Seismic Vulnerability of Cylindrical Steel Tanks Using Static and Dynamic Analysis and Fluid Wave Height Control

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SUMMARY:
In industrial centers risk studies, the natural hazards including earthquakes should be considered. Fragility analysis of industrial components present some aspects that requires the development of specific reliability tools. Above ground cylindrical steel tanks are mostly used in oil refinery complexes. Tanks with average capacity of 20000 m^3, diameter of about 40-60m and height of about 14m are common samples in Iran Oil Refinery Complexes. The tanks should resist against unfavorable impacts such as earthquakes. During past earthquakes such as 1964 Alaska and 1999 Turkey observed that these tanks were so vulnerable against ground motions. roof damage after earthquake result to fire. The freeboard level of tank plays a major role in the seismic performance of the storage tanks. Its significance depends on H/D ratio of the tank. In this paper 8 above ground cylindrical steel tanks including floating-roof tanks and fixed-roof tanks with different H/D ratios will be studied. Also some failure mechanism such as elephant foot buckling, diamond elastic buckling, failure of roof, sliding, overturning, uplift and unsymmetrical settlement will be studied using nonlinear analysis according to international codes such as ASCE and API 650.

Keywords: Seismic Vulnerability , Cylindrical Tanks, Fluid Wave Height, Sloshing Wave, H/D Ratio

1. INSTRUCTIONS

Fluid storage tanks are one of the most important components of industrial centres and vital installations in urban water supply systems and firefighting that failure will lead to occurrence fundamental problems and non-suppression fire. Therefore the importance of seismic behaviour investigation of those tanks is beyond than economic value of the tanks and what they contain. Past earthquake experiences such as 1933 Long Beach, 1964 Alaska, 1999 Turkey and 2011 Japan prove it.

In storage tanks during earthquake if fluid wave height in tank increases, the fluid wave may damage the roof or some parts of roof holders.

In this paper 5 tanks with different H/D ratios in an oil refinery complex in Iran have been studied using static and dynamical analysis (linear and non-linear). Spectrum and time history linear and non-linear analysis is done in order to find the fluid wave height and also ratio of wave height to the tank diameter.

2. FAILURE MODES OF THE STORAGE TANKS

Earthquake force leads to several failures that can be observed in 7 modes. Sloshing of the liquid in tank during earthquake may damage roof or some parts of roof holders. Large axial compressive stress in tank shell may lead to elephant-foot buckling (Elasto-Plastic Buckling). Overturning of the tanks is one of failure modes that occur because of increasing of overturning moment. If the base shear force exceeds the base friction, tank will slide. Uplifting in tanks bottom during earthquake causes to break the piping system connected to tank. Settlement affect the tanks in the same way. Combination of compressive and tensile stresses in tank shell lead to diamond buckling (Elastic Buckling) in tanks.

3. SPECIFICATIONS OF THE STUDIED TANK

A tank named TK3001 in an oil refinery complex in Iran has been selected to consider static and dynamic analysis and seismic vulnerability survey. Table 3.1 shows the specification of this tank including diameter, height, shell thickness, shell courses, base anchorage type and roof type.

Table 3.1. Specifications of The Studied Tank

Tank	H	D	Capacity	Liquid Level	Special Density of Liquid	Base Support	t_b	t_r	Range of Shell Thickness
	m	m	m^3	m	ton/m^3		mm	mm	mm
TK3001	14.6	57.97	38500	14	0.9	unanchored	9.5	6.35	8-25

H: heigh t_b: thickness of the bottom
D: diameter t_r: thickness of the roof

4. ANALYSIS

In order to investigate seismic vulnerability of liquid storage tanks in this paper linear and non-linear analysis is done. In this paper the tank modelled as three dimensional liquid tank by using finite element method (FEM) with the aid of ANSYS software. For considering the unanchorage system of the tank, GAP element has been used. The tank wall is modelled by using SHELL 63 element and the volume by FLUID 80 element. According to the risk analysis , Peak Ground Acceleration (PGA) of 0.4g for seismic vulnerability with 10% occurrence probability in 50 years with return period of 475 years and according to API650 appendix E the 5% damping used for convective mass and 0.5% damping for impulsive mass were considered. Site-specific acceleration response spectra for Tehran is used in analysis. Also 3compatible earthquake records (such as Tabas , El Centro , Golbaft) in three directions (x,y,z) with 30 degrees deviation on x axis has been considered in time history analysis of the tank in order to study fluid wave height of liquid in the tank during earthquake.

Bottom nodes of tank are allowed to move on vertical direction and fluid elements nodes are allowed to move on tank shell and are allowed to move on vertical direction on the surface of the liquid. In time history analysis 0.02 sec time interval are considered.

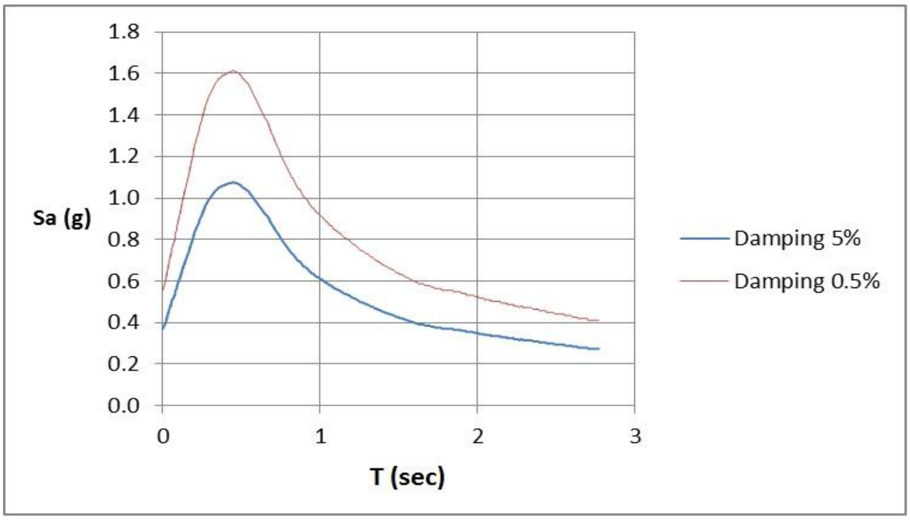

Figure 1. Site-specific response spectra , damping 5% and 0.5% and 10% occurrence probability in 50 years

FEM used model of the tank TK3001 in ANSYS software in order to linear and non-linear static and dynamic analysis is shown in figure 2.

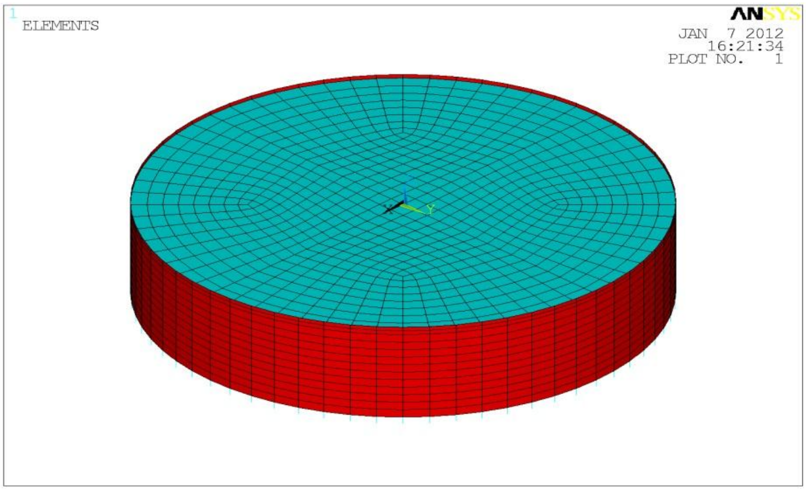

Figure 2. Used FEM model of the tank TK3001 in analysis

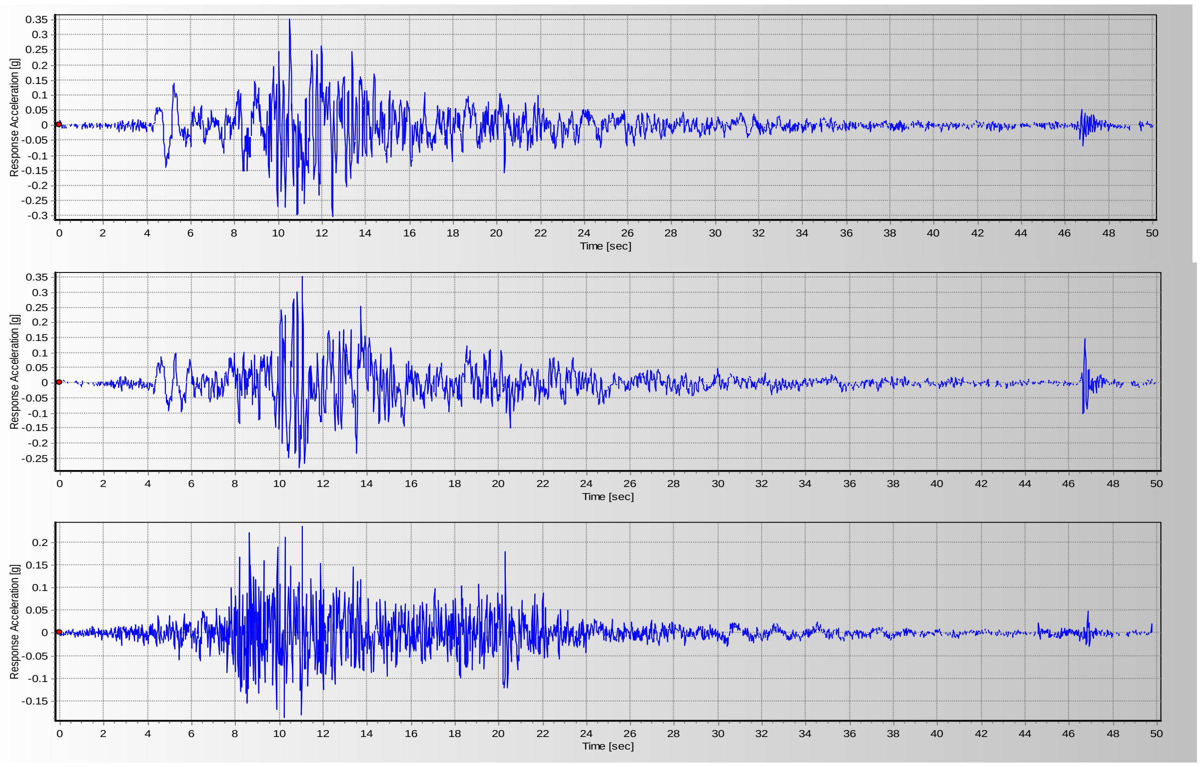

Figure 3. Horizontal(L,T) and Vertical (V) components of Tabas earthquake acceleration record

4.1. Analysis Results

The hydrostatic pressure on the shell by static analysis is found to be 1.2kg/cm^2. Results of static analysis verifies the modeling method. The first horizontal impulsive and convective modes frequencies of TK3001 tank were found 0.2 Hz and 0.1 Hz. According to Haroun, Malhotra and Housner studies and mechanical models the upper part of liquid in tank vibrate in long period (low frequence) that leads to sloshing wave on the surface of liquid and the high frequency mode effects on tank shell and the other part of liquid. Figure 4 shows maximum fluid wave height in tank due to spectral analysis. This value is 1.16 m .

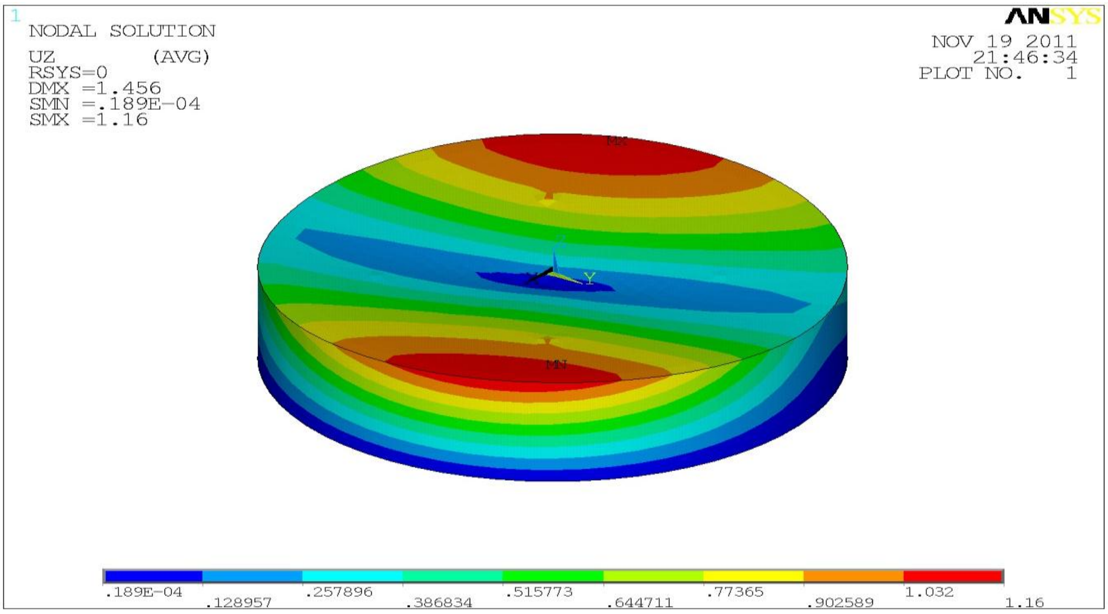

Figure 4. Maximum fluid wave height in tank TK3001 due to spectral analysis

Fluid sloshing displacement of 2 apposite nodes on the upper edge of liquid by Tabas and El Centro records is shown in figure 5 and figure 6, and the values of maximum fluid wave height is shown in table 4.1 .

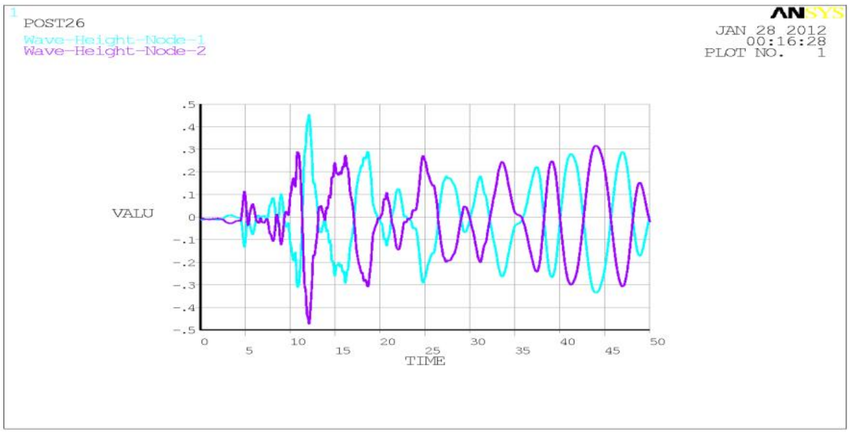

Figure 5. Maximum sloshing wave of liquid affected to Tabas record

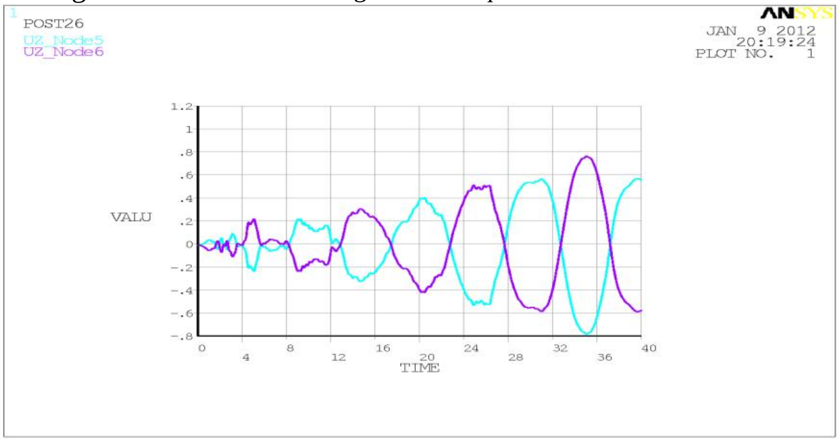

Figure 6. Maximum sloshing wave height due to El Centro time history analysis

Table 4.1. Sloshing Wave Height Due To 3 Earthquake Records

Record	Maximum Sloshing Wave Height (cm)
Tabas	45.33
El Centro	76.25
Golbaft	10.06

All nodes on the surface of the liquid controlled and observed that in analysis affected Tabas record the maximum fluid sloshing wave occurred in middle part of liquid surface. In this case sloshing wave height is 61.22 cm that shown in figure 7.

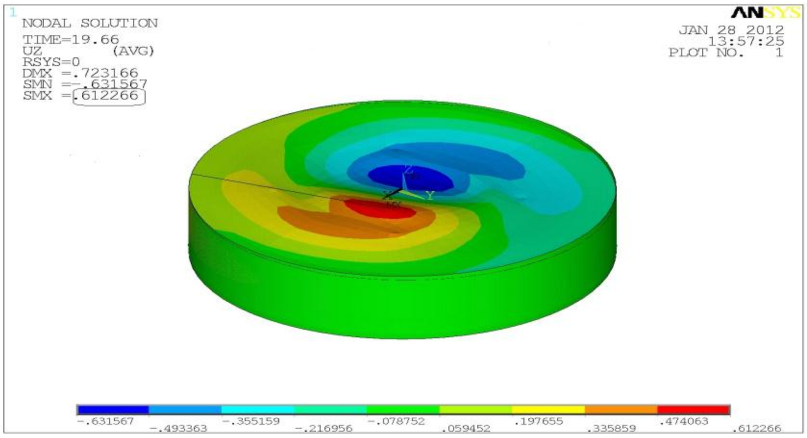

Figure 7. Maximum sloshing wave height in TK3001 tank due to Tabas record

In order to compare the H/D ratio and sloshing wave height in this study, the liquid level in TK3001 tank has been decreased in 4 steps and time history analysis using Tabas record is considered for 4 model. 4 models with the same diameter and different height is used.The reason that Tabas record is selected for this analysis is that Tabas earthquake record is a high frequency record. The other specifications of the 4 model is shown in table 4.2 and results of time history analysis is shown in next section. Plus model number 1 is the model that liquid level in it is 14 m and analysis results is done in the above sections.

Table 4.2. Specification of 5 models of tank TK3001 with different H/D ratio

Model No.	Liquid Level (m)	H/D
1	14	0.24
2	13.4	0.23
3	12.17	0.21
4	10.95	0.19
5	9.74	0.17

Sloshing wave height values of liquid in tank TK3001 due to time history analysis by Tabas earthquake record and API650 values is shown in table 4.3 and figure 7.

Table 4.3. Sloshing wave height (Analytical and API650 values) of 5 models due time history analysis

Model No.	Liquid Level (m)	H/D	Sloshing Wave Height (Analytical) (cm)	Sloshing Wave Height (API650) (cm)
1	14	0.24	61.22	65.69
2	13.4	0.23	59.48	63.90
3	12.17	0.21	57.88	59.93
4	10.95	0.19	56.24	55.57
5	9.74	0.17	49.72	50.83

Compression of sloshing wave height between analytical values and API 650 values for 5 models due time history analysis is shown in figure 8.

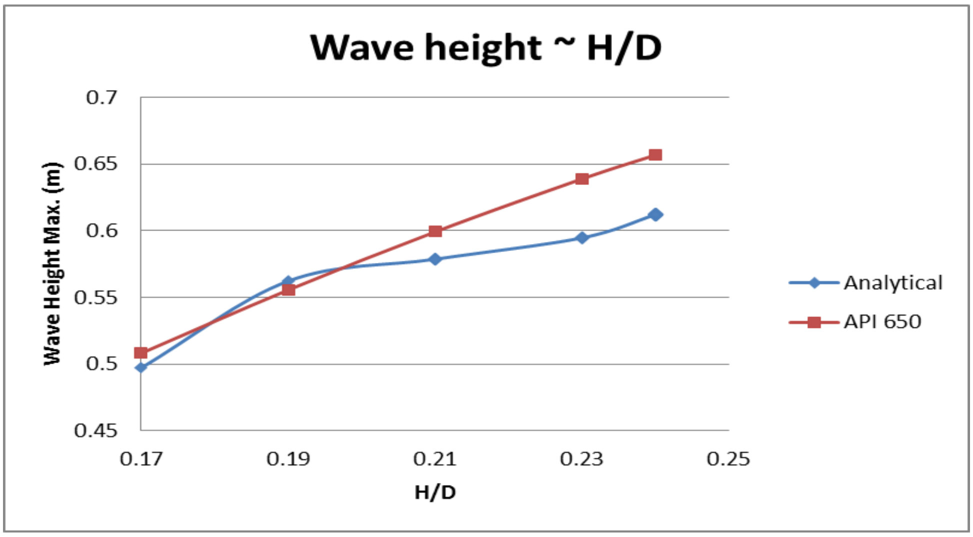

Figure 8. Diagram of sloshing wave height with respect to H/D ratio (Analytical and API650 values)

5. VULNERABILITY ANALYSIS

Based on linear and non-linear studies ,and the allowable values according to the international codes , the vulnerability analysis summerized in table 5.1. Results show that tank TK3001 is vulnerable to roof damage against earthquake forces. Elephant foot buckling (Elasto-Plastic Buckling) and diamond buckling (Elastic Buckling) will not occur in the tank due to earthquake forces.

Table 5.1. Siesmic Vulnerability results of tank Tk3001

Failure Pattern	Analytical Results	Allowed Values According To Codes	Vulnerability Results
Overturning	0.839	1.54	OK
Elastic Buckling	35.79 MPa	41.2 MPa	OK
Sliding	30776 KN	118549 KN	OK
Elephant Foot Buckling	222.86 MPa	261 MPa	OK
Roof Damage	76.25 cm	65 cm	NOT OK
Uplift	111 mm	300 mm	OK
Settlement	19 mm	50 mm	OK

CONCLUTION

According to seismic vulnerability analysis by using finite element method (FEM) and linear and non-linear static and dynamic analysis, sloshing wave height does not affect on increasing of shell stresses and the main reason for shell stress increasing is uplift and settlement of tank bottom during earthquake.

Maximum sloshing liquid wave height in the tank is due to H/D ratio and liquid level of fluid in the tank. In tank with constant diameter, sloshing wave height increases by increasing liquid level in tank.

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