Intelligent Automation And Soft Computing, 2018
Copyright © 2018, TSI® Press
Vol.24,no.3,643–651

The Data Analyses of a Vertical Storage Tank using Finite Element SOFT Computing

Lin Gao, Mingzhen Wang

College of Architecture Engineering, Chongqing University of Arts and Sciences, Chongqing, China

ABSTRACT
With the rapid development of the petrochemical industry, the number of large-scale oil storage tanks has increased significantly, and many storage tanks are located in potential seismic regions. It is very necessary to analyze seismic response of oil storage tanks since their damage in an earthquake can lead to serious disasters and losses. In this paper, three models of vertical cylindrical oil storage tank in different sizes, which are commonly used in practical engineering are established. The dynamic characteristics, sloshing wave height and hydrodynamic pressure of the oil tank considering the liquid-structure coupling effect are analyzed by using ADINA finite element software, which are compared with the result of the standard method. The close numerical values of both results have verified the correctness and reliability of finite element model. The analytic results show that liquid sloshing wave height is basically in direct proportion to ground motion peak acceleration, the standard method of portion sloshing wave height calculation is not conservative. The hydrodynamic pressure generated by liquid sloshing caused by ground motion is not negligible compared with the hydrostatic pressure. The tank radius and oil height have a significant effect on the numerical value of hydrodynamic pressure. The ratio of the hydrodynamic pressure and hydrostatic pressure, which is named hydraulic pressure increase coefficients, is related to the height, which given by the GB 50341-2014 code in China have a high reliability. The seismic performances of tank wall near the bottom needs to be enhanced and improved in the seismic design of the oil tank.

KEY WORDS: Vertical storage tank, ADINA, Dynamic characteristic, Hydrodynamic pressure, Sloshing wave height

1 INTRODUCTION

AN oil storage tank is a container to store oil. It is the main equipment in petrochemical engineering. Storage tanks can be divided into various forms by material, location, installation and shape. Among them, the vertical cylindrical oil storage tank is widely applied. All the previous earthquake disasters show that oil tanks are easily damaged in strong earthquakes. The breakage of oil tanks will not only lead to damages in its own structure direct economic losses, but also cause greater indirect economic losses and serious secondary disasters. Apart from its own inertia force and hydrostatic pressure, when the oil tank is subjected to seismic actions, the hydrodynamic pressure generated by the liquid sloshing in the tank is also the main damage reason of the tank. Therefore, it's necessary to carry out seismic response analyses on the oil storage tank to study dynamic characteristics, oil sloshing wave height and hydrodynamic pressure distribution of the oil tank. At present, the acceleration, stress and displacement distributions of oil tanks under the actions of earthquakes are analyzed, but the study of sloshing wave height and hydrodynamic pressure are slightly less. In 1963, the hydrodynamic pressure of tanks assumed to be rigid under seismic excitation was analyzed by Housner (1963). The contribution of hydrodynamic pressure on a tank wall was divided into the impulsive pressure and convective pressure. Since the tanks were not absolutely rigid, Haroun and Housner (1981) showed that the hydrodynamic pressure was influenced significantly by the flexible behavior of tank walls. Veletsos (1974), Veletsos and Younan (1998) assumed that liquid storage tanks

CONTACT Mingzhen Wang wmz917@126.com

under horizontal ground motions were like a cantilever beam and the effects of the flexible tank wall was considered by applying a cantilever beam type mode to the equation of motion for the storage tank.

The seismic-isolating cylindrical liquid storage tanks were studied considering of fluid-structure interaction. Shekari, et. al. (2009) observed that seismic isolation was more effective in slender tanks in comparison with broad tanks and the liquid surface displacement increases due to seismic isolation especially in slender tanks. Ghaemmaghami and Kianoush (2010), Kianoush and Ghaemmaghami (2011), Hashemi, et. al. (2013) studied the dynamic response of the concrete rectangular liquid containing structure by using the theory and finite element method considering its three dimensional space structure and soil structure interaction. Moslemi and Kianoush (2012) carried out parametric studies on the dynamic behavior of cylindrical ground-supported tanks. Park, et. al. (2016) conducted experiments to study the dynamic behavior of a cylindrical liquid storage tank subjected to seismic excitation. The dynamic test results of the dynamic behavior characteristics including beam-type and oval-type vibration of a cylindrical liquid storage tank under horizontal earthquake excitation were obtained. Goudarzi and Danesh (2016) carried out a numerical investigation of a vertically baffled rectangular tank under seismic excitation. The results of reduction in sloshing wave height caused by the baffles were estimated for selected tanks subjected to the seismic excitations. A simple procedure to estimate the reduction in sloshing amplitude due to the presence of baffles was proposed and validated using the time history numerical results. At present, using software for computational analyses are the main research method, like the reference Tian and Jiao (2016). Manser, et. al. (2017) studied the maximum sloshing wave height in cylindrical metallic tanks by using ANSYS V11.0, and the results were compared with the Euro code 8.

In this paper, the ADINA finite element software is used to analyze the dynamic characteristics and seismic response of the vertical cylindrical storage tanks since ADINA software has powerful solvers and advantages in dealing with liquid-solid coupling problems, as described in the reference Gao, (2015). Three actual ground motion records on the Wenchuan earthquake are used to analyze the maximum sloshing wave height, the distributions of hydrodynamic pressure and the effective stress of the tank under earthquake action. And the finite element analysis results are compared with theoretical calculation results.

2 FLUID-SOLID COUPLING THEORY

THE dynamic effects caused by liquid shaking under earthquakes are applied to the tank body, and the tank body will generate a series changes simultaneously, including stress, displacement and shape. The existing analyses show that with the contacting time of the tank and the liquid in it increases, the interaction between the solid and liquid changed too, which refers to the mutual liquid-solid coupling problem. The liquid-solid coupling problems between tank and oil are analyzed in this paper.

3 TANK MODEL

THE large, medium and small-capacity oil tanks are selected, which are common in practical engineering. The capacity is $2000m^3$, $1000m^3$ and $500m^3$ respectively. The specific parameters of three oil tanks are listed in Table 1. The purpose of this setting is to compare the effects of different parameters on the seismic response of oil tanks. The abbreviations are set for three oil tanks for convenience. The capacity $500m^3$ is called tank A for example. The oil height is 90% of the total tank height. The tank bottom and wall are set as shell units. The oil in the tank is set as 3-D potential fluid unit considering its liquid sloshing characteristic. The unit assumes that the fluid is non-viscous, non-rotational, non-heat exchange and incompressible. To get more accurate results, linear potential-based fluid elements are used in the static and modal analyses, and subsonic potential-based fluid elements are used in the dynamic time history analyses. The subsonic potential-based fluid elements can better reflect the liquid movement under dynamic state.

After setting the unit types of oil tank, the material properties are determined. The properties of steel material are as follows: The elastic modulus is 2×10^{11} N/m^2, the density is 7800 kg/m^3 and the Poisson ratio is 0.3. The properties of liquid material are as follows: The bulk modulus is 1.767×10^9 N/m^2, the density is 812 kg/m^3 and the damping ratio is 0.005.

The mesh of liquid part is divided into a copper type. Each side is divided into 18 copies, and the height direction is divided into one copy per 0.3 meters. The mesh at the intersection of the tank and liquid is the same. That is the common node. The upper tank wall on top of the liquid surface is divided into one copy per 0.3 meters along the height direction. Take tank B as an example, the mesh of tank and liquid are shown in Fig.1.

4 DYNAMIC CHARACTERISTIC ANALYSES

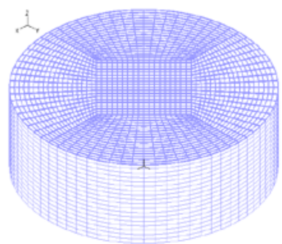
THE dynamic characteristics of oil tanks are analyzed previous to the seismic dynamic time history analyses. The basic period calculation formula is given in Code (2014) for Design of Vertical Cylindrical Welded Steel Oil Tanks (GB 50341-2014). The finite element and the standard calculation results are compared to verify the correctness of the established model. The basic period results of two methods for three tanks are listed in Table 2.

Table 1. The Specific Parameters of Three Oil Tanks.

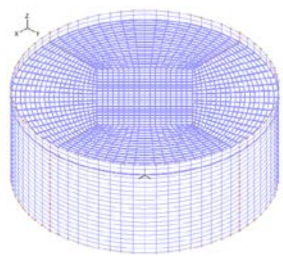
Tank Abbreviation	Capacity (m^3)	Radius (m)	Total height (m)	Bottom thickness (mm)	Wall thickness (mm)	Storage oil height (m)
Tank A	500	3.75	12.00	6	7	10.8
Tank B	1000	7.50	6.00	6	7	5.4
Tank C	2000	7.50	12.00	6	7	10.8

Table 2. The Basic Period Results of Two Methods for Three Tanks.

Order	First order		Second order	Third order
	Standard method	ADINA method		
Tank A	2.867	2.863	1.675	1.315
Tank B	4.357	4.346	2.377	1.873
Tank C	4.076	4.071	2.376	1.873



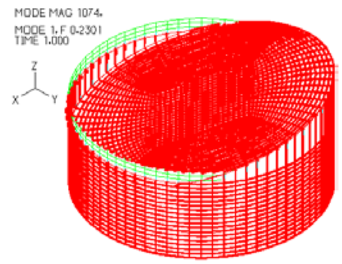
a) Liquid Mesh



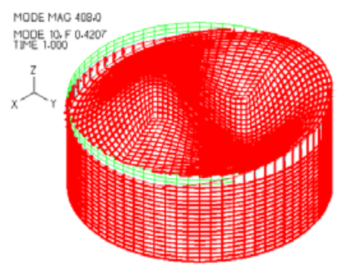
b) Whole Model Mesh

Figure 1. The Finite Element Model of Tank B.

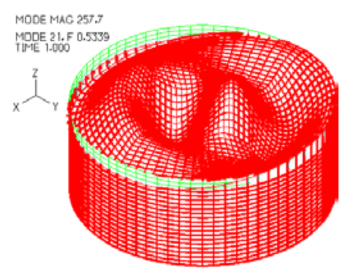
The basic periods calculated results of two methods for three tanks are almost the same as can be seen from Table 2. The fore three orders sloshing periods of three tanks are also listed in Table 2. The fore three orders liquid vibratory types of tank B are displayed in Fig.2.



a) The First Order



b) The Second Order



c) The Third Order

Figure 2. The Liquid Sloshing Vibration Modes of Fore Three Orders for Tank B.

The first order liquid sloshing period is the maximum among all sloshing periods for the same oil tank from Table 2. And with the order increase, the liquid sloshing periods reduce gradually. For the same modal order, when the storage oil heights are the same, the larger the tank radius, the longer the sloshing period. When the tank radiuses are the same, the oil height decreases, and the sloshing period increases. But when the order increases, the differences between the adjacent two periods are less significant. The above analyses show that the tank radius is the most important factor affecting the liquid sloshing period. As seen from Fig.2, liquid sloshing is violent, and deformation of the tank wall, the liquid is small compared to that of liquid. The low-frequency vibration of the oil tank is liquid sloshing. The liquid sloshing period is longish. The modal quality participation percentage of the first order is the maximum and has the greatest impact on the whole system. All the liquid sloshing vibration modes present the *cosθ* beam vibration type.

5 SEISMIC RESPONSE ANALYSES

THE Rayleigh damping coefficients are calculated for seismic response analyses of the oil tank according to the dynamic characteristics analyses results. For the problems of nonlinear, long duration and large deformation, the Bathe time iteration method in ADINA software is used, because of its good accuracy and stability. Three groups of natural ground motion records named Heishuidiban, Baoji and Chencang in the Wenchuan earthquake are selected to simulate the dynamic response of oil tank under actual ground motion. The total duration of all ground motions are 30 seconds. The peak acceleration of all ground motions are adjusted to 100gal, 200gal and 400gal. The basic information of ground motions are shown in Table 3. The ground motions are both input to the X direction of models. And the results of each condition are extracted respectively after calculations.

5.1 Sloshing Wave Height

The wave height time history and stress nephogram graph of the maximum sloshing wave height in each working condition are extracted. Taking tank B as an example, the time history curve of the sloshing wave height under Heishuidiban ground motion at different acceleration peaks are shown in Fig.3. And the stress nephogram graph of the maximum wave height at 400gal peak acceleration is drawn in Fig. 4. The maximum shaking wave heights of the three tanks under unidirectional ground motion are listed in Table 4.

Table 3. The Basic Properties of Selected Three Ground Motions.

Name of ground motion	Predominant period (s)	Site classification
Heishuidiban	0.095	II
Baoji	0.611	III
Chencang	1.138	III

Table 4. The Maximum Shaking Waves of Three Tanks under Unidirectional Ground Motion (Unit: Meter).

Ground motion	Tank A	Tank B	Tank C
HSDB-EW-100gal	0.1048	0.0932	0.0870
HSDB-EW-200gal	0.2126	0.1879	0.1791
HSDB-EW-400gal	0.4282	0.3771	0.3641
BJ-EW-100gal	0.3495	0.3619	0.3694
BJ-EW-200gal	0.7020	0.7257	0.7440
BJ-EW-400gal	1.4046	1.4523	1.4935
CC-NS-100gal	0.7795	0.4478	0.4281
CC-NS-200gal	1.0410	0.8967	0.8609
CC-NS-400gal	2.0844	1.7933	1.7249

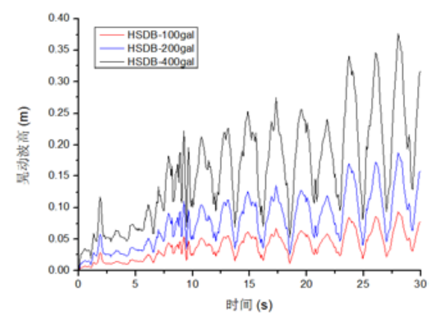


Figure 3. Time History Curve of Sloshing Wave Height under Heishuidiban Ground Motion at Different Acceleration Peaks.

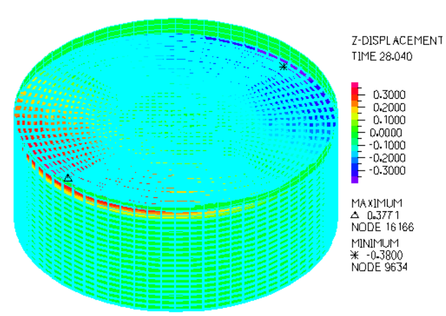


Figure 4. Stress Nephogram Graph of the Maximum Wave Height under Heishuidiban Ground Motion at 400 gal Peak Acceleration.

By comparative analysis, it is found that when the tank is not damaged, the ratio of sloshing wave heights for three tanks under 200gal peak acceleration and 100gal peak acceleration is close to two, and the ratio of sloshing wave heights for three tanks under 400gal peak acceleration and 100gal peak acceleration is close to four. That means the sloshing wave height is basically in direct proportion to the peak acceleration of ground motion. At the same time, the calculated results also show that the sloshing degrees of oil under different ground motions are different. The degree of surface sloshing under the long period ground motion is greater than that under the short period ground motion. The liquid sloshing under the ground motion actions could not be ignored since the maximum wave height is more than two meters in some conditions. The calculation formula of sloshing wave height in the oil tank under the horizontal earthquake action is given by note D.3.9 Specification for Design of Vertical Cylindrical Welded Steel Oil Tanks (GB 50341-2014), which is shown in Eq.1. The calculated damping ratio of oil is 0.005.

$$h_v = 1.5\eta\alpha R \tag{1}$$

The sloshing wave height results of the finite element and the standard method for three tanks at 100gal peak acceleration are shown in Table 5.

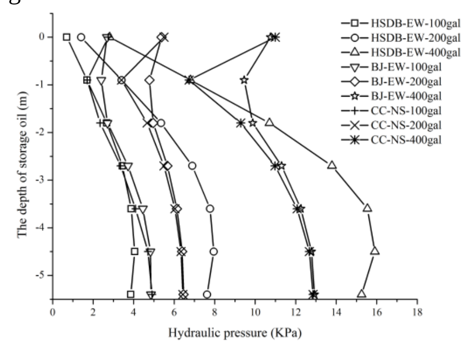
Table 5. The Sloshing Wave Height Results of the Finite Element and the Standard Method for Three Tanks at 100 gal Peak Acceleration (Unit:Meter).

Tank name	Method	Heishui-diban	Baoji	Chen-cang
Tank A	Finite element	0.1048	0.3495	0.7795
	Standard method	0.3246	0.3444	0.3444
Tank B	Finite element	0.0932	0.3619	0.4478
	Standard method	0.5307	0.5705	0.5705
Tank C	Finite element	0.0870	0.3694	0.4281
	Standard method	0.5526	0.5925	0.5925

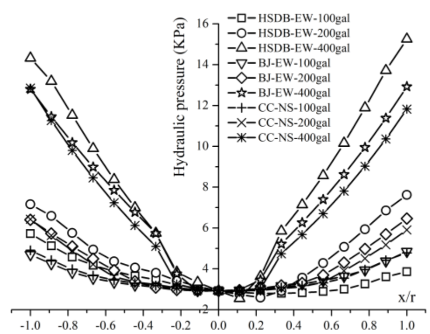
The sloshing wave height results of the finite element method are smaller than that of the standard method under the short period ground motion such as the Heishuidiban seismic motion. The sloshing wave height results of the finite element method are similar to that of the standard method under the long period ground motion, but the result of the finite element method are less than the standard method in some conditions. The sloshing wave height calculated by the standard method is somewhat unsafe in some cases.

5.2 Hydrodynamic Pressure

Structure designers don't concern the real-time values of the structural responses under earthquake actions. Instead, they care about the maximum values of the structural responses to be used in structure design. To the analyzed vertical storage tank in this paper, the hydrodynamic pressures for the tank wall and bottom in the direction of the unidirectional seismic action are the largest. The maximum hydrodynamic pressure distribution of the tank wall in the height direction and the bottom radial direction at different peak acceleration ground motions are shown in Fig.5.



a) The Tank Wall in the Height Direction



b) The Tank Bottom in the Radial Direction

Figure 5. Hydrodynamic Pressure Distribution at Different Peak Acceleration Ground Motions for Tank B.

It can be seen from Fig.5 that the hydrodynamic pressure at the same position is increased with the increase of the peak acceleration under the same ground motion, and the increase multiple of hydrodynamic pressure is the same as the increase multiple of the peak acceleration. When the other conditions are the same, the hydrodynamic pressures under the Heishuidiban ground motion are larger than pressures under the Baoji and Chencang ground motion. The hydrodynamic pressures under the Baoji and Chencang ground motion are almost the same. Although the hydrodynamic pressure values of the tank wall and bottom under different ground motions are different, the curve shapes, namely the distributions of hydrodynamic pressure, are basically the same. The hydrodynamic pressure distribution trend of the tank wall in the height direction for tank B shows a large bottom and a small top in Fig. 5a. Under some ground motions, the hydrodynamic pressure of the liquid surface position is the minimum, and the hydrodynamic pressure at one meter below the liquid surface is the minimum. The hydrodynamic pressures don't change obviously at about 2m above the bottom, and the hydrodynamic pressure reaches the maximum at about one meter above the bottom of the tank. This is one of the main reasons for buckling failure of the bottom part of the tank wall under seismic actions. In Fig. 5b, no matter what kind of ground motion actions, the maximum hydrodynamic pressures along the radial direction are almost symmetrical about the center of the tank bottom. The hydrodynamic pressures at the center of the bottom are almost equal at different peak accelerations and in different ground motions. There is a positive correlation between the hydrodynamic pressure and the peak acceleration of ground motions under the different peak accelerations and in the same ground motion. Therefore, only the calculation results under the 100gal peak acceleration are employed at a later study.

In order to analyze the effect of tank radius to the hydrodynamic pressure distribution, the tank wall hydrodynamic pressure distributions under the same ground motions of tank A and tank C with the same heights are compared and plotted in Fig. 6. In order to analyze the effect of oil height to the hydrodynamic pressure distribution, the tank bottom pressure distributions under the same ground motions of tank B and tank C with the same radius are compared and plotted in Fig. 7.

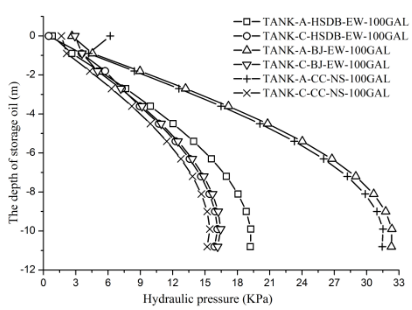


Figure 6. **Influence of Tank Radius on Hydrodynamic Pressure Distribution for the Tank Wall in Condition of the Same Storage Oil Height.**

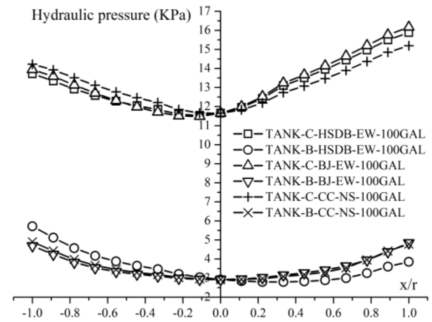


Figure 7. **Influence of Storage Oil Height on Hydrodynamic Pressure Distribution for the Tank Bottom in Condition of the Same Radius.**

The tank wall hydrodynamic pressures of tank A under different ground motions are larger than that of tank C can be seen in Fig. 6, and the hydrodynamic pressures at the same position even increase more than one time under long-period ground motions such as the Heishuidiban and Chencang ground motion. When the oil height remains the same, the smaller the tank radius, the larger the hydrodynamic pressure is. The regularity that the hydrodynamic pressure of the bottom part of tank wall is large and the hydrodynamic pressure near the liquid surface is small keeps unchanged. From Fig. 7, the tank bottom hydrodynamic pressures of tank C are larger than that of tank B under different ground motions, and the pressures at the same position even increase more than two times. When the tank radius remains the same, the larger the storage oil height, the larger the hydrodynamic pressure. The regularity remains unchanged that the hydrodynamic pressure near the center of tank bottom is the minimum, the pressure at the radius position is the maximum and the distribution is linear from the center to the radius.

In order to compare the relative value between hydrostatic and hydrodynamic pressures, the hydrostatic pressure, and the hydrodynamic pressure under different peak accelerations of Heishuidiban ground motion and the total hydraulic pressure of tank B are compared and plotted in Fig. 8. As the hydrodynamic pressure under Heishuidiban ground motion of tank B is larger than that under other ground motions, only the hydrodynamic distribution under Heishuidiban ground motion is shown here.

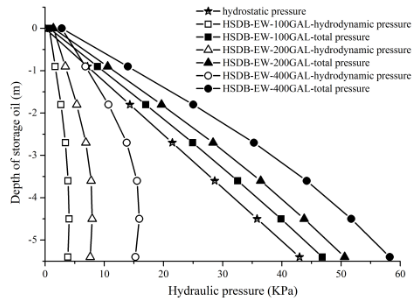
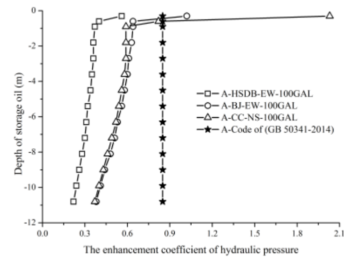


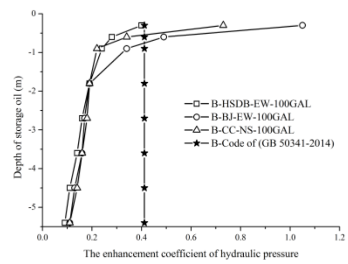
Figure 8. Distribution Conditions of Hydrostatic Pressure, Hydrodynamic Pressure and the Total Hydraulic Pressure.

It can be seen from Fig. 8 that the hydrostatic pressure and hydrodynamic pressure near free liquid surface are small. With the increase of oil depth, the hydrostatic pressure increases linearly, the incremental rate of hydrodynamic pressure decreases gradually, and the hydrodynamic pressure at about one meter to the bottom reaches the maximum. The distribution of total hydraulic pressure obtained by the superposition of hydrostatic and hydrodynamic at the same depth is approximately linear. The larger the peak acceleration of ground motion, the larger the hydrodynamic pressure at the same position, and the increase multiple is seismic coefficient k. The hydrodynamic pressure generated by liquid sloshing under ground motion is not negligible compared with the hydrostatic pressure. Therefore, the hydrodynamic pressure must be taken into account in the oil tank seismic design, and the value of hydrodynamic pressure should be reasonably estimated. The ratio of hydrodynamic pressure and hydrostatic pressure under 100gal peak acceleration ground motion of the three tanks are shown in Fig.9, which also includes the value given by the D.3.7 of Specification (GB 50341-2014). The ratio of hydrodynamic pressure and hydrostatic pressure is referred as hydraulic pressure increase coefficient. Since the hydrostatic pressure at the liquid surface is zero, the hydraulic pressure increase coefficient cannot be calculated. So the only the increase coefficients of hydraulic pressures at 0.3 meters lower than the surface are calculated in Fig. 9.

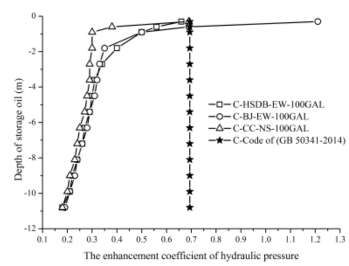
It can be seen from Fig. 9 that the hydraulic pressure increase coefficient increases gradually from tank bottom to liquid surface regardless of tank types. And the increase rate rises at it get closer to the surface. The hydraulic pressure increase coefficients listed in the code are exactly the same along the height of tank wall for calculation convenience and partial conservative. The results show that the hydraulic pressure increase coefficients listed in the code exceed most results by the finite element calculation. The finite element results under partial ground motions are larger than the code results in the range of one meter below liquid surface. Although the partial finite element value exceeds the code value, the hydrodynamic pressure near the liquid surface is smaller, which does not cause a significant change of the total hydraulic pressure. The oil tank is relatively safe near the liquid surface.



a) Results of Tank A



b) Results of Tank B



c) Results of Tank C

Figure 9. Hydraulic Pressure Increase Coefficient of the Finite Element Method and Standard Method for Three Tanks.

Moreover, if the standard values are all beyond the finite element values, it will lead to larger hydraulic pressure, and result in serious imbalance between the economy and function in structural design. The hydraulic pressure increase coefficient by standard calculation still has a high reliability based on the analyses results.

6 CONCLUSIONS

ADINA finite element software is used to analyze the dynamic characteristics and seismic responses of vertical storage tanks in this paper. The following four conclusions are obtained.

(1) The sloshing periods and vibration modes of oil in tanks are obtained through the dynamic

characteristic analyses. The fundamental period of liquid sloshing is calculated using the standard formula given by the Specification and compared with the finite element calculation results. The two values are close to each other, and the correctness and reliability of the finite element model are verified, which lays the foundation for seismic response analyses.

(2) Three natural ground motions are used to analyze the seismic response of oil storage tank, and the distribution characteristics of sloshing wave height are studied: the sloshing wave height is basically in direct proportion to the peak acceleration of the ground motion when the ground motion is the same. The surface sloshing under long period ground motions is fiercer than that under short period ground motions. The sloshing wave height calculated by the standard method is somewhat unsafe in some cases.

(3) The calculation results of hydrodynamic pressure show that the hydrodynamic pressure caused by liquid sloshing cannot be neglected under ground motions. The incremental rate of hydrodynamic pressure decreases gradually in the up-down liquid height direction. The hydrodynamic pressure changes not much at two meters above the tank bottom, and the hydrodynamic pressure is the maximum at about one meter from the tank bottom. The maximum hydrodynamic pressure in the radial direction of the tank bottom is almost symmetrical about the bottom center. The hydrodynamic pressure of bottom center is the smallest and the hydrodynamic pressure of bottom radius is the largest. When the oil height remains the same, the smaller the tank radius, the larger the hydrodynamic pressure is. When the tank radius keeps the same, the larger the storage oil height, the larger the hydrodynamic pressure is. The hydraulic pressure increase coefficients given by the Specification have a high reliability.

(4) The seismic performance of the bottom part of tank wall should be strengthened and improved in the tank seismic design.

7 ACKNOWLEDGMENT

THIS work was supported by Scientific Research Fund for Chongqing University of Arts and Sciences (R2015JJ06, 2017RJJ32). This work was supported by Scientific Research Fund of Chongqing Municipal Education Commission (KJ1601132).

8 REFERENCES

L. Gao, (2015). Self-healing, leakage experimental investigations and seismic response analyses of the ground reinforced concrete tank, *Institute of Engineering Mechanics, China Earthquake Administration*.

A.R. Ghaemmaghami & M.R. Kianoush, (2010). Effect of wall flexibility on dynamic response of concrete rectangular liquid storage tanks under horizontal and vertical ground motions, *Journal of Structural Engineering, ASCE*. 136(4), 441-451.

M.A. Goudarzi & P.N. Danesh, (2016).Numerical investigation of a vertically baffled rectangular tank under seismic excitation, *Journal of Fluids and Structures*.61, 450-460.

M.A. Haroun & G.W. Housner, (1981). Earthquake response of deformable liquid storage tanks, *Journal of Applied Mechanics*. 48(2), 411-418.

S. Hashemi, M.M. Saadatpour and M.R. Kianoush, (2013). Dynamic analysis of flexible rectangular fluid containers subjected to horizontal ground motion, *Earthquake Engineering and Structural Dynamics*. 42(11), 1637-1656.

G.W. Housner, (1963).The dynamic behavior of water tanks, *Bulletin of the Seismological Society of America*. 53(2), 381-387.

M.R. Kianoush & A.R. Ghaemmaghami, (2011). The effect of earthquake frequency content on the seismic behavior of concrete rectangular liquid tanks using the finite element method incorporating soil-structure interaction, *Engineering Structures*. 33(7), 2186-2200.

W.S. Manser, M. Touati and R.C. Barros, (2017).The maximum sloshing wave height evaluation in cylindrical metallic tanks by numerical means, *MATEC Web of Conferences*.95, 17005.

M. Moslemi & M.R. Kianoush, (2012). Parametric study on dynamic behavior of cylindrical ground-supported tanks, *Engineering Structures*. 42, 214-230.

J.H. Park, D. Bae, and C.K. Oh, (2016). Experimental study on the dynamic behavior of a cylindrical liquid storage tank subjected to seismic excitation, *International Journal of Steel Structures*. 16(3), 935-945.

M.R. Shekari, N. Khaji, and M.T. Ahmadi, (2009).A coupled BE-FE study for evaluation of seismically isolated cylindrical liquid storage tanks considering fluid-structure interaction, *Journal of Fluids and Structures*. 25(3), 567-585.

The National Standards of P.R.C., (2014). Code for design of vertical cylindrical welded steel oil tanks (GB 50341-2014), *China Planning Press*.

J.F. Tian & H.Q. Jiao, (2016). A kind of dynamic software behavior trust model based on improved subjective logic, *Intelligent Automation & Soft Computing*. 22(4), 621-629.

A.S. Veletsos, (1974).Seismic effects in flexible liquid storage tanks, *Proceedings 5th World Conference on Earthquake Engineering*. 630-639.

A.S. Veletsos & A.H. Younan, (1998). Dynamics of Solid-Containing Tanks. II: Flexible Tanks, *Journal of Structural Engineering*. 124(1), 62-70.

9 NOTES ON CONTRIBUTORS

Lin Gao received Ph.D. degree in Structure Engineering at the Institute of Engineering Mechanics, China Earthquake Administration. She works at the College of Architecture Engineering, Chongqing University of Arts and Sciences in China. She is an associate professor. Her research interests are finite element calculation simulation analysis of engineering structure.

Mingzhen Wang received Ph.D. degree in Structure Engineering at the Institute of Engineering Mechanics, China Earthquake Administration. He works at the College of Architecture Engineering, Chongqing University of Arts and Sciences in China as a Lecturer. His research interests are finite element calculation simulation analysis of engineering structure.