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SEISMIC RESPONSE OF LIQUID STORAGE GROUND SUPPORTED TANKS FOR DIFFERENT SLENDERNESS RATIO

Abstract

Ground-supported cylindrical tanks are used to store a variety of liquids. This paper provides the theoretical background for takes into account impulsive and convective (sloshing) actions of the fluid in concrete containers fixed to rigid foundations; it has been adopted in Eurocode 8. Seismic responses – base shears, the bending and overturning moments – are calculated by using the response spectra of the earthquake in Loma Prieta, California (18.10.1989). As the examples is analyzed the ground supported cylindrical concrete tanks, fluid filling is $H = 2$ m and R are depended from tank slenderness ratio $\gamma = H/R$. For considered tank slenderness ratios $\gamma = 0.3$, 0.5, 0.7, 1, 2, 3 R are given 6.667 m, 4 m, 2.857 m, 2 m, 1 m and 0.667 m.

Keywords

Fluid, earthquake, tank.

1 INTRODUCTION

Ground-supported cylindrical tanks are strategically very important structures, since they have vital uses in industries, nuclear power plants and are connected to public life. Liquid storage tanks are used to store a variety of liquids, e.g. water for drinking and fire fighting, petroleum, oil, liquefied natural gas, chemical fluids, chemical and radioactive wastes. Seismic safely of liquid tanks is of considerable importance [1–8]. Water storage tanks should remain functional in the post earthquake period to ensure potable water supply to earthquake-affected regions and to cater the need for fighting demand. Industrial liquid tanks containing highly toxic and inflammable liquids and these tanks should not lose their contents during the earthquake. Satisfactory performance of tanks during strong ground shaking is crucial for their modern facilities. The seismic behavior of liquid storage tanks is highly complex problem due to liquid-structure interaction. Tanks that were inadequately designed or detailed have suffered extensive damage during past earthquakes [9–12].

2 MECHANICAL MODEL

The dynamic analysis of a liquid-filled tank may be carried out using the concept of generalized single-degree-of freedom (SDOF) systems representing the impulsive and convective modes of vibration of the tank-liquid system (Fig. 1). The impulsive mass of liquid m_i (near the base of the tank moves with the tank wall) is rigidly attached to tank wall at height h_i or h_i^*. Similarly convective masses m_{cn} (near the top experiences free-surface sloshing motion) are attached to the tank wall at height h_{cn} or h_{cn}^* by a spring of stiffness k_{cn}. The impulsive mass m_i and the convective masses m_c are of fraction of the total liquid mass m. For practical applications, only the first convective mode of vibration needs to be considered in the analysis of mechanical model. The natural period of vibration of the impulsive mass is from 0.1 s to 0.3 s and that of the convective mass from 2 s to 6 s.

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The mass, height and natural period of each SDOF system are obtained by the methods described in Eurocode 8 [11].

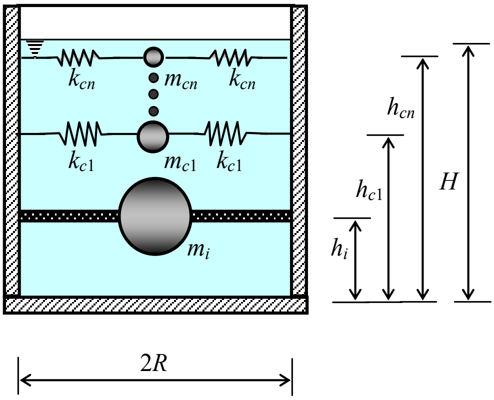

Fig. 1: liquid-filled tank modeled by generalized single degree of freedom systems

Values m_i, h_i, h_i^*, m_{cn}, h_{cn} and h_{cn}^* for rigid vertical circular tanks on ground, fixed to the foundation in Eurocode 8 - 4 [13] are shown in Fig. 2 – 4.

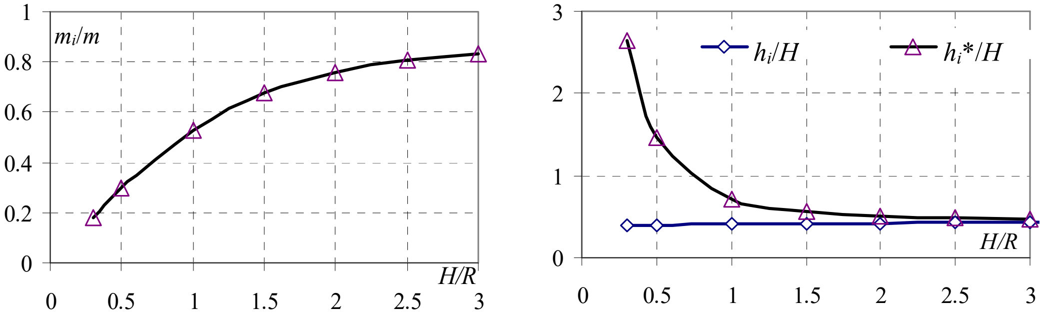

Fig. 2: Ratios m_i/m, h_i/H and h_i^*/H as functions of the tank slendersness

$$m_i = m2\gamma\sum_{n=0}^{\infty}\frac{I_1(\nu_n/\gamma)}{\nu_n^3 I_1^{'}(\nu_n/\gamma)},$$

$$h_i = H\frac{\sum_{n=0}^{\infty}\frac{(-1)^n I_1(\nu_n/\gamma)}{\nu_n^4 I_1^{'}(\nu_n/\gamma)}\left(\nu_n(-1)^n-1\right)}{\sum_{n=0}^{\infty}\frac{I_1(\nu_n/\gamma)}{\nu_n^3 I_1^{'}(\nu_n/\gamma)}}, \tag{1}$$

$$h_i^* = H\frac{\frac{1}{2}+2\gamma\sum_{n=0}^{\infty}\frac{\nu_n+2(-1)^{n+1}I_1(\nu_n/\gamma)}{\nu_n^4 I_1^{'}(\nu_n/\gamma)}}{2\gamma\sum_{n=0}^{\infty}\frac{I_1(\nu_n/\gamma)}{\nu_n^3 I_1^{'}(\nu_n/\gamma)}}.$$

In which $I_1(\cdot)$, $I_1^{'}(\cdot)$ denote the modified Bessel Function of order 1 and its derivate. The derivate can be expressed in terms of the modified Bessel functions of order 0 and 1 as $I_1^{'}(x) = \dfrac{dI_1(x)}{dx} = I_0(x) - \dfrac{I_1(x)}{x}$.

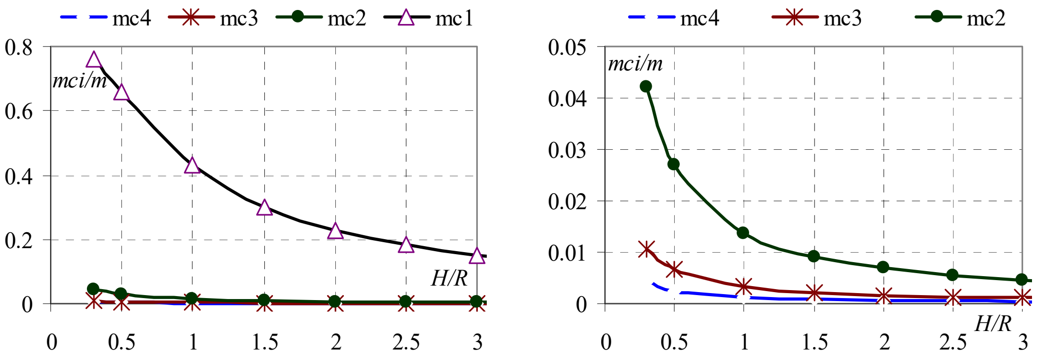

Fig. 3: Ratios m_{ci}/m as functions of the tank slenderness

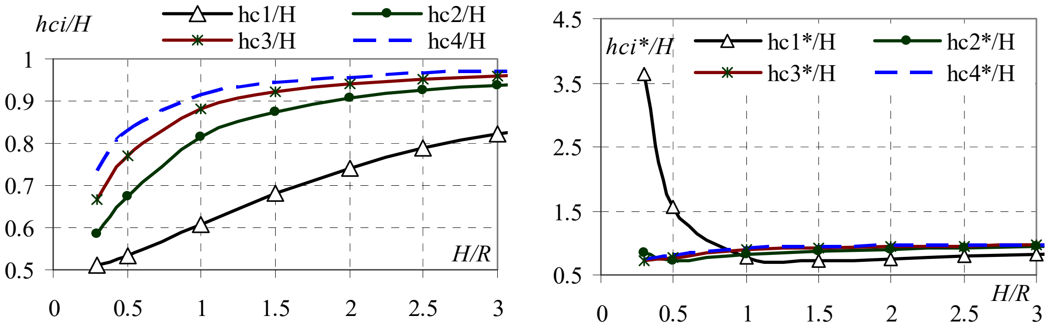

Fig. 4: Ratios h_{ci}/H and h_{ci}^{*}/H as functions of the tank slenderness ratio

$$m_{cn} = m\frac{2\tanh(\lambda_n\, H/R)}{(\lambda_n\, H/R)(\lambda_n^2 - 1)},$$

$$h_{cn} = H\left(1 + \frac{1 - \cosh(\lambda_n \cdot H/R)}{(\lambda_n \cdot H/R)\cdot \sinh(\lambda_n \cdot H/R)}\right), \tag{2}$$

$$h_{cn}^{*} = H\left(1 + \frac{2 - \cosh(\lambda_n\, H/R)}{(\lambda_n\, H/R)\cdot \sinh(\lambda_n\, H/R)}\right),$$

where λ_n are the Bessel function of first order, λ_1=1.8412; λ_2=5.3314; λ_3=8.5363, λ_4=11.71, λ_5=14.66 and $\lambda_{5+i} = \lambda_5 + 5\,i$ (i=1,2,...); *H* is the height of fluid filling; h_{cn} and h_{cn}^{*} are the level where the oscillators of convective masses; h_i and h_i^{*} are the heights of impulsive mass; *R* is the inner radius of cylindrical container; *m* is the total mass of the fluid. For practical applications, only the first few modes of vibration need to be considered in the analysis, (*n* = 1). Tank's slenderness ratio is given by the relation $\gamma = H/R$.

3 NUMERICAL RESULTS

In this study is analyzed fluids filling of ground supported cylindrical rigid tank. The characteristics of fluid filling for $H = 2$ m, where R - inner radiuses of cylindrical tanks are depended from tank slenderness ratios $\gamma = H/R$. For tank slenderness ratio $\gamma = 0.3$, the inner radius of tank R is given 6.667 m, for $\gamma = 0.5$ ⇨ R is 4 m, for $\gamma = 0.7$ ⇨ R = 2.857 m, for $\gamma = 1$ ⇨ R = 2 m, for $\gamma = 2$ ⇨ R =1 m, and for $\gamma = 3$, R is given 0.667 m. The material characteristics of fluid filling (H_2O) are: bulk modulus $B = 2.1 \cdot 10^9$ N/m^2, density $\rho_w = 1\,000$ kg/m^3. As the excitation input we consider horizontal earthquake load given by the accelerogram of the earthquake in Loma Prieta, California (18.10.1989), Fig. 5a. Seismic responses of tanks are calculated by using the response spectrums for the Loma Prieta accelerogram, California (18.10.1989), Fig. 5b.

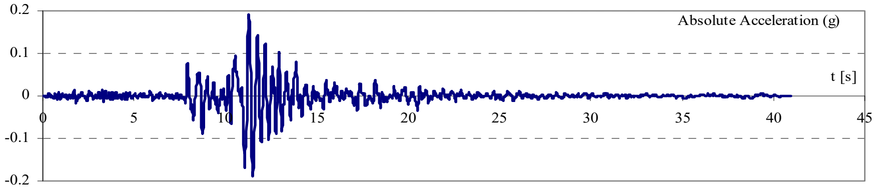

Figure 5a: Accelerogram Loma Prieta, California

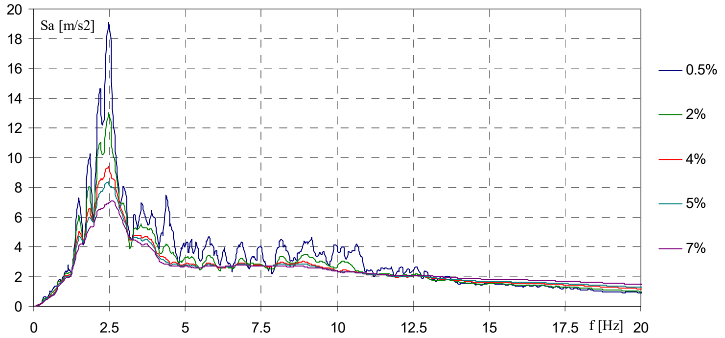

Figure 5b: Response spectrums for the Loma Prieta accelerogram from Figure 5a

The elastic response spectrums of the Loma Prieta accelerogram (Figure 5b) were used for simulation of earthquake. The impulsive spectral accelerations are obtained from a 5% damped elastic response spectrum (for concrete tanks) and the convective spectral accelerations are obtained from a 0.5% damped elastic response spectrum.

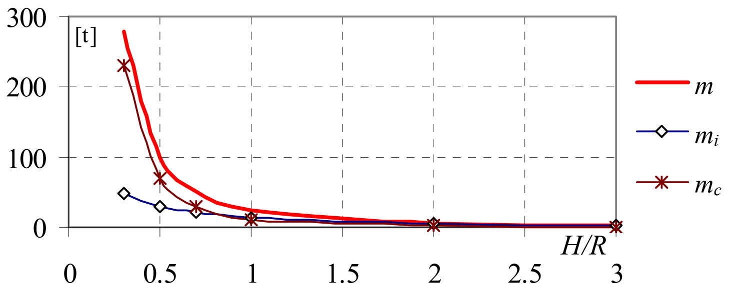

Fig. 6: Impulsive and convective masses in [t] as fractions of the total liquid mass in the tank

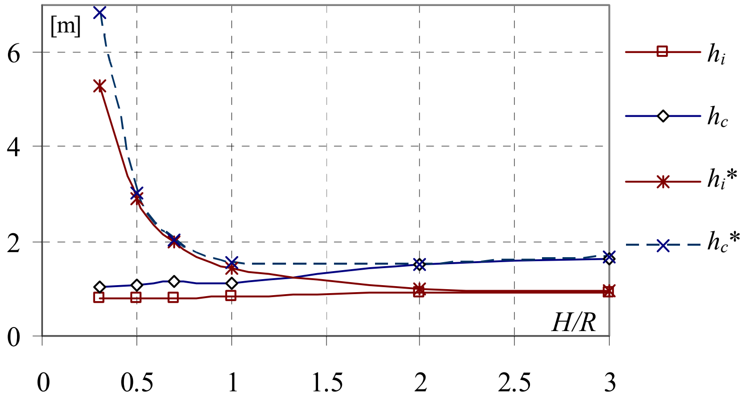

Fig. 7: Impulsive and convective heights in [m], as fractions of the height of the liquid in the tank

The Fig. 6 and 7 are shown the values m, m_i, m_c, h_i, h_i^* h_c and h_c^*, as functions of the tank slenderness ratios, The Fig. 6 m, m_i, m_c, and Fig. 7 h_i, h_i^* h_c. Comparison of the total base shears *V*, the bending moments *M* and overturning moments M^* of fluid as functions of the tank slenderness ratios for diameters *D* = 2*R* are shown in Tab. 1.

Tab.1: Comparison of the total base shears, the bending and overturning moments of fluid as functions of the tank slenderness ratios

	γ= 0.3	**γ= 0.5**	**γ= 0.7**	**γ= 1**	**γ= 2**	**γ= 3**
D [m]	13.333	8	5.7142	4	2	1.333
V [kN]	7643.55	7751.87	2153.03	1744.58	179.517	46.86
M [kNm]	7780.72	8284.86	2349.75	2065.91	224.97	50.42
M* [kNm]	51013.9	23463.3	4352.12	2711.89	235.39	51.79

4 CONCLUSIONS

The ground supported cylindrical tank was excited by ground motion of Loma Prieta in California. Basic responses of the interest were: the total base shears, the bending and overturning moments of fluid as functions of the tank slenderness pressure in the fluid.

ACKNOWLEDGMENT

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