



Numerical Investigation of a Horizontally Baffled Rectangular Tank Subjected to Seismic Excitation

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ABSTRACT

In this study, the damping effect of the horizontal baffles inside a liquid storage tank is investigated. For this purpose, a numerical model based on the finite volume method is established. The numerical model is used to evaluate the accuracy of the analytical model developed to estimate the hydrodynamic damping caused by wall bounded baffles. For this purpose, several full-scale baffled tanks with different aspect ratios are numerically analyzed, and the validity of the analytical model is discussed with respect to the numerical results. Next, the reduction in sloshing wave height due to the presence of the baffles is considered for selected tanks subjected to seismic excitations. Finally, a simple procedure to seismically evaluate the reduction of sloshing amplitude due to the presence of baffles is proposed and validated using the time history numerical results.

Keywords:

Damping; Horizontal baffles; Rectangular tank; Earthquake; Sloshing

1. Introduction

Sloshing that is the free surface motion inside a container is caused by any disturbance to partially filled liquid containers. Detecting the sloshing phenomenon has various complex aspects, some of which (nonlinearity for example) are subjects unto itself [1]. On the other hand, investigating the consequences of sloshing has also been the focus of many investigations. For example, if the liquid sloshing may cause additional forces exerted on the tank roof [2] and walls, it may lead to the structural failure or other types of instabilities. A sufficient freeboard is generally provided to let the liquid slosh freely in upper part of the tank and consequently to prevent sloshing impact on the tank roof. However, in most of the tanks, especially those with small aspect ratio (i.e. height to length ratio), providing required freeboard leads to uneconomical design.

As another alternative, slosh suppression devices can be employed to damp the liquid motions and prevent sloshing damages. Several types of slosh suppression devices have been employed or have undergone consideration in various applications to increase the damping of liquid sloshing. Due to the simple installation and high performance, baffles are most effective internal components used in most practical problems. Extensive investigations have been carried out to study the sloshing suppression effects of various types of baffles. The majority of these studies have been performed based on experimental methods.

From an analytical point of view, the baffle effects are usually represented as the damping ratio in the mathematical models. Goudarzi et al. [3] developed an analytical model based on the velocity

potential formulation and linear wave theory to estimate the hydrodynamic damping ratio of liquid sloshing for wall bounded baffles. A series of experiments were carried out with a rectangular liquid tank excited by harmonic oscillation in order to evaluate the accuracy of analytical solutions [3]. Maleki and Ziyaeifar [4] also developed an analytical solution using Laplace's differential equation to estimate the damping ratio of liquid sloshing in baffled tanks undergoing horizontal excitation. This method involved the assessment of a dissipated fraction of total sloshing oscillation energy caused by the flow separation around the baffles. A series of experiments employing a tank model on a shake table were carried out to validate the theoretically predicted damping ratio [4]. They also considered the effectiveness of the baffles for seismically isolated cylindrical liquid storage tanks [5]. Panigrahy et al. [6] carried out a series of experiments on a square tank with and without baffles attached to a shaking table. Pressure and displacement were considered by various excitation frequencies of the shaking table and fill levels in the tank.

Zahrai et al. [7] experimentally studied a type of tuned liquid damper with some installed rotatable baffles. The main idea behind installing such baffles was to compensate the effects of probable mistuning of the tuned liquid damper, and it is an effort toward making them more controllable to move forward to a semi-active damper.

The numerical methods are more efficient than the experimental methods for the complex problems especially real scale tanks. The fluid flow field inside a tank equipped by baffles is quite complicated and demands the extensive computational efforts. However, most of the previous researchers employed the computational methods to investigate the behavior of the baffled tanks. Hasheminejad and Aghabeigi [8] introduced a two-dimensional hydrodynamic analysis based on the linear potential theory to study the natural sloshing frequencies of transverse modes in a half-filled non-deformable horizontal cylindrical container of elliptical cross section. A pair of inflexible horizontal baffles of arbitrary extension positioned at the free surface was considered. The Gauss-Laguerre quadrature formula was used to approximate the integral Eigen-Problem obtained in the un-baffled tank. Hasheminejad and Mohammadi [9] also studied the sloshing characteristics of

transverse oscillation modes in a circular cylindrical baffled container. The solution was obtained by the method of successive conformal coordinate transformations, leading to standard truncated matrix eigenvalue problems on rectangular regions, which were then solved numerically for the resonance Eigen-frequencies.

Sygułski [10] investigated the natural frequencies and mode shapes of liquid sloshing in three-dimensional baffled tanks. The boundary element method was used to solve the considered problem. The baffles were treated as double layers immersed in liquid. Belakroum et al. [11] also numerically studied the damping effect of the baffles on sloshing in tanks partially filled with liquid. The studied phenomena formulation is based on an arbitrary Lagrangian-Eulerian description of the governing equations. The stabilized finite element method known as Galerkin least square was used in their study.

Wu et al. [12] used a time-independent finite difference scheme with fictitious cell technique to study viscous fluid sloshing in 2-D tanks with baffles. The governing equations in a moving coordinate system are derived and they are mapped onto a time-independent and stretched domain. An experiment setup was also made to validate the present numerical sloshing results in a tank with baffles. Cho et al. [13] investigated the numerical analysis of the resonance characteristics of liquid sloshing in a 2-D baffled tank subjected to the forced lateral excitation. Sloshing flow was formulated based on the linearized potential flow theory. Finite element method was developed for the resonant sloshing analysis in frequency domain.

Akyildiz and Unal [14] have numerically and experimentally carried out the pressure variations and three-dimensional effects on liquid sloshing loads in a moving partially filled rectangular tank. A numerical algorithm based on the volume of fluid technique was used to study the non-linear behavior and damping characteristics of liquid sloshing on several configurations of both baffled and un-baffled tanks.

Three-dimensional liquid sloshing in a baffled tank was also considered using the numerical models [15]. The second-order volume-of-fluid method was used to track the distorted and broken free surface. The baffles in considered tank were modeled by the concept of virtual boundary force method.

Xue and Lin [16] developed another three-dimensional numerical model to study viscous liquid sloshing in a tank with internal baffles. The numerical technique named virtual boundary force method was used to model the internal baffles with complex geometries. In the mentioned study, laboratory experiments were also conducted for non-linear sloshing in a rectangular tank with and without vertical baffles. Liquid sloshing in a 3-D prismatic tank with different ring baffle arrangements were further investigated under near-resonant excitations of surge and pitch motions.

Biswal and Bhattacharyya [17] considered the dynamic interaction between the liquid and elastic tank baffle system to evaluate the coupled response of liquid and tank baffle system using the finite element method. The finite element equations of liquid motion and structure domains are numerically integrated by Newmark integration scheme. The interaction effect between the two fields was studied by transferring the structural normal acceleration to the liquid domain and liquid pressure to the structure domain. Effects of different parameters, such as composite baffles, lamination scheme on the slosh frequencies, and coupled vibration frequencies in the liquid filled composite tanks were studied.

Hosseini et al. [18] presented a method for reducing the analysis duration based on conducting several dynamic analysis cases by using ANSYS-CFX for rectangular tanks of various dimensions, subjected to seismic excitations. They used neural network to create simple relationships between the dominant frequency and amplitude of the base excitations and the maximum level of liquid in the tank during the sloshing.

Although many studies have been performed on the baffled tanks, the seismic behaviors of liquid tanks equipped by the baffles are very rare. In a previous study, the authors developed an analytical method for evaluating the damping effects of horizontal baffles inside a rectangular container. The results of the analytical solution were validated by experimental measurements on small scale tanks [3]. This paper complements the author's previous study in two ways: First, the validity of analytical solution for full-scale liquid tanks is considered. Second, the effect of baffles on the height reduction of sloshing wave caused by a seismic excitation is considered. In this regard, three tanks with different aspect

ratios are numerically analyzed under real earthquake excitations, and their results for baffled and unbaffled tanks are compared. Finally, a useful practical procedure to estimate the reduction in Maximum Sloshing Wave Height (MSWH) due to the presence of horizontal baffles is proposed. The validity of proposed method is examined by the results of numerical analysis.

2. Analytical Evaluation of Horizontal Baffle Damping Effects

The derivation of analytical model to predict the damping effects of the horizontal baffles was presented by the Goudarzi et al. in a previous paper [3]. In the referred paper, an analytical model was developed to estimate the hydrodynamic damping ratio of liquid sloshing for wall bounded baffles using the velocity potential formulation and linear wave theory. The final results of the mentioned analytical solution for the damping ratio caused by horizontal baffles were obtained as:

$$\xi_h = \frac{6}{a^2} \sqrt{L\eta_{\max}} \left(\frac{\sinh\left(\frac{\pi Z}{2a}\right)}{\sinh\left(\frac{\pi h}{2a}\right)} \right)^{2.5} \tanh\left(\frac{\pi h}{2a}\right) \lambda \quad (1)$$

where, η_{\max} is the maximum sloshing amplitude, and λ is a constant value that represents the effect of velocity variation along the baffle length.

$$\lambda = \left[\frac{a}{6\pi} \sin\left(\frac{3\pi L}{2a}\right) + \frac{3a}{2\pi} \sin\left(\frac{\pi L}{2a}\right) \right] \quad (2)$$

For relatively small baffle length, λ can be assumed to be equal to the baffle length (L). Based on this approximation, which is valid for practical range of horizontal baffle lengths ($L/a < 0.25$), the above relation can be simplified as :

$$\xi_h = 6 \left(\frac{6}{a} \right)^{1.5} \sqrt{\frac{\eta_{\max}}{a}} \left(\frac{\sinh\left(\frac{\pi Z}{2a}\right)}{\sinh\left(\frac{\pi h}{2a}\right)} \right)^{2.5} \tanh\left(\frac{\pi h}{2a}\right) \quad (3)$$

where, Z is the vertical location of baffle measured from the tank bottom, and the other related parameters are presented in Figure (1). The details of the analytical background for extracting the above relations can be found elsewhere [3].

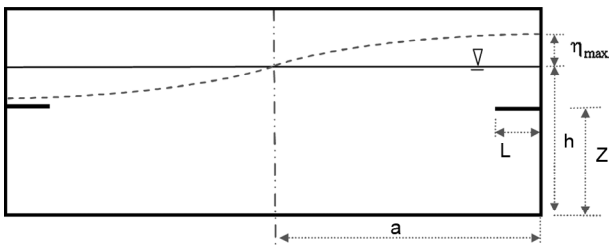


Figure 1. Schematic model of the tank with corresponding parameters.

3. Numerical Model

To obtain solution for real flow, a numerical approach is developed. Under this approach, the governing equations are replaced by algebraic approximations and are solved using a numerical method. In this paper, the numerical modeling is implemented in a CFD code, ANSYS CFX, to establish the nonlinear volume of fluid model. Free surface flow refers to a multi phase situation where the fluids are separated by distinct resolvable interface. Due to its comparatively low computational cost and good numerical stability, the homogeneous model has usually been preferred and used in the sloshing studies [19]. In fact, this model is one type of the Eulerian-Eulerian homogeneous models under which the volume fractions of the phases are equal to one or zero everywhere except for the phase boundaries.

The equations for the homogenous multi phase model are discretized using the element-based finite volume method. Gauss's divergence theorem, and the implicit second-order backward Euler are used to discretize different phases. Each step of the solution is iterated on the full grid as the algebraic multi-grid solution strategy has been found to result in computational instabilities. The solution for two phases is obtained by solving the equations for volume continuity, conservation of mass and momentum for each phase. More details on the numerical modeling and related theoretical background can be found in CFX theory manual [20].

4. Verification of the Numerical Model

In order to verify the numerical model, the shaking table tests on a rectangular tank conducted by the author at the hydraulic institute of Stuttgart University are used [1]. In these experiments, the response of the rectangular tank was studied under

the harmonic sinusoidal excitation. The details of the experiment specifications can be found in reference [1].

The liquid sloshing is strongly dependent on the natural frequency of the contained liquid as well as the amplitude and frequency of the tank motion. Therefore, three experimental cases in which the forced frequency is less, close, or greater than the natural tank frequency are selected used to validate the numerical model. The tank geometry and the harmonic sinusoidal input excitations are identical under the numerical analysis and the conducted experiments. The results of the numerical model for sloshing wave height are compared with the results of the corresponding experimental measurements. These comparisons for the free surface displacement at the left wall of the tank with aspect ratio (h/a) of 0.4 are shown in Figure (2). As can be seen, the numerical results are in well agreement with the experimental measurements that confirms the validity of the numerical modeling.

5. Assessment of the Analytical Solution for Full-Scale Tanks

In this section, the accuracy of the developed analytical solution in the case of full-scale liquid storage tanks is examined. For this purpose, the numerical model validated in previous section is employed.

5.1. Specifications of the Considered Full-Scale Tanks

Three rectangular tanks are selected with aspect ratios of $h/a = 0.3, 1, \text{ and } 2$ representing the broad, medium, and slender tanks, respectively. Two relative baffle lengths are used for each tank ($a/L = 0.2$ and 0.11). For each aspect ratio (h/a), the baffles are located at three relative vertical heights ($Z/h = 0.6, 0.7, \text{ and } 0.9$). Considering the variables, the total numbers of 21 cases are numerically analyzed in parametric study, the specifications of which are presented in Table (1).

5.2. Numerical Results

The considered tanks are oscillated at the resonant frequency until reaching enough large free surface displacement. Then the oscillation is stopped and the decay rate of free surface displacement is monitored in the free vibration mode. As an example,

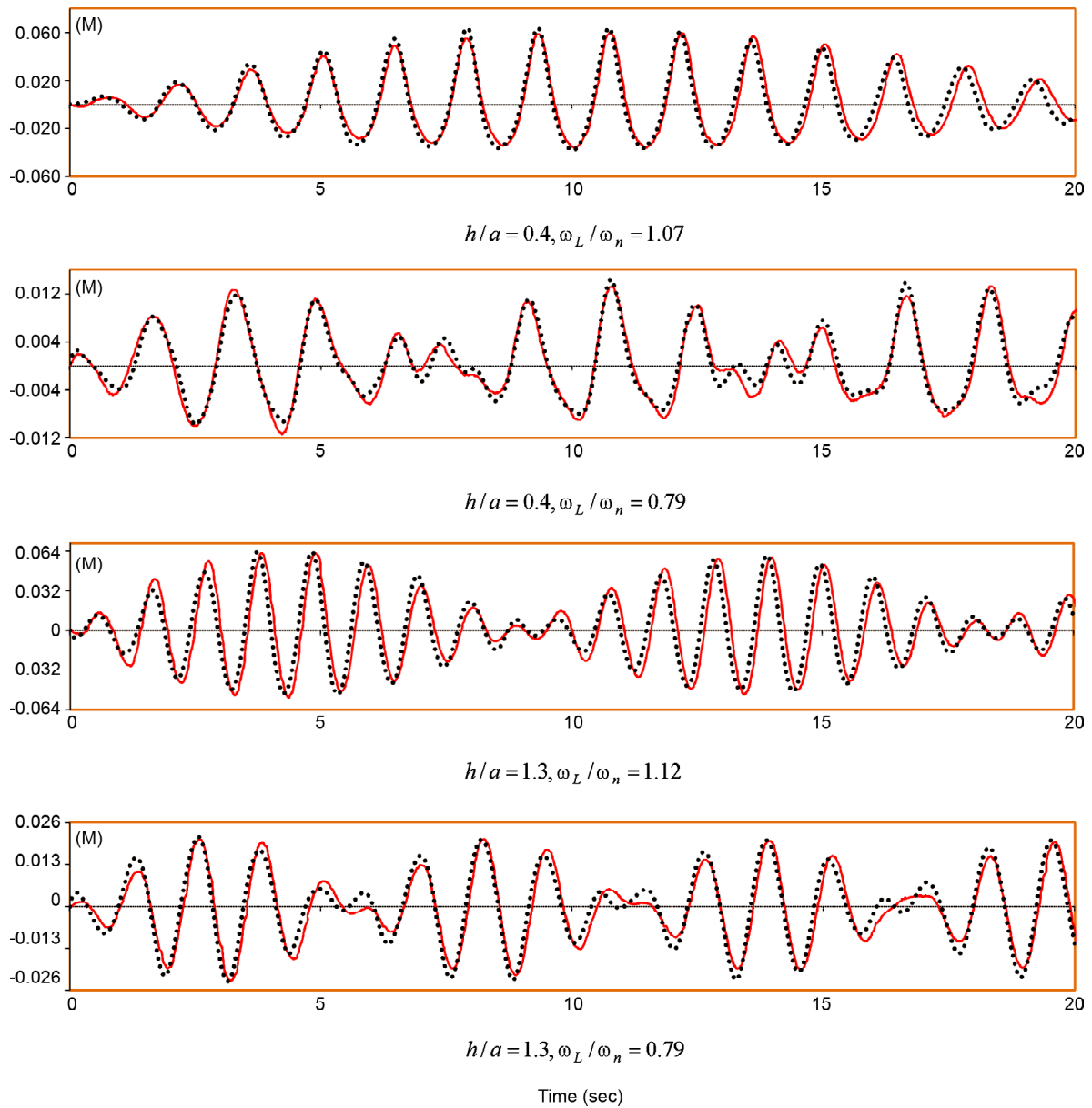


Figure 2. Comparison between experimental and numerical results.

Table 1. Specifications of the full-scale tank used for numerical analysis.

	h (m)	a (m)	h/a	L/a	Z/h	T_1 (sec)
Case 1	3	10	0.3	5	0.6	7.64
Case 2	3	10	0.3	5	0.75	7.64
Case 3	3	10	0.3	5	0.9	7.64
Case 4	3	10	0.3	9	0.6	7.64
Case 5	3	10	0.3	9	0.75	7.64
Case 7	3	10	0.3	9	0.9	7.64
Case 7	10	10	1	5	0.6	5.28
Case 8	10	10	1	5	0.75	5.28
Case 9	10	10	1	5	0.9	5.28
Case 10	10	10	1	9	0.6	5.28
Case 11	10	10	1	9	0.75	5.28
Case 12	10	10	1	9	0.9	5.28
Case 13	12	6	2	5	0.6	3.92
Case 14	12	6	2	5	0.75	3.92
Case 15	12	6	2	5	0.9	3.92
Case 16	12	6	2	9	0.6	3.92
Case 17	12	6	2	9	0.75	3.92
Case 18	12	6	2	9	0.9	3.92

the time history of relative sloshing wave height during free vibration phases for the broad tank are shown in Figure (3). In this figure, for each baffle vertical position (h/Z), the results are compared for two different baffle lengths ($L/a = 1.5$ and 1.9). As can be seen, for the larger baffle length (i.e., $L/a = 1.5$) sloshing amplitude descends more rapidly under all baffle positions because the larger baffle provides higher hydrodynamic damping. In other words, the system shows lower settling time responses in high-damped cases. Besides, it is noticeable that using larger baffle can elongate the oscillation period at free vibration condition.

In Figure (4), the time histories of the normalized sloshing responses are presented for various vertical baffle positions but constant baffle length. According to this figure, as the relative vertical baffle height is

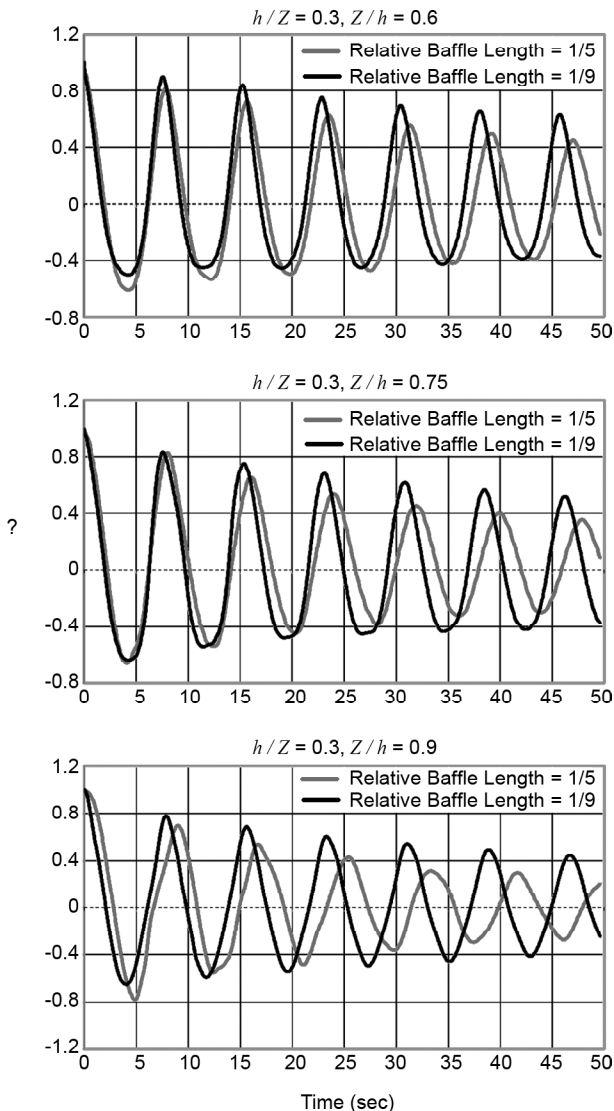


Figure 3. Time history of relative sloshing wave height in free vibration phase for two different baffle lengths.

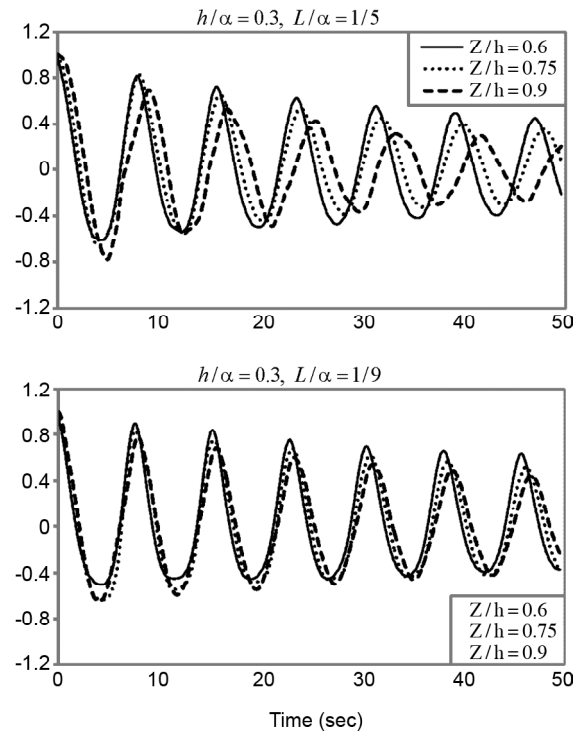


Figure 4. Time history of relative sloshing wave height in free vibration phase for two different baffle lengths.

increased (i.e. the baffle is moved closer to the free surface), the elongation of free oscillation period and the rate of sloshing suppressing are increased. The same trend is observed for other tank aspect ratios. The hydrodynamic damping provided by horizontal baffles are extracted from numerical analysis for considered tanks and presented in Figures (5) and (6). In these figures, corresponding damping ratio obtained from analytical solution (Eq. (3)) are also presented. Before discussing these results, it should be noted that the analytical solution can only calculate the damping ratio caused by horizontal baffles. However, the damping ratio is also dependent on the inherent viscosity that should be taken into account. In real world storage tanks, the damping ratio provided by baffles is usually much higher than viscous damping (which is less than 0.5%), and its effect is generally negligible. However, in order to properly compare the analytical and numerical results, the viscous damping of considered cases should be evaluated. For this purpose, the viscous damping is numerically obtained from free vibration analysis of considered un-baffled tanks. The calculated viscous damping ratios for broad, medium, and slender tanks are 0.21, 0.28, and 0.25, respectively. Hence, the analytical damping ratios presented in Figures (5)

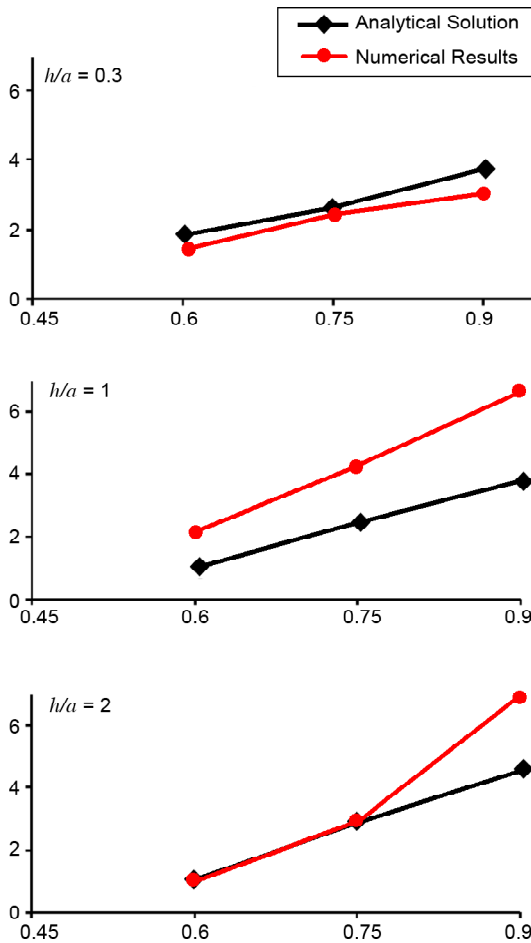


Figure 5. Hydrodynamic damping ratio of horizontal baffles (Relative baffle length $L/a=1/5$).

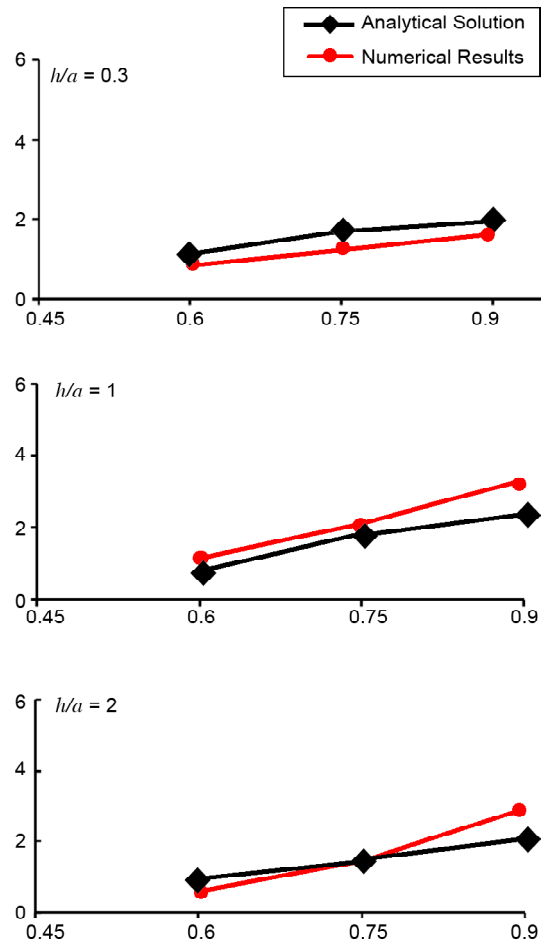


Figure 6. Hydrodynamic damping ratio of horizontal baffles (Relative baffle length $L/a=1/9$).

and (6) are calculated by adding the viscous damping to the baffle damping predicted by Eq. (3).

According to Figures (5) and (6), the damping ratio in all cases generally increases with an increase in the relative vertical position of the baffles (Z/h). In addition, it is seen that using the larger baffle length (L/a) leads to relatively higher damping ratio in all cases. The similar trends are also predicted by the analytical solution (Eq. (3)). In general, it can be concluded that the predictions of the analytical solution are in good agreement with the results of numerical analysis, especially for the cases with smaller baffle length ($L/a=1.9$). However, it is not the case for the cases with the larger baffle length ($L/a=1.5$). This is due to the fact that larger baffle length occupies the larger part of a tank width that results in more velocity field disturbance inside the tanks. Therefore, the linear theory and other related assumptions, which are originally developed for un-baffled tanks are no longer valid. Therefore, it is expected that the accuracy of the analytical predic-

tions is reduced for larger baffle lengths.

In Figures (5) and (6), it is also noticeable that the differences between analytical and numerical results are increased by increasing the vertical position of the baffles (especially for $Z/h=0.9$). The same justification can be given to explain this discrepancy, that is, the liquid velocity is increased near the free surface. Therefore, as the baffle is moved closer to the free surface, more disturbances are caused by the presence of the baffle, and again, the accuracy of velocity potential theory is reduced.

6. Real-Scale Tanks with Baffles under Earthquake Excitation

In this section, the efficiency of horizontal baffles to reduce the Maximum Sloshing Wave Height (MSWH) caused by the seismic excitation is examined. For this purpose, the three tanks introduced in the previous section (with aspect ratio of 0.3, 1, and 2) are selected for seismic response analyses. Due to the fact that the storage tanks usually have a

significantly longer fundamental natural liquid motion period than most of the building structures, the liquid natural frequencies are generally excited by long period motion records which considerably affect the liquid sloshing response of the tanks. Therefore, the numerical simulations of large amplitude sloshing are conducted for the considered tanks subjected to the Kocaeli 1999 earthquake from Yarimca (YPT060) station. This record, known as a long period ground motion is scaled for peak ground acceleration of 1.32 m/s^2 .

The relative baffle length (L/a) of $1/7$ and the relative height (Z/h) of 0.85 is used for each tank. The time history of liquid sloshing amplitude caused by exerted seismic record is extracted at a point near the tank wall. These results for the baffled and un-baffled tanks are compared in Figure (7). It can be seen, regardless of the base excitation input, that the sloshing amplitudes oscillate predominantly at a frequency very close to the fundamental natural frequency of the liquid.

From a design viewpoint, the MSWH is usually more important than free surface. As can be seen in Figure (7), the MSWH of the slender tank ($h/a = 2$) occurs in free vibration phases after the seismic excitation, while, for broad and medium tanks, the MSWH occurs during the seismic excitation. It is also seen that even using the small horizontal baffles can efficiently suppress the sloshing motion and significantly reduce the MSWH. The MSWH for broad, medium, and slender tanks with and without baffles are 0.28 , 0.62 , 0.78 and 0.47 , 1.11 , 1.13 , respectively. Therefore, the reductions of 40% , 0.44% and 30% in design free board can be achieved by using the horizontal baffles in the considered tanks, which indicates that the baffles are efficient suppression devices against the seismic loads.

7. Application for Seismic Design of Liquid Storage Tank

The aim of this section is to suggest a practical method to estimate the reduction in the sloshing wave height for a tank equipped by horizontal baffles and subjected to earthquake excitations. Where overtopping is tolerable, no freeboard provision is necessary. While, if the loss of liquid should be prevented (for example, tanks for the storage of toxic liquids), or the overtopping of liquid may result in scouring of the foundation materials or cause damage to pipes and

tank roof, then a freeboard allowance should be provided or the roof structure should be designed to resist the resulting uplift pressure. In this regard, the amount of required freeboard in liquid tanks is commonly determined by the famous seismic design codes and standards based on the maximum vertical displacement of the free surface caused by the earthquake acceleration.

Therefore, design codes generally suggest the relation for evaluating the MSWH. For example, the American Concrete Institute standard (ACI 350.3-01) gives the following expression to calculate the MSWH or maximum vertical displacement in rectangular tanks:

$$d_{\max} = \left(\frac{L}{2} \right) \times (ZSI \times C_c) \quad (4)$$

where, L is the length of the tank, Z is the seismic zone factor, S is the soil profile coefficient, and C_c is the spectral amplification factor which is usually computed according to the natural period of the first convective mode. In above relation, it is assumed that the inherent viscous damping of liquid is equal to 0.5% . However, with regard to the type of liquid and the dimensions of the considered tank, the viscous damping may be less or greater than 0.5% . Therefore, for the condition in which the damping ratio (ξ) is not equal to 0.5% , guidelines are needed to provide the provisions for evaluating the MSWH. In this regard, ACI suggests that the period dependent spectral acceleration should be modified by the ratio (δ_c) to account for the influence of damping on the spectral amplification as follows:

$$\delta_c = \left(\frac{3.043}{2.73 - 0.45 \times \ln(\xi)} \right) \quad (5)$$

For a damping ratio of 0.5 percent ($\xi = 0.5$), the modification factor is equal to one ($\delta_c = 1$).

Based on the above modification factor context, a procedure for estimation of MSWH with the presence of the baffles is proposed. When the horizontal baffles are used inside a tank, the hydrodynamic damping is increased by the presence of the baffles. This hydrodynamic damping can be calculated from the analytical relation (Eq. (3)), as discussed in previous sections. Therefore, the modification factor (Eq. (5)) can be used to evaluate the horizontal baffle damping effects on the liquid sloshing height.

Considering foregoing discussion, the subsequent steps are proposed to evaluate the reduction in MSWH due to the presence of a horizontal baffle.

1. The damping ratio caused by the horizontal baffles is calculated from Eq. (3).
2. Using the damping ratio caused by the baffles (and calculated in step 1), the modification factor is computed from Eq. (5).
3. The MSWH is calculated from Eq. (4) for the tank without baffles.
4. The MSWH for the tank equipped by baffles is obtained by multiplying the MSWH of un-baffled tank (Calculated in step 3) divided by the modification factor (calculated in step 2).

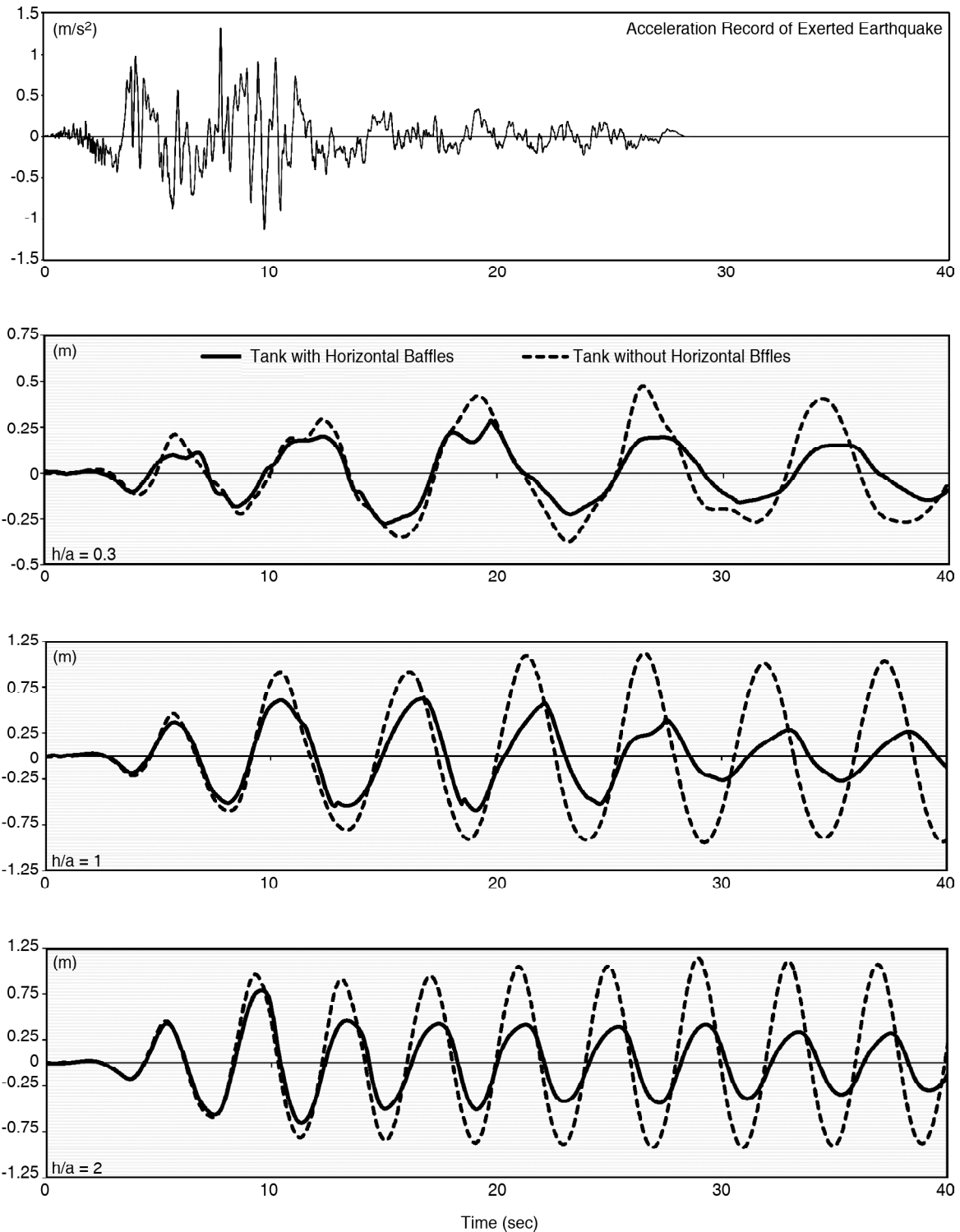


Figure 7. Comparison between the time histories of liquid sloshing caused by seismic excitation for the considered baffled and un-baffled tanks.

Although the tanks considered here are subjected to a specific earthquake excitation, it is interesting to use the above proposed method for three full-scale tanks numerically analyzed under real earthquakes. The MSWH for the un-baffled tanks are extracted from the numerical results. Then, the damping ratio caused by the baffles and the modification factor are calculated from Eq. (3) and Eq. (5) for each tank. These variables are presented in Table (2). Finally, the MSWH for the tanks equipped by horizontal baffles are predicted by the MSWH of the un-baffled tanks divided by the corresponding modification factors.

As can be seen, the predictions of the proposed method are in a very good agreement with the numerical results for baffled tanks, regarding the assumptions and approximations involved in the analytical relation of baffle damping and modification factor as well as the inherent random nature of the exerted record.

8. Conclusion

In this study, the hydrodynamic damping effects of the horizontal baffles in full-scale tanks are numerically investigated. First, the numerical strategy is validated by comparing its results with the available experimental measurements on small-scale tanks. Then, the accuracy of the analytical model is examined for tanks with real dimensions. Three rectangular tanks are selected with aspect ratios of $h/a=0.3, 1$ and 2 , which represent the broad, medium, and slender tanks, respectively. Two relative baffle lengths and three relative vertical positions are considered for each tank. The total numbers of 21 cases are numerically modeled for parametric study. The numerical results in term of the hydro-dynamic damping are compared with ana-

lytical solution results, and the validity of analytical formulation for using in real applications is discussed. The following conclusions can be made:

1. The analytical predictions are in well agreement for most of the cases. However, for few cases (with large baffle length), the analytical model predictions underestimate the hydrodynamic damping. In these cases, the baffle length is relatively large compared with the other tank dimensions, and the analytical assumptions are no longer valid.
2. The larger the baffle length is, the more rapidly sloshing amplitude decreases and the more elongation of the oscillation period at free vibration condition is observed.
3. As the baffles is moved closer to the free surface, the damping ratio in all cases generally increases.

In second part, the efficiency of horizontal baffles under seismic excitation is considered, and the design procedure to evaluate the effect of horizontal baffles on the suppression of sloshing wave height is proposed. In this regard, the predictions of proposed method are compared with numerical analysis results.

The following conclusions can be achieved:

1. The horizontal baffles can efficiently suppress the sloshing motion and significantly reduce the Maximum Sloshing Wave Height (MSWH). The reduction of 40% of MSWH is averagely achieved for the cases considered in this study.
2. The seismic design procedure is proposed and examined by the numerical results. The predictions of the proposed method are in a very good agreement with the numerical results, regarding the assumptions and approximations involved. The procedure should be verified for further input excitation.

Table 2. The comparison of numerically evaluated and new method predicted MSWH for the considered tanks equipped by horizontal baffles.

	Tanks Specifications					Numerical Results		$\xi(\%)$	δ_c	Proposed Method	Error (%)
	h	a	h/a	Z/h	a/L	Un-Baffled $\eta_{1N\max}$ (m)	Baffled $\eta_{2N\max}$ (m)	$\xi(\%)$	δ_c		
Broad	3	10	0.3	0.85	7	0.46	0.285	2.5	1.31	0.35	16%
Medium	10	10	1	0.85	7	1.1	0.625	5.62	1.56	0.7	10%
Slender	12	6	2	0.85	7	1.14	0.78	4.78	1.5	0.76	2%

$\eta_{2P\max}$ is the maximum sloshing height for the tank with baffle predicted by the new proposed method

$\eta_{2N\max}$ is the maximum sloshing height the tank with baffle obtained from numerical analysis

$\eta_{1N\max}$ is the maximum sloshing height the tank without baffle obtained from numerical analysis

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