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Comparison of Standard No. 2800 with ASCE7 to Scale Earthquake Records for Seismic Assessment of Existing Steel Oil Storage Tanks

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Abstract

The significance of earthquake effects on storage tanks compels researchers to investigate tanks seismic responses. In spite of the recent design codes developments, there is no accepted procedure to scale ground motions to perform time-history analysis for these very stiff structures. Nevertheless, standards for conventional structures have long been minimized in a predefined range of periods the difference between the response spectra of chosen records and the target spectrum. Since design specifications have important differences in their scaling procedures, it gives rise to affect on seismic response of structures. In this paper, the various seismic responses of several existing cylindrical tanks in an oil storage complex in Kashan, Iran are evaluated. The earthquake records have been separately scaled according to the procedure described in Iranian Standard No. 2800 and ASCE/SEI 7-10. The results indicate the different consequences of the scaling procedures for the tanks responses.

Keywords: Storage tank, Design code, Scaling procedure, Target spectrum, Seismic response.

1- INTRODUCTION

Petroleum storage tanks are essential structures that provide basic supplies The primary sources of fossil fuels and also it has a flammable chemical structure, which in case of entrance and distribution to the environment, damaged it. It is very important that this kind of structure remain operational after a destructive seismic event to facilitate rapid recovery. Because of the importance of these structures many studies have been carried out [e.g. 1–3] and standards and design guides have been established [4 , 5] and compared [6]. Yet despite the importance of storage tanks, there is no specific widely accepted procedure for time-history analysis to enable an estimation of the behavior of oil storage tanks under a specific seismic excitation. Current design practice only provides seismic coefficients based on a pseudo-dynamic method of assessment. Using this design method, it is impossible to see the potential for successive plastic incursions of the structural elements of storage tanks (shell and base plate). It has been shown [7] that such plastic behavior will lower the impact of earthquake loading whilst imposing ductility requirements. Kalogerakou et al. [8] worked on the hydrodynamic response of

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cylindrical liquid-containing tanks with stiff walls under seismic excitations and they conclude The simulation of near-fault records by simplified wave lets is a useful tool to estimate near fault effects on structures; however, caution should be paid when calculating response quantities that are affected by the high frequency content of strong ground motion. Thus, it is essential to have an appropriate selection criteria and scaling procedure of the ground motions. There are two distinctly different sources of obtaining ground motions for time-history analysis [9-11]. Standards, design guides and codes, e.g. Standard No. 2800[12], ASCE/SEI 7-10 [13], Code 038[5] and API 650 [4], recommend the use of recorded motions from previous events. However, if there is insufficient recorded data the two design specifications above [12-13] allow the use of supplementary simulated ground motions to make up the total number of records required. All two documents agree in the requirements for choosing the records to be used. The ground motions should have compatible seismological characteristics, i.e. magnitude, distance, fault mechanism and soil conditions, to the tectonics of the region and the site of the structure. Studies have been carried out in a number of locations to obtain ground motions that meet the requirements imposed by standards and codes.

Behnam Far et al. [14] and Cooper [15] state the criteria for selecting ground motions for using the Standard No. 2800 [12] and ASCE/SEI 7-10 procedures, respectively. Contrary to the criteria for selecting records, where there is agreement between the standards and codes, the scaling procedures to apply to the chosen records differ slightly in important ways. The procedures defined in the two design specifications implemented here specify different period ranges of interest. Over these ranges the chosen record should be matched as close as possible to the target spectrum. To the author's knowledge, a comparison of the application of the ASCE 7 and Standard No. 2800 to steel oil storage tanks has not been reported. In this research, Kashan petroleum storage tanks (KPST) have been used as a case study, which includes eight tanks with a different aspect ratio (H/D). The objective of the current work is to evaluate the consequences of the procedures for the analysis of the seismic performance of KPST and to reveal the differences and similarities of the outcomes resulting from application of the mentioned specifications.

2- Description of Storage Tanks

Current specifications for seismic design of storage tanks are based mainly on the damped spring-mounted mass analogy proposed by Housner [1]. This analogy proposes that a tank-liquid system can be represented by two vibration modes [2, 3]. The portion of the liquid contents which moves together with the tank shell is known as the impulsive mass m_i. The portion of the contents which moves independently of the tank shell and develops a sloshing motion is known as the convective mass m_c. The predominant mode of vibration of liquid storage tanks during an earthquake is the impulsive mode [16,17] and its period is very short, generally a few tenths of a second. In this study, the impulsive period of vibration will be considered as the fundamental period in the analyses presented. The Geometric characteristics of representative tanks are shown in Table 1. Where; *t*= tank wall thickness; *D*= tank diameter; *H*= The maximum height of tank Υ_L = unit weight of the liquid;

Table 1- Geometric characteristics of representative tanks

Tank No	Type of Roof	*t* , cm	Nominal Capacity , Liters	*D* , m	*H* , m	Product	Υ_L , g/cm^3
1	Fixed	1.65	1065000	12.206	9.150	Fuel Oil	0.8940
2	Floating	1.77	1200000	12.221	10.980	Gas Oil	0.8350
3	Fixed	1.73	2200000	14.660	12.810	Gas Oil	0.8470
4	Floating	1.77	2820000	17.097	12.810	Gas Oil	0.8350
5	Floating	2.35	1230000	12.205	10.920	MOGAS 90 RUN	0.7530
6	Floating	2.40	2820000	17.097	12.800	MOGAS 90 RUN	0.7530
7	Floating	2.41	5730000	24.410	12.810	KEROSENE NIOC	0.7990
8	Floating	2.95	5730000	24.392	12.800	MOGAS 90 RUN	0.7530

The impulsive period of vibration, T_i, is computed from Eq. (1) given by [5]:

$$T_i = C_i H_L \sqrt{\frac{\rho_L D}{2 t_e E_t}} \tag{1}$$

Where; H_L= The maximum height of liquid; E_t= Young's modulus of the tank material; t_e=equivalent thickness; C_i= impulsive dimensionless coefficient which depends on the ratio of the height of liquid to tank radius;

The convective period of vibration, T_c is computed from Eq. (2) given by [5]:

$$T_c = C_c \sqrt{\frac{D}{2}} \tag{2}$$

where C_c= convective dimensionless coefficient which depends on the ratio of the height of liquid to tank radius.

The convective and impulsive mass, m_c and m_i, is computed from Eqs. (3), (4) and (5) given by [5]:

$$m_i = \left[\frac{\tanh(0.866 \frac{D}{H_L})}{0.866 - 0.218 \frac{D}{H_L}} \right] m_p \qquad \text{for } \frac{D}{H_L} \geq \frac{4}{3}: \tag{3}$$

$$m_i = \left[1 - 0.218 \frac{D}{H_L} \right] m_p \qquad \text{for } \frac{D}{H_L} < \frac{4}{3}: \tag{4}$$

$$m_C = 0.230 \frac{D}{H_L} \tanh(\frac{3.67 H_L}{D}) m_p \tag{5}$$

The height of the center of the impulsive mass, h_i, is computed from Eqs. (6) and (7).

$$h_i = 0.375 H_L \qquad \text{for } \frac{D}{H_L} \geq \frac{4}{3}: \tag{6}$$

$$h_i = \left[0.500 - 0.094 \frac{D}{H_L} \right] H_L \qquad \text{for } \frac{D}{H_L} < \frac{4}{3}: \tag{7}$$

The height of the center of the convective mass, h_c, is computed from Eq. (9).

$$h_c = \left[1 - \frac{\cosh\left(\frac{3.67 H_L}{D}\right) - 1}{\frac{3.67 H_L}{D} \sinh\left(\frac{3.67 H_L}{D}\right)} \right] H_L \tag{8}$$

In this study eight petroleum storage tanks in Kashan were considered and are shown in Table 1. Properties of the storage tanks calculated of the tanks are shown in Table 3. Housner's model [1] is used for the elastic time-history analysis carried out herein. The damping ratios recommended in [5], i.e. 5% for the impulsive mode and 0.5% for the convective mode, are used in this study. Table 2 shows the dimensionless coefficient C_c and C_i.

Table 2- Calculated period coefficients [5]

H_L/D	0.15	0.25	0.35	0.5	0.75	1	1.25	1.5
C_i	9.28	7.74	6.97	6.36	6.06	6.21	6.56	7.03
C_c	2.09	1.74	1.6	1.52	1.48	1.48	1.48	1.48

Table 3- Properties of the storage tanks calculated in the study

Tank No	H_L, m	D, m	t, cm	T_i, s	T_c, s	m_p, Kg	m_i, Kg	m_c, Kg	h_i, m	h_c, m
1	9.882	12.221	1.77	0.072	3.658	1002000	731862	283505	3.792	6.878
2	8.235	12.206	1.65	0.064	3.656	952110	636009	320026	3.088	5.425
3	11.52	24.392	2.95	0.100	5.308	4314690	2235851	1973981	4.320	6.870
4	11.529	24.41	2.41	0.114	5.310	4578270	2372520	2094499	4.323	6.875
5	11.52	17.097	2.4	0.081	4.327	2123460	1417370	714595	4.320	7.586
6	9.828	12.205	2.35	0.059	3.656	926190	675447	263115	3.767	6.832
7	11.529	17.097	1.77	0.099	4.327	2354700	1572460	791838	4.323	7.594
8	11.529	14.66	1.73	0.094	4.007	1863400	1346859	541593	4.386	7.957

3- GROUND MOTION RECORDS AND SCALING PROCEDURE

3-1- SELECT THE GROUND MOTION RECORDS

A set of seven different pairs of records has been used in the time history analysis. The earthquakes selected are shown in Table 4. The Standard No. 2800 will be used to determine the design spectrum for this site. Both horizontal components of each earthquake are used in this study. ASCE/SEI 7-10 and Standard No. 2800 require at least seven records to be utilized before the average response can be considered for design purposes. To determine the design spectrum, Standard No. 2800 works in conjunction with Code 038, which is the Iran design guide for storage tanks. In a similar way to Standard No. 2800, ASCE/SEI 7-10 works in conjunction with API 650 [4] to obtain the seismic load for storage tanks. To enable useful comparison between the design specifications, only one of these three spectra has to be chosen as the target spectrum. in this study The target spectrum selected in this study is given by Standard No. 2800 [12] in conjunction with Code 038 [5]. The parameters necessary to compute the spectrum were selected for Kashan and site classifications of soil III (soil D in ASCE 7). The return period of the target spectrum considered is 2500 years. Site subsoil class III, are defined by [12]. In this study, one record in three in each set, have a forward directivity component, whilst the remainder of the set have been of near-neutral or backwards directivity. Not all near source records have a forward directivity component. Somerville and Smith [19] reported that two conditions have to be met for forward directivity effects: (a) the rupture propagation has to be towards the site and (b) the direction of the slip on the fault has to be aligned with the site. This is the reason why even though most of the pairs shown in Table 4 are from near source earthquakes only three case in site class have a forward directivity component.

Table 4- Earthquake records used

ID	Event	Station	Year	M_w	*d* , *km*	Depth , km	PGA , g	FD
EQ1	El Centro, USA	0117	1940	7	6	10	0.348	No
EQ2	Tabas, Iran	(i)	1978	7.4	2	5	0.931	Yes
EQ3	Michoacan, Mexico	UNIO	1985	8.1	16	15	0.169	No
EQ4	Landers, USA	Lucerne Valley	1992	7.3	1	5	0.813	Yes
EQ5	Kocaeli, Turkey	Darica	1999	7.5	74	15	0.211	Yes
EQ6	Duzce, Turkey	(ii)	1999	7.2	8	10	0.535	No
EQ7	Hokkaido, Japan	HKD085	1903	8.3	43	33	0.282	No

d = Distance to the epicenter. FD = forward directivity component. (i) Latitude & Longitude: 33.6000, 56.9200; (ii) Available at http://peer.berkeley.edu/nga_files/ath/DUZCE/DZC270.AT2 and DZC180.AT2

3-2- METHOD FOR SCALING RECORDS

A summary of the two design specifications used in this study is presented below. All two design specifications require the computation of a multiplication factor to apply to the chosen time history to ensure a match to the target spectrum in the period range of interest. However, this factor is computed differently depending on the standard or code considered.

3-2-1- STANDARD NO. 2800

This design specification requires the use a family of at least three pairs of horizontal ground motions recorded in seismic events. The selected events shall have similar seismological characteristics (magnitude, fault mechanism, source-to-site distance and near-surface soil profile) to the characteristics of the events that mainly contributed to the seismic hazard at the site over the period range of interest. When there are insufficient suitable recorded ground motions available for a site, simulated ground motion records may be used to complete the family of records. The period rang of interest defined by this standard is between 0.2 T_1 and 1.5 T_1 (similar to ASCE7-10), where T_1 is the fundamental period of the structure in the direction analyzed. The duration of the earthquake shall be more than 10 seconds or three times the fundamental period of the structure. The selected scale factor should be that the scale factor is determined by the criterion that the average SRSS of the response spectrums shall not be less than the 1.3 times target spectrum in the period range of interest defined by Standard No. 2800. When seven or more pairs are used to perform the analysis, the average response will be considered for design purposes. This design specification allowed the average SRSS values of response spectrums up to 10% are below the design spectrum if seven ground motions are used, then the maximum response will be considered.

3-2-2- ASCE/SEI 7-10

ASCE/SEI 7-10 requires the use of at least three pairs of ground motions. The selected events shall have magnitudes, fault distance, and source mechanisms consistent with the expected maximum earthquake considered in the analysis. Soil profile similarities are not required explicitly by this standard. Appropriate simulated ground motion pairs can be used to make up the total number of ground motions when the required number of recorded ground motions is not available. The square root of the sum of the squares (SRSS) of the 5% damped response spectrum of each ground motion must be computed from the scaled pair that forms the records. The same scale factor shall apply to both horizontal components, i.e., each pair has a unique scale factor. The scale factor is determined by the criterion that the SRSS of the response spectrum of each pair shall not be less than the target spectrum in the period range of interest defined by ASCE/SEI 7-10. The period range is specified as being between 0.2 T_1 and 1.5 T_1, where T_1 is the fundamental period of the structure in the direction analyzed. When seven or more pairs are used to perform the analysis, the average response will be considered for design purposes. If less than seven ground motions are used, then the maximum response will be considered. The scale factors computed according to ASCE/SEI 7-10 and Standard No 2800, have been shown in Table 5.

Table 5- Scale factors computed using the three procedures

Tanks	Code	EQ1	EQ1	EQ1	EQ1	EQ1	EQ1	EQ1	Average value	Standard deviation
T1	Standard 2800	2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T2		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T3		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T4		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T5		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T6		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T7		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T8		2.873	1.074	6.993	1.269	4.651	1.945	3.546	3.197	2.10
T1	ASCE 7	2.147	2.096	3.636	3.530	4.261	2.192	2.458	2.903	0.89
T2		2.402	1.522	3.390	3.234	4.410	2.037	1.846	2.692	1.03
T3		2.617	1.558	3.333	3.168	4.439	1.977	1.859	2.707	1.02
T4		2.270	1.418	3.141	3.196	4.172	1.974	2.005	2.597	0.95
T5		2.147	2.096	3.636	3.530	4.261	2.192	2.458	2.903	0.89
T6		2.196	1.468	3.392	3.248	4.315	2.064	1.806	2.641	1.03
T7		2.147	2.096	3.636	3.530	4.261	2.192	2.458	2.903	0.89
T8		2.147	2.096	3.636	3.530	4.261	2.192	2.458	2.903	0.89

4 -RESULTS

4-1- BASE SHEAR

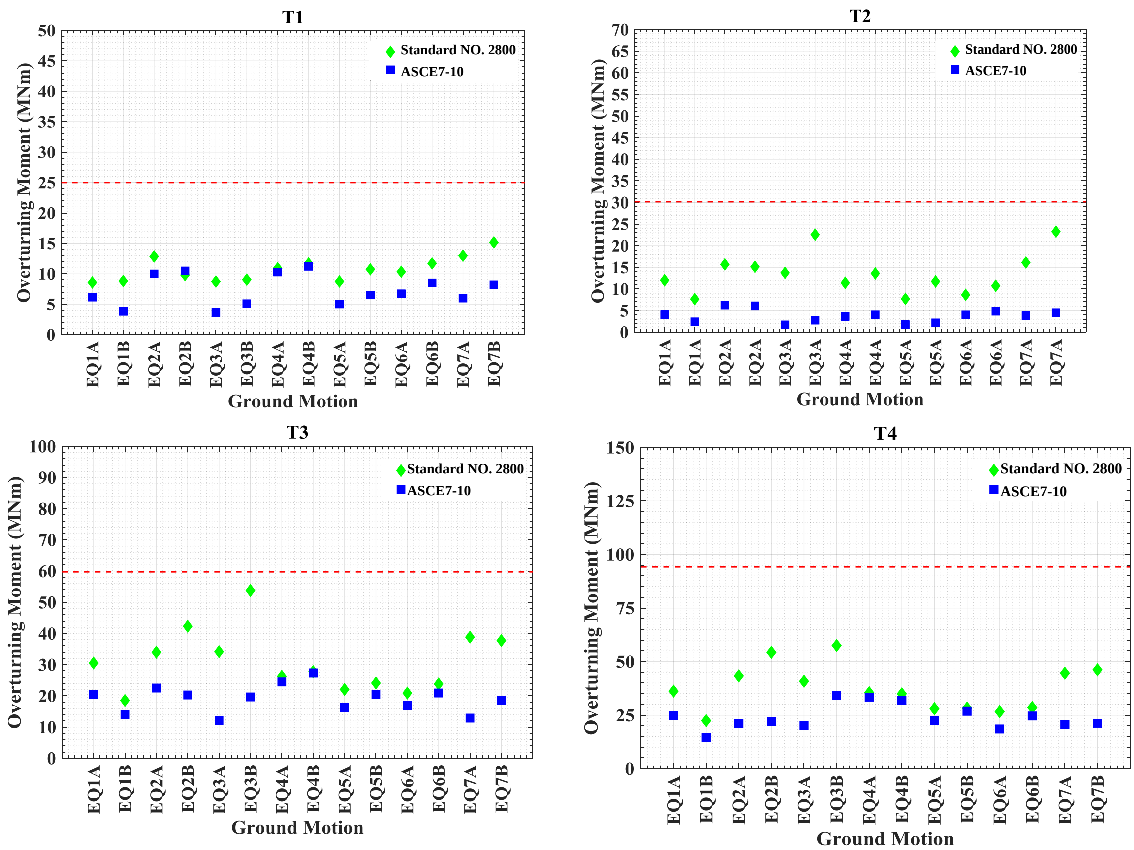
Generally, seismic base shear depends on the frequency content and the total weight of the storage tank including both liquid and structure. The values of the scale factors are just one aspect of computing the applied load. The other aspect is the records. To analysis the effects of these two aspects combined, the tank response has to be studied. Table 6 show the average of base shears (V_b) obtained from all the ground motions, computed by the two scaling procedures and for all the tanks analyzed [5]. Table 6 show that, Standard No. 2800 gives higher average values of base shear than the other procedure, which is consistent with the scale factors shown in Table 5.

Table 6- Base shear

Tanks	V_b (MN)	
	ASCE/SEI 7-10	Standard No. 2800
T1	2.9	4.4
T2	1.2	4.6
T3	5.4	9.3
T4	7.1	11.2
T5	2.9	4.2
T6	5.9	9.6
T7	12.8	19.1
T8	11.9	18.1

4-2- Overturning Moment

Figure 1. shows that the maximum values of overturning moment by Standard No. 2800, are almost higher than ASCE 7. Dashed lines in Figure 1. indicate the capacity of the tank. These results are also consistent with those shown in Table 4 [5]. The seismic response of a tank for a given record is directly related to the scale factor of the record.



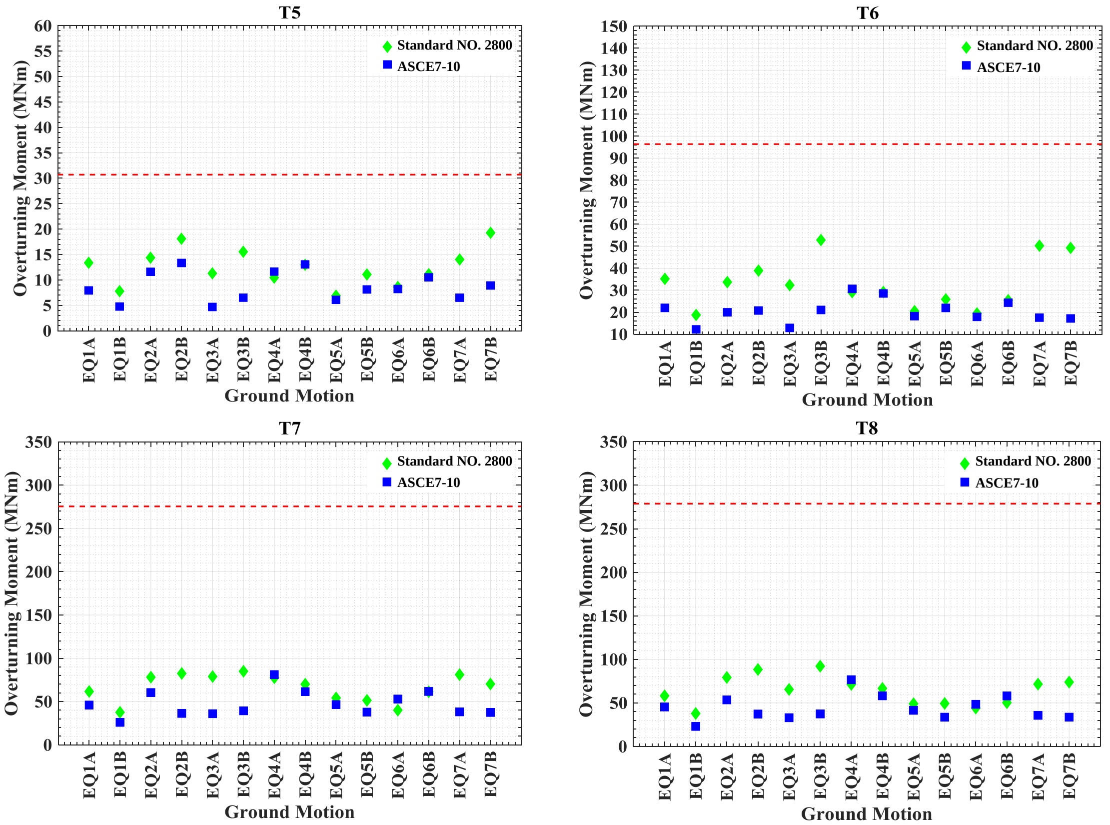


Figure 1- Maximum overturning moment. Dashed line indicates the capacity of the tank in terms of overturning moment

4-3- Dynamic Hoop Stress

From the point of view of structural integrity, it is necessary to check the dynamic hoop stress in the tank wall. To enable comparison between the two scaling procedures, Code 038 [16] will be used to calculate the dynamic hoop stress in the tank shell. Eq. (9-14) is the expression given by [16] to compute the stress for dynamic liquid hoop stress in membrane. Table 7 show the dynamic hoop stress obtained from all the ground motions, computed by the two scaling procedures and for all the tanks analyzed.

$$\sigma_s = N_s / t \tag{9}$$

$$N_s = \sqrt{N_i^2 + N_C^2 + (A_V N_h)} \; ; \quad N_h = 0.5 g D (Y - 0.3) \rho_L \tag{10}$$

$$N_i = 0.864 A_i \rho_L g D H_L \left[\frac{Y}{H_L} - 0.5 \left(\frac{Y}{H_L} \right)^2 \right] \tanh\left(0.866 \frac{D}{H_L} \right); \quad \text{for } \frac{D}{H_L} \geq \frac{4}{3} \tag{11}$$

$$N_i = 0.532 A_i \rho_L g D^2 \left[\frac{Y}{0.75D} - 0.5 \left(\frac{Y}{0.75D} \right)^2 \right] \quad \text{for } \frac{D}{H_L} < \frac{4}{3}; \quad \text{if; } Y \geq 0.75D \tag{12}$$

$$N_i = 0.264 A_i \rho_L g D^2 \quad \text{for } \frac{D}{H_L} < \frac{4}{3}; \quad \text{if; } Y < 0.75D \tag{13}$$

$$N_c = \frac{0.189 A_c \rho_L g D^2 \cosh\left[\frac{3.67 (H_L - Y)}{D} \right]}{\cosh\left[\frac{3.67 H_L}{D} \right]}; \quad \text{for all proportions of } D/H \tag{14}$$

Where σ_s= Hoop stress in the shell due to impulsive and convective forces of the stored liquid(MPa);

N_i= Impulsive hoop membrane force in tank shell (N/m); N_c= Convective hoop membrane force in tank shell (N/m); Y= Distance from liquid surface to analysis point, (positive down) (m); A_i= Impulsive response spectrum acceleration coefficient, %g; N_h= Product hydrostatic membrane force, N/mm; A_c= Convective response spectrum acceleration coefficient, %g

Table 7- Dynamic hoop stress

Tanks	σ_s (MPa)	
	ASCE/SEI 7-10	**Standard No. 2800**
T1	39.86	41.90
T2	41.12	42.76
T3	60.82	64.15
T4	68.85	73.25
T5	28.21	28.62
T6	45.59	47.97
T7	70.28	75.88
T8	53.95	58.01

5- CONCLUSIONS

A series of time-history earthquake response analyses have been carried out using 2 different procedures to match an earthquake record to a target spectrum. Eight different liquid storage tanks were considered. The main aim was to evaluate the different scaling procedures given by two used design specifications and to develop an understanding of the different consequences of the scaling procedures for the tank response. Using the ground motions and the target spectrum considered in this study, the investigations reveal, Standard No. 2800 scaling procedure gives in most cases, the higher scale factors against the ASCE 7-10 design specifications studied in this work. Standard No. 2800 also gives the higher values of base shear and overturning moment in most cases and in dynamic hoop stress term, this standard gives more than the ASCE 7-10, approximately.

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