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Effect of Near-Fault Earthquakes on the Sloshing Behavior of Concrete Rectangular Liquid Storage Tanks

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ABSTRACT: One of the most important components of water supply systems is liquid storage tanks. Regarding the importance of the effects of near-fault earthquakes and their effect on seismic behavior and structures loads, in this study, the sloshing height and vibration of 2D concrete rectangular tanks under near- and far-fault earthquakes was investigated using numerical methods. The effect of tank's dimensions, water's depth and ground motion characteristics on the maximum sloshing height was taken into account with considering 9 typical tank models and 10 near- and far-fault ground motion records. The acquired results of this study indicated that the median values of maximum sloshing height in the near-fault records are significantly higher than those related to far-fault records. The average of increase of sloshing heights in tanks with lengths 20, 40 and 60 meters is 65, 77 and 100 percentages, respectively. In tanks subjected to far- and near-fault earthquakes, sloshing height had the highest correlation with Arias Intensity and PGV, respectively. According to the results of this research, correction coefficients for the relations and formulas presented in the codes can be proposed to consider the effects of near-fault earthquakes in calculating the maximum sloshing height.

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1-Introduction

Based on increasing the population and development of cities, design, instruction and maintenance of the water storage tanks, have great importance. One of the most important issues related to fluid-structure interaction (FSI) in the liquids storage tanks is the sloshing phenomenon resulted by earthquake excitation of tank. Heretofore, many studies have been performed by different researchers on seismic behavior of water storage tank as analytically [1], experimentally [2] and numerically [3]. In these investigations, the effect of amplitude, natural excitation frequency of tank, depth and characteristic of fluid, geometry and location of tank, flexibility of wall, nonlinear sloshing, existence of horizontal and vertical baffle in the wall and floor of the tank have been surveyed. In these researches the effects of different phenomena on the behavior of tank under earthquake have been examined. However, difference between tank behaviors under near-fault records and far- ones in the past researches has been studied briefly. Base shear values and sloshing heights in the cylinder tanks with rigid wall under some near-fault records has been examined by Kalogerakou et.al. [4]. The results of their studies revealed that the maximum values of mentioned parameters are underestimate compared to criteria in the Euro code 8. In the current research, due to lack of sufficient resources in order to predict the behavior of liquid tanks under near-fault earthquake, the parameters which plays an important role in the behavior of tanks under these records has been studied. For this purpose, 9 typical tanks with different dimension under 10 near-fault records and the same one for far-fault records have been analyzed using ANSYS software and their behavior has been investigated.

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2-Numerical Modeling

Schematic layout of a 2D tank has been illustrated in Figure 1. The characteristics and dimensions of studied tank has been also presented in Table 1 that Hw , tw and HL are height and wall thickness of tank and height of liquid inside the tank, respectively.

Table 1. Properties and dimensions of the studied tanks

Specifications	H_L=6m H_w=6.5m t_w=0.6m	H_L=9m H_w=9.75m t_w=0.9m	H_L=12m H_w=13m t_w=1.2m
Type of tank	Shallow (H_L=6m)	Medium (H_L=9m)	Tall (H_L=12m)
Short(L=20m)	20×6	20×9	20×12
Medium(L=40m)	40×6	40×9	40×12
Long(L=60m)	60×6	60×9	60×12

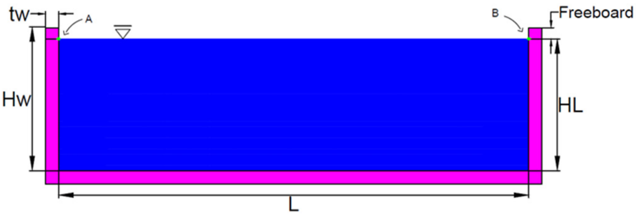

Figure 1. A Schematic view of model

In the modeling, it is assumed that the tank has plain strain behavior and tank's wall is flexible. The foundation of the tank is rigid and the behavior of structure and liquid is linear. In order to evaluate the linear finite element model, the sloshing height at the "point A», resulted from linear model have been calculated and compared with those of analytical which presented by Goudarzi and Sabbagh-Yazdi [5]. The time history diagram presented in Figure 2 shows a comparison between numerical and analytical methods for obtained values of sloshing height.

The results showed that there is a good relevance between both numerical and analytical methods. Furthermore the numerical method has proper performance for prediction of liquid sloshing height.

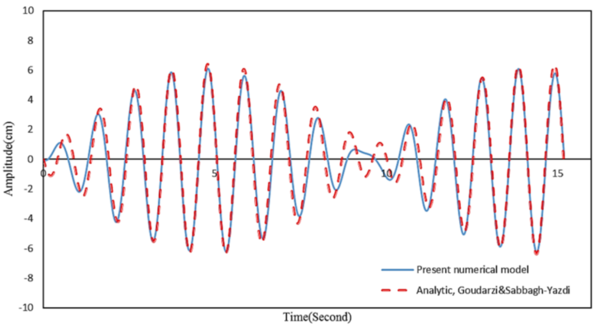

Figure 2. Comparison of obtained values of sloshing height in "point A" extracted from numerical and analytical methods

3-Results and Discussion

In order to determine the effect of different parameters of near- and far-fault earthquake on studied models, 10 near-fault records and also 10 far- ones have been selected. In the Tables 2 and 3 the characteristics of these records have been presented. Moreover, in the current study the records have been scaled using Charney method [6].

Table 2. Near -fault ground motion records

No	Event	Year	Closest
1	Whittier Narrows-01	1987	2.8
2	Morgan Hill	1984	0.5
3	Kobe Japan	1995	1.5
4	Superstition Hills-02	1987	1
5	Northridge-01	1994	5.5
6	Cape Mendocino	1992	8.2
7	Imperial Valley-06	1979	0.1
8	Imperial Valley-06	1979	4
9	Loma Prieta	1989	8.5
10	Landers	1992	2.2

Table 3. Far -fault ground motion records

No	Event	Year	Closest
1	Kocaeli, Turkey	1999	15.4
2	Manjil, Iran	1990	12.6
3	Kobe Japan	1995	19.2
4	Duzce, Turkey	1999	12
5	Northridge-01	1994	12.4
6	Cape Mendocino	1992	14.3
7	Imperial Valley-06	1979	12.5
8	Imperial Valley-06	1979	22
9	Loma Prieta	1989	12.8
10	Landers	1992	19.7

The maximum values of sloshing height extracted from time history analysis which is related to one of the corners of the tank have been presented in the Tables 4-6.

Table 4. Maximum sloshing height (mm) in short tanks

Tank	20×6		20×9		20×12	
Event row	Far	Near	Far	Near	Far	Near
1	1309	146	678	177	685	316
2	415	176	506	199	536	252
3	902	365	714	473	599	528
4	351	1728	393	1404	360	1757
5	177	2053	300	1649	344	2067
6	411	495	332	625	405	741
7	576	1765	527	1863	615	1465
8	675	1848	1550	1965	2093	1649
9	355	872	413	2269	801	1267
10	469	1615	469	1438	512	3122
Median	490	772	522	882	597	1007

The accuracy of results which presented in the above Tables confirm that the median values of maximum height of sloshing increase in the near-fault ground motion records in comparison with far-fault ones. The average of this height increscent in tank with 20 m width is 65 %, in tank with a width of 40 m is 77% and for tank with 60 m width is 100 %. One of the most important structural features which influence significantly on sloshing height is dimension of tank. Based on presented results it is observed that with increase of tank's depth, the median of maximum height of sloshing increases in the near-fault ground motion records.

Table 5. Maximum sloshing height (mm) in medium tanks

Tank	40×6		40×9		40×12	
Event	Far	Near	Far	Near	Far	Near
1	591	109	352	156	350	352
2	152	141	290	158	488	218
3	660	320	690	405	470	420
4	305	1108	417	976	308	1410
5	120	1462	202	1450	247	1905
6	331	405	345	487	529	637
7	283	1556	424	1689	713	1339
8	511	1427	1057	1576	1057	1151
9	299	394	355	1317	745	998
10	288	1800	431	1662	525	3554
Median	312	589	411	725	498	857

Table 6. Maximum sloshing height (mm) in long tanks

Tank	60×6		60×9		40×12	
Event	Far	Near	Far	Near	Far	Near
1	597	95	323	146	285	225
2	184	115	219	135	270	196
3	453	270	352	374	319	395
4	238	1116	290	818	237	1031
5	116	1390	189	1321	226	1732
6	289	362	313	445	420	580
7	259	1494	276	1628	375	1273
8	396	943	775	986	1076	1003
9	268	435	310	913	627	688
10	157	1243	208	1554	323	2917
Median	265	513	300	617	367	735

For further study about correlation of sloshing height with near- and far-fault earthquake parameters, the values of sloshing height with parameters of Peak Ground Velocity (PGV), Peak Ground Acceleration (PGA), ratio of PGV to PGA, ARIAS intensity, pulse period (Tp) and Pseudo Spectral Displacement (PSD) have been studied. A linear regression has been performed between logarithm of sloshing height and logarithm of mentioned parameters and their correlation coefficient has been obtained. The investigation of the correlation coefficient revealed that in the far-fault records, the sloshing height has the most correlation with ARIAS parameter and for near-fault records, it is correlated with PGV. Moreover, the median of maximum values of sloshing height related to different tank which computed using finite element method, has been studied and also compared with sloshing height obtained of ACI criteria [7] and presented formulas by Housner [8]. In this research, the earthquake coefficient of convective mass has been computed using two approaches. In the first method, the design spectra used by ACI criteria considering an assumption of SDS=0.9g. The selected SDS is a number between spectra components corresponding with type II and III soils which extracted from design spectra in 2800 code [9]. In the second approach, median spectra of the records has been used. The obtained results have been shown in Figure 3.

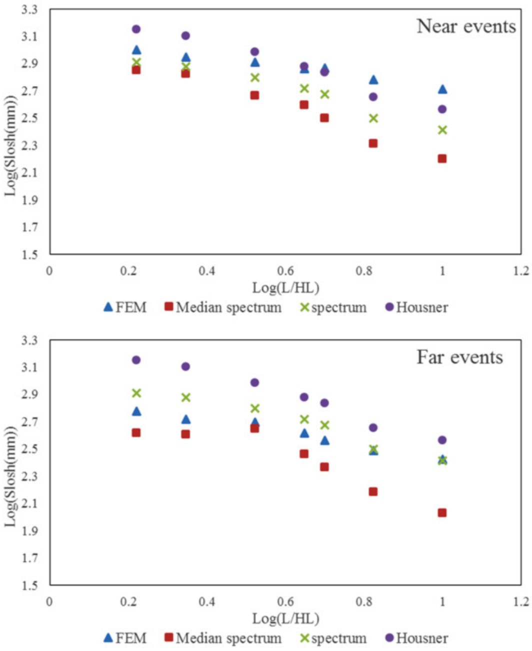

Figure 3. The logarithm of maximum values of sloshing height versus logarithm of L/HL ration in the near- and far-fault records

As shown in the Figure 3, it is concluded that in the far-fault ground motion records, the computed values of sloshing height using design spectra obtained by ACI criteria are less than numerical values. This difference especially in the high ratios of L/HL is little, but under the near-fault records, is less than numerical method.

4-Conclusions

With considering the performed comparisons, the median values of maximum height of sloshing in the near-fault ground motion records show significant increase in comparison with far ones. The average of this sloshing increase, in tanks listed as 20, 40 and 60 m, are 65%, 77% and 100%, respectively. The change in the median value of maximum sloshing height is different with the change of liquid's depth and width of tank. In the other hand, with increasing of the liquid's depth and width of tank, the median of maximum sloshing height increases and decreases, respectively. In tanks which excited by far-fault ground motion, the sloshing height has the most correlation with ARIAS intensity and in the near-fault ones it has the best correlation with PGV. In the far-fault ground motion records, the maximum sloshing height computed by ACI criteria has a good relevance with the numerical method, but in the near-fault ones these values have a great difference with each other. Therefore, it seems that the relation and formulas should be reviewed and modified for near-fault earthquakes. Based on performed analyses, a modification coefficient which is predicted for short, medium and long tanks are 1.21, 1.44 and 1.72, respectively.

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