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STRONG MOTION TIME-HISTORY FOR STORAGE TANKS BY USING SEVEN DIFFERENT EARTHQUAKE ACCELEROGRAMS

Enrico Zacchei

Reyolando M. L. R. F. Brasil

enricozacchei@gmail.com

reyolando.brasil@poli.usp.br

Polytechnic School, University of São Paulo (USP), SP, Brazil

380 Prof. Luciano Gualberto Avenue, Zip-Code: 05508-010, São Paulo - SP, Brazil

Abstract. *This paper aims to describe the seismic performance of circular oil storage tanks by calculating the total base shear induced from each seismic horizontal acceleration: magnitude varies between 6 and 8, and depth from 0 km to 35 km. Time-history analysis has been made considering that the stresses are not excited at the same time. The equations used are in accordance to Eurocode 8 and for the response spectra seven different accelerograms of seven different stations have been considered. The main objective is to provide an approach that describes many important seismic actions in tanks as well as their implications for the dynamic analysis of structural instability. Despite the area of oil being considerably discussed, there are few studies on this topic in Brazil. The results of the analysis show the importance to study the dynamic action and its effects.*

Keywords: *Response time-history, Seismic action, Oil storage tanks, Structural engineering*

1 INTRODUCTION

This paper describes the seismic evaluation time-history of circular oil storage tanks. It is divided into two parts: seismic events studied and structure response time-history. The former shows the feature of the earthquakes and the latter relates to the analysis of practice design which helps to quantify the shear forces. During seismic actions, the hydrodynamic impulsive and convective forces induced due to the acceleration of liquid create stresses. These stresses are not excited at the same time, because the natural periods have different frequencies: in the practice design it is common to sum the stresses independently of frequencies, to the disadvantage of the economy of the structure. It has been considered seven seismic events with similar characteristics – in terms of magnitude and depth – in four different continents: Asia, Australia, Europe and South America.

2 SEISMIC EVENTS CONSIDERED

For the evaluation of the time series for the analysis, events of magnitude between 6 and 8 (moderate and great events respectively) and depth from 0 km to 35 km (superficial earthquake) have been considered. These events are better described in the following paragraph. The events recorded have been made according three instrumental orientations: East-West, North-South and Up-Down. Only the heaviest is shown. In general, earthquakes of possible engineering interest for this type of analysis have been considerate.

2.1 Time series of earthquakes

The accelerograms files are obtained from the Engineering Strong-Motion Database. The characteristic events are defined in Table 1 by epicenter geographical coordinates (latitude and longitude), hypocentral depth, magnitude moment (M_w), PGA and style of fault ruptures that generate the seism.

Table 1. Time series of the seven earthquakes

Event	Lat. [°]	Long. [°]	Depth [Km]	Magnitude (M_w)	PGA [cm/s^2]	Style of faulting
Portugal, 1969	35.97	-10.58	14.00	7.8	25.97	Oblique
Montenegro, 1979	42.24	18.75	5.00	6.2	142.27	Thrust
Greece, 1981	38.17	23.12	30.00	6.3	122.18	Normal
Turkey, 1999	40.81	31.19	10.40	7.1	119.94	Strike-slip
Iran, 2005	30.77	56.81	12.98	6.4	45.51	Thrust
Colombia, 2007	3.00	-77.90	28.98	6.8	0.02	Normal
Vanuatu, 2008	-19.81	169.06	34.32	6.4	1.74	Thrust

In Fig. 1 the seven accelerograms in the time-domain are shown. It is possible to see the maximum acceleration for each event which corresponds to peak ground values of acceleration. All accelerograms have been corrected using the “baseline correction” and “frequency filtering”. The first removes large errors, more evident in the displacements, which are caused by double time-integration; the second removes unwanted frequency components caused, for example, by noise. The general criteria used preserves the information to analyses based on fourier and power spectra.

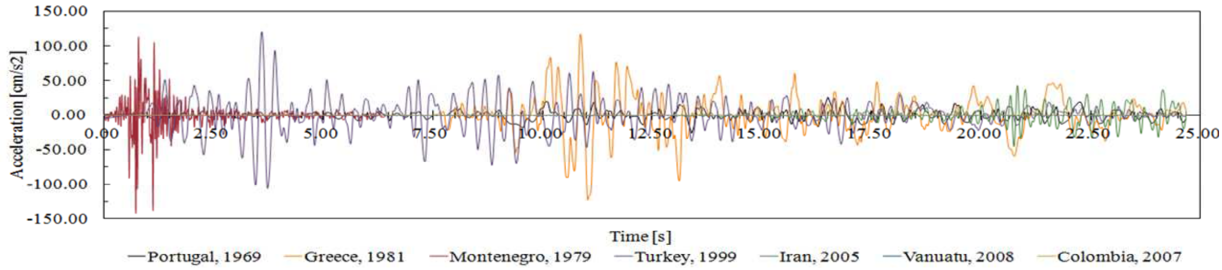

Figure 1. Time-history for the earthquakes analysed. Data was taken from SeismoSignal©software

3 EVALUATION OF RESPONSE TIME-HISTORY

This analysis was conducted in accordance with the provisions of EN 1998-4:2006 and a comparative analysis of the obtained results is presented. The model used is the simple mechanical model for the cylindrical tanks of easier application. An example of a parametric case study to fully understand the concepts was given.

3.1 Elastic spectrums

For the dynamic analysis, the lumped-mass model, defined by Housner (1954), is used. This analysis represents the impulsive and convective modes of vibration of the tank-liquid system which is modeled by two single-degree-of-freedom system. The impulsive and convective natural periods and the total base shear are shown in Zacchei and Brasil (2015). The convective spectral acceleration is obtained from a 0.5% damped elastic response spectrum and the impulsive spectral acceleration is obtained from a 2.0% damped elastic response spectrum for welded steel (Fig. 2).

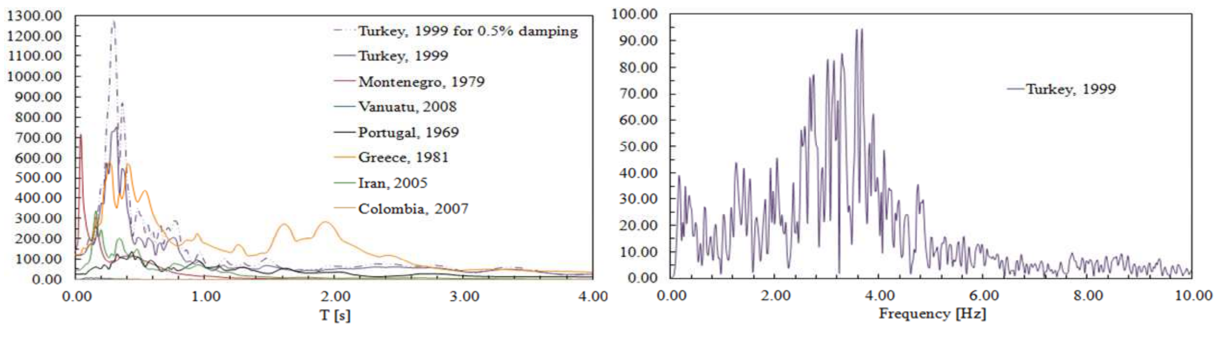

Figure 2. Elastic response spectra [cm/s^2] (left) and fourier amplitude spectra [cm/s] (right)

Figure 2 shows response spectra acceleration for seven earthquakes for 2.0% damping – only for the Turkey 1999 record, there is the spectra acceleration for 0.5% damped elastic. It shows also the fourier amplitude spectra which demonstrates how the amplitude of the ground motion is distributed with respect to frequency, effectively meaning that the frequency content of the given accelerogram can be fully determined. The maximum amplitude has at frequency f = 3.69 Hz (T = 0.27 s). The impulsive periods for two cases to study have values T_i = 0.18 s (for H/R = 3) and T_i = 0.04 s (for squat tank: H/R = 0.7). Both are quite far at resonance phenomenon, which happens when the frequency of the applied loading equals the natural vibration frequency structure (Clough and Penzien, 1976). If resonance happens only for the impulsive mode of the slender tank (first case) the response will be about 2.3 times higher.

3.2 Case study

The fixed-base cylindrical steel tank with roof, used as an example, has the following input data: R = 5 m, H_t = 17 m (height of the tank), E = $2x10^5$ MPa, s = 8 mm (uniform for tank), ρ = 9 kN/m^3 (petroleum) and ρ_s = 78.50 kN/m^3 (mass density of steel). Fixed geometrical properties have been chosen because the idea of the study is to investigate the behavior of the tank in function of the height of the liquid. The earthquake chosen is Turkey 1999, which gives the great demand (see Table 2) and gives a significant duration of 15.05 s based on intensity of motion. In Fig. 3 the seismic response time-history of the base shear of the impulsive and convective component for slender and squat tank is shown. The wall and roof mass terms, in the equation of total base shear, are included in the impulsive component. In the analysis it is proven that for the squat tank the convective effect is more influent in relation to the convective effect for slender tank: in the first case the influence can reach up to 58.5% of impulsive effect; in the other case it can reach up to 4.9%. In Fig. 3 it is possible to see that, for the squat tank (figure below), the blue curve is more visible.

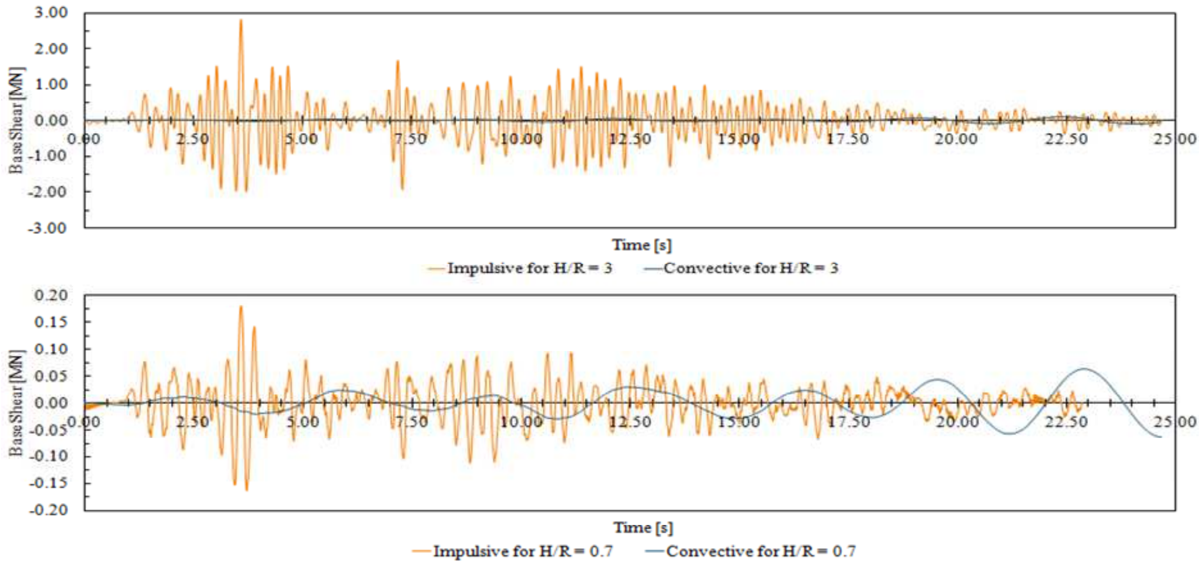

Figure 3. Seismic response for Turkey 1999 record, for two different tanks

Table 2 shows the possible maximum total response for each event. It shows the impulsive base shear (Q_i) and the convective base shear (Q_c) for two tank types. It is important to say that the maximum value for each one does not happen at the same time, because the natural periods have different frequencies. The maximum impulsive response acceleration occurs at time t = 3.58 s, instead the maximum convective response occurs at t = 22.60 s (see Fig. 3). If the concomitance of the effects are not considered, the larger difference in the total base shear happens with the squat tank with a overestimate about 35.0%. This overconservative estimate is common practice because it is more simple. It has been made by Eq. A.37 of EN 1998-4:2006. In Table 1 it is possible to notice that while the greatest PGA is in the second event, the greatest seismic response is in the fourth event. This is because the fourth event's frequency, which gives the greater amplitude, is closer to the impulsive frequency of the tank.

Table 2. Seismic response (the values are kN)

		Portugal, 1969	Montenegro, 1979	Greece, 1981	Turkey, 1999	Iran, 2005	Colombia, 2007	Vanuatu, 2008
Slender Tank	Q_i =	532.01	1942.70	2525.67	2837.33	2211.14	0.19	74.15
	Q_c =	26.09	1.30	79.63	102.15	8.23	0.00	0.53
Squat Tank	Q_i =	40.56	1058.17	184.10	180.43	72.05	0.11	3.45
	Q_c =	23.75	0.98	60.06	63.22	4.89	0.00	0.38

4 CONCLUSIONS

The records taken must be carefully analysed, by taking appropriate corrections and focusing on elastic response spectra and fourier amplitude spectra (for structure response and energy content). About the event considered, even if they are with similar characteristics in terms of magnitude and depth, the seismic response of the tank can be very different. The maximum value for each one does not happen at the same time and because of this it is necessary to be careful with overconservative estimates. For the slender tank the impulsive mode is predominant in respect to the convective mode, instead for the squat tank the convective mode can take important values. The base shear force can reach significant values (of the order of 0.20 – 3.00 MN), for this reason it is very important to analyse the hydrodynamic stresses.

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