TOTAL SEISMIC RESPONSE OF CIRCULAR OIL STORAGE TANKS: A SIMPLIFIED ANALYSIS

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Abstract. *The focus of this presentation is to describe the total seismic response of circular oil storage tanks by carrying out a simplified analysis with a series of geometrical properties. The main objective is to provide an approach that describes seismic actions in tanks as well as their implications for the structural dynamic analysis of instability. Many companies work on projects outside Brazil where they have to deal with such issues. Despite the area of oil being considerably discussed, not many studies on this topic are found concerning the Brazilian context. The seismic response has been calculated by the base shear and the overturning moment by using the simplified procedure adopted in Eurocode 8. For the response spectra, Venezuelan code Covenin has been used. In order to study the principal cause of critical elastic-plastic instability modes of collapse, the procedure adopted takes impulsive and convective actions of the natural period of the liquid to obtain the hydrodynamic pressure in function of the lateral accelerations.*

Keywords: *Seismic response, Oil storage tank, Structural engineering*

INTRODUCTION

The focus of this paper is to describe the total seismic response of circular oil storage tanks. During seismic actions, the hydrodynamic forces induced due to the acceleration of liquid creates stresses: a simplified analysis can quantify these stresses.

1 DYNAMIC ANALYSIS

For the dynamic analysis, the lumped-mass model, defined by Housner (1963), is used. This analysis represents the impulsive and convective modes of vibration of the tank-liquid system.

1.1 Elastic spectrum reference

For the evaluation of the response spectra for the site, the Venezuelan code Covenin is used with the following input data: A_0 = 0.3 (horizontal acceleration coefficient for seismic zone 5), α = 1.3 (importance factor for group A) and spectrum form S2 (for the soil type).

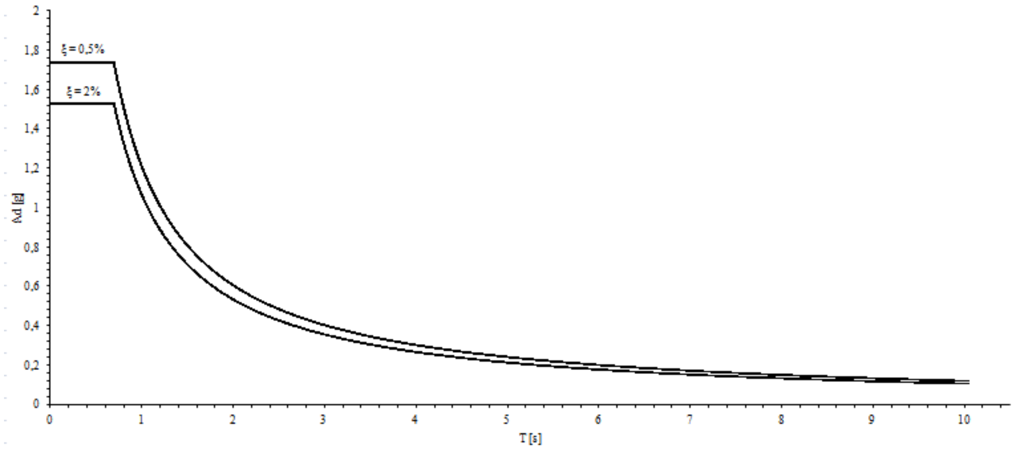

Figure 1. Elastic design response spectra for 0.5% and 2% damping

2 TOTAL SEISMIC RESPONSE: SIMPLIFIED PROCEDURE

The analysis was conducted in accordance with the provisions of Eurocode 8 and a comparative analysis of the obtained results is presented.

2.1 Model properties and equations used

The tank-liquid system is modeled by two single-degree-of-freedom system (SDOF), one corresponding to the impulsive and convective (sloshing) components. The respectively natural periods of Eurocode 8 are:

$$T_i = C_i \frac{H\sqrt{\rho}}{\sqrt{S/R}\sqrt{E}} \tag{1}$$

$$T_c = C_c\sqrt{R} \tag{2}$$

where H is the height of the liquid, ρ is the mass density of the liquid, s is the uniform thickness of the tank, R is the radius of the tank, E is the modulus of elasticity of the material and C_i and C_c are the coefficients of first mode. For the seismic response analysis it is necessary to calculate the total base shear by:

$$Q = (m_i + m_w + m_r) S_e(T_{imp}) + m_c S_e(T_{con}) \tag{3}$$

where m_w is the mass of the tank wall, m_r is the mass of the tank roof, m_i and m_c is the impulsive and convective mass respectively. The convective spectral acceleration $S_e(T_{con})$ is obtained from a 0.5% damped elastic response spectrum and the impulsive spectral acceleration $S_e(T_{imp})$ is obtained from a 2% damped elastic response spectrum for welded steel (Figure 1).

Besides it is necessary to calculate the overturning moment immediately above the base plate (M) and immediately below the base plate (M'), by:

$$M = (m_i h_i + m_w h_w + m_r h_r) S_e(T_{imp}) + m_c h_c S_e(T_{con}) \tag{4}$$

$$M' = (m_i h'_i + m_w h_w + m_r h_r) S_e(T_{imp}) + m_c h'_c S_e(T_{con}) \tag{5}$$

where h_w and h_r are the heights of the gravity centres of the tank wall and roof, respectively. The heights h_i and h_c are heights of the resultant of the impulsive and convective hydrodynamic wall pressure respectively, and h'_i and h'_c are the same heights added by the hydrodynamic pressure on the base plate. All values are obtained by Table A.2 of Eurocode 8.

2.2 Example of parametric case study

The fixed-base cylindrical steel tank with roof, used as example, has the following input data: R = 5 m, H_t = 16 m (height of the tank), E = 2x10^5 MPa, s = 8 mm, ρ = 9 kN/m^3 (petroleum) and ρ_s = 78.50 kN/m^3 (mass density of steel). The choice of fixed geometrical properties is quite logical, because the main idea of the study is to investigate the behavior of the tank in function of the height of the liquid. The seismic response is presented in Table 1.

Table 1. The seismic response of the analysed tank

H/R	T_i [s]	T_c [s]	Q [MN]	M [MNm]	M' [MNm]
0.3	0.02	4.67	1.12	5.90	7.77
0.5	0.03	3.89	1.79	6.87	9.89
0.7	0.04	3.58	2.63	8.66	12.65
1.0	0.05	3.40	4.08	13.34	18.20
1.5	0.08	3.31	6.65	26.49	31.43
2.0	0.10	3.31	9.31	46.27	50.56
2.5	0.14	3.31	11.96	72.14	75.92
3.0	0.18	3.31	14.61	103.34	107.76

The graphs below show the results of the analysis. It is important to notice that all values, except T_c, increase almost linearly with the increase of the ratio H/R. The T_c decreases on the ratio H/R and is practically a constant value for the H/R > 1.5. The sloshing effect depends mainly on the R.

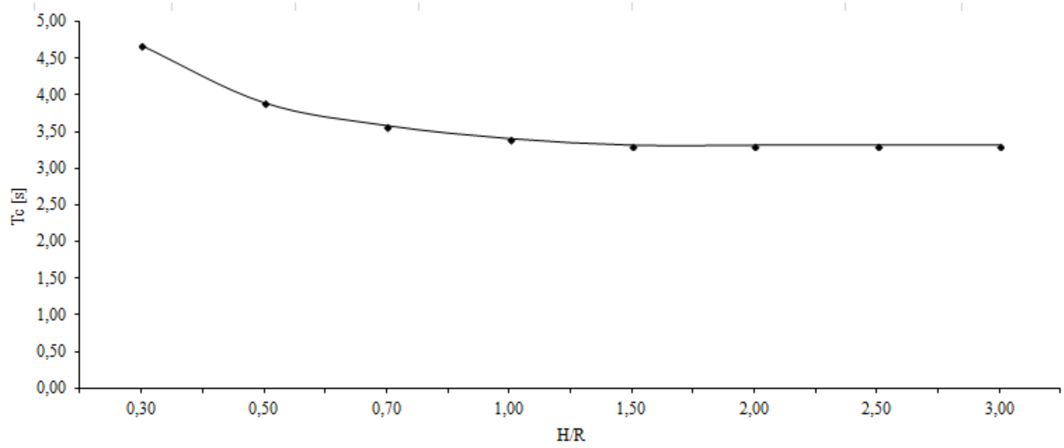

Figure 2. Convective periods of vibrations on the ratio H/R

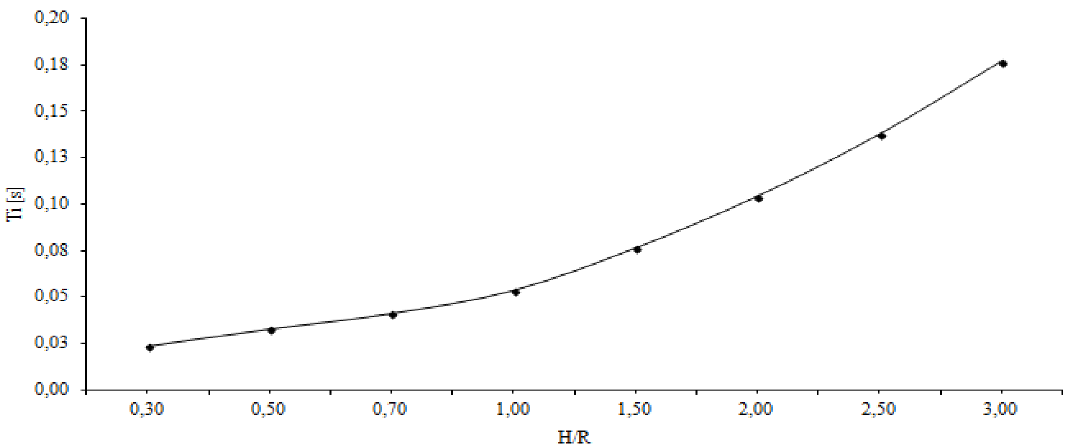

Figure 3. Impulsive periods of vibrations on the ratio H/R

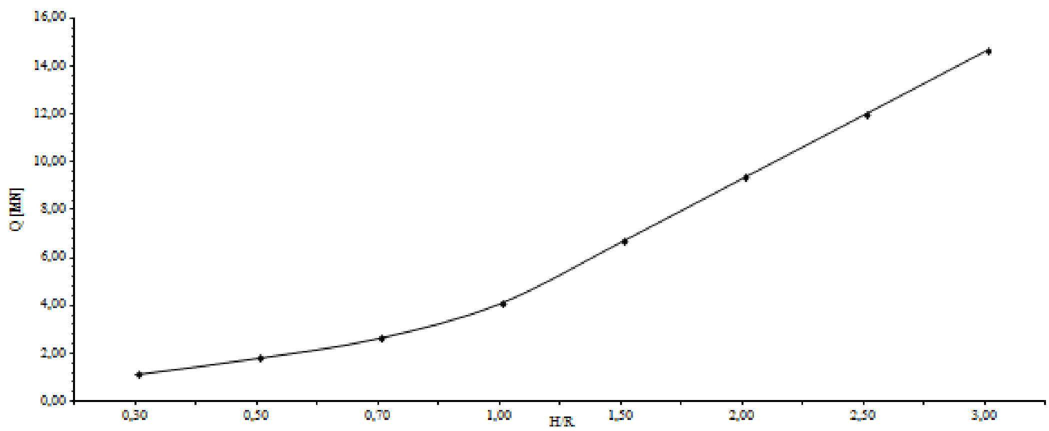

Figure 4. Base shear force on the ratio H/R

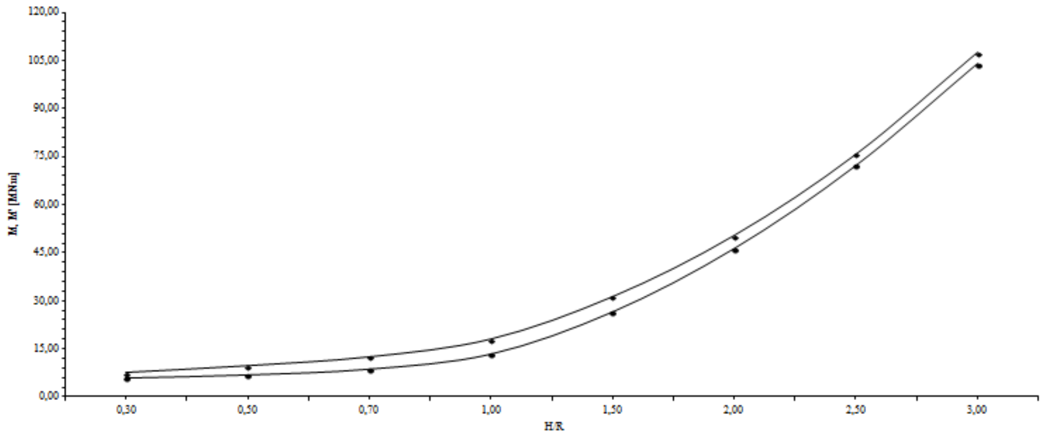

Figure 5. Overturning moments (M, M') on the ratio H/R

It is important to notice that the difference between M and M' is very small, this is because the hydrodynamic pressure on the base plate slightly depends on the horizontal acceleration.

3 CONCLUSIONS

The seismic response of a tank structure mainly depends on the response of the impulsive mass mode in relation to the convective mass mode, in particular when the ratio is $H/R > 1.5$. The base shear force and the overturning moment can reach significant values, for this reason it is important to analyse the hydrodynamic pressure in function of the lateral accelerations.

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