake Spectra 2000;16(2):473-492
4. Manos G. , Clough RW. ; “ Tank Damage During The May 1983 Coalinga Earthquake “ ;Earthqake Engineering And Structural Dynamics 1985 ; 13 :449-466
5. ASCE ; “ Guidelines For Seismic Evaluation And Design of Petrochemical Facilities “ ; Task Committee on Seismic Evaluation And Design of Petrochemical Facilities ; 1994
6. Eshghi S. , Seyed Razzaghi M. ; “ Performance of Petrochemical Facilities Due to Near-Fault Earthquakes ; IIEES (In Persian) ; 2004
7. EERI ; “1999 Kocaeli-Turkey Earthquake “; EERI V.16 ; 2000