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DYNAMICAL ANALYSIS OF COMPOSITE RESERVOIR

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Abstract: *This paper provides the theoretical background of simplified seismic design of liquid storage cylindrical ground - supported tanks. It takes into account impulsive and convective (sloshing) actions of the liquid in concrete tanks fixed to rigid foundations. This paper follows the influence of filling level and category of sub-soil of concrete cylindrical tank on total base shear V and overturning moment M.*
Keywords: *tank, liquid, earthquake*

1. INTRODUCTION

Large-capacity ground-supported tanks are used to store a variety of liquids, e.g. water for drinking and for fighting, petroleum, chemicals, and liquefied natural gas. Satisfactory performance of tanks during strong ground shaking is crucial for modern facilities. Tanks that were inadequately designed or detailed have suffered extensive damage during past earthquakes [2-4, 6].

2. PROPERTIES OF IRREGULARLY REINFORCED COMPOSITE WITH SHORT FIBERS

We assume the composite with unidirectionally oriented short fibers. We can write the longitudinal and transverse modulus of these composites with help of so-called Halphin-Tsai equations

$$E_1 = E^{(m)} \frac{1+\frac{l}{d}\zeta_E \eta_L \xi}{1-\eta_L \xi} \qquad E_2 = E^{(m)} \frac{1+\zeta_E \eta_T \xi}{1-\eta_T \xi} \tag{1}$$

where
η_L and η_T are described in [5],
l is length of the fibre, d is diameter of the cross section, ξ is fibre volume fraction, ζ_E depends on the shape of cross section of the fibre.
For the modulus of elasticity for irregularly reinforced composite with short fibres we can write the empirical equation [1,7]

$$E = \frac{3}{8}E_1 + \frac{5}{8}E_2 .$$

3. SEISMIC DESIGN OF LIQUID STORAGE TANKS

Seismic design of liquid storage tanks has been adopted in [5, 8, 9]. When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base, in addition to the hydrostatic pressure. 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. For practical applications, only the first convective mode of vibration need to by considered in the analysis (Figure 1). The impulsive mass of liquid m_i is rigidly attached to tank wall at height h_i (or $h_i^{'}$). Similarly convective mass m_c is attached to the tank wall at height h_c (or $h_c^{'}$) by a spring of stiffness k_c. The mass, height and natural period each SDOF system are obtained by the methods described in [5, 8, 9]. For a horizontal earthquake ground motion, the response of various SDOF systems may be calculated independently and then combined to give the net base shear and overturning moment. For most tanks have got slimness of tank γ, whereby $0{,}3 < \gamma < 3$. Tank's slimness is given by relation $\gamma = H/R$, where H is the height of filling of fluid in the tank and R the tank radius [5, 9].

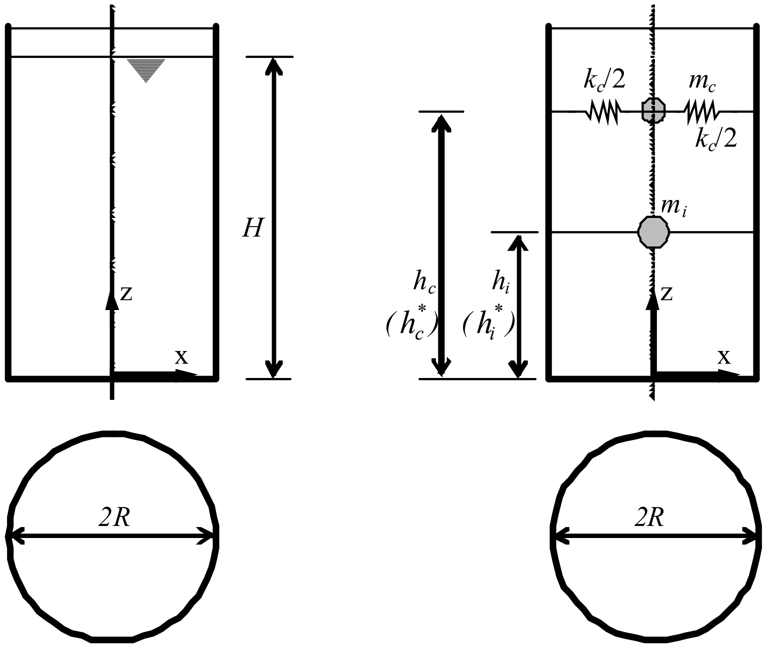

Figure 1: Two single – degree – of freedom systems for ground supported cylindrical tank

For a ground supported cylindrical tank, in which the wall is rigidly connected with the base slab, the naturals period of the impulsive mode of vibration T_i, in seconds, is given by

$$T_i = C_i \frac{H\sqrt{\rho}}{\sqrt{s/R}\sqrt{E}} \tag{2}$$

where
H – height to the free surface of the liquid;
R – tank's radius;
s – equivalent uniform thickness of the tank wall;
ρ – mass density of liquid of tank material;
E – Modulus of elasticity of tank material;
Ci – the dimensionless coefficient, which is obtained from Figure 2 [5, 8, 9].
For a ground supported cylindrical tank, in which the wall is rigidly connected with the base slab, the natural period of the convective mode of vibration T_c, in seconds, is given by

$$T_c = C_c\sqrt{R} \tag{3}$$

where
R – tank's radius;
C_c – the coefficient is expressed in $s/\sqrt{m}$, which is obtained from Figure 2 [5, 8, 9].
Total base shear of ground supported tank at the bottom of the wall can by also obtained by base shear in impulsive mode and base shear in convective mode:

$$V = (m_i + m_w + m_r)S_e(T_i) + (m_c)S_e(T_c) \tag{4}$$

Total base shear of ground supported tank at the bottom of base slab is given also by base shear in impulsive mode and base shear in convective mode:

$$V^{'} = (m_i + m_w + m_b + m_r)S_e(T_i) + (m_c)S_e(T_c) \tag{5}$$

The overturning moment of ground supported tank immediately above of the base plate is given also by

$$M = (m_i h_i + m_w h_w + m_r h_r)S_e(T_i) + (m_c h_c)S_e(T_c) \tag{6}$$

and the overturning moment of ground supported tank immediately below of the base plate is given also by

$$M = \left(m_i h_i^{'} + m_w h_w + m_b h_b + m_r h_r\right) S_e\left(T_i\right) + \left(m_c h_c^{'}\right) S_e\left(T_c\right) \tag{7}$$

where

m_i – the impulsive mass of fluid, given in Figure 3 [5, 8, 9];

m_c – the convective mass of fluid, given in Figure 3 [5, 8, 9];

h_i – height of wall pressure resultant for the impulsive component, given in Figure 4 [5, 8, 9];

h_c – height of wall pressure resultant for the convective component, given in Figure 5 [5, 8, 9];

$h_i^{'}$ – height resultant of pressures on the wall and on the base plate for the impulsive component, given in Figure 4 [5, 8, 9];

$h_c^{'}$ – height resultant of pressures on the wall and on the base plate for the convective component, given in Figure 5 [5, 8, 9];

$S_e(T_i)$ – impulsive spectral acceleration, is obtained from a 2% damped elastic response spectrum for steel and prestressed concrete tanks, or a 5% damped elastic response spectrum for concrete and masonry tanks;

$S_e(T_c)$ – convective spectral acceleration, is obtained from a 0,5% damped elastic response spectrum;

m_w – mass of the tank wall;

m_b – mass of the tank base plate;

m_r – mass of the tank roof;

h_w – the height of center of gravity of wall mass;

h_b – the height of center of gravity of base plate mass;

h_r – the height of center of gravity of roof mass.

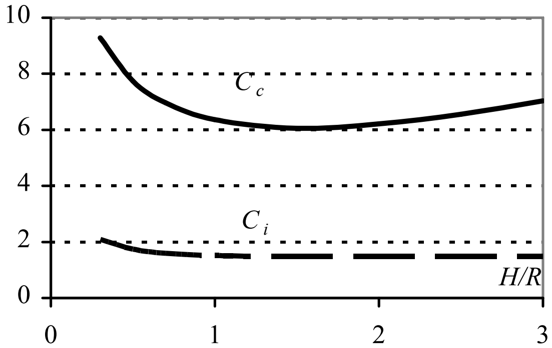

Figure 2: Impulsive and convective coefficients C_i and C_c

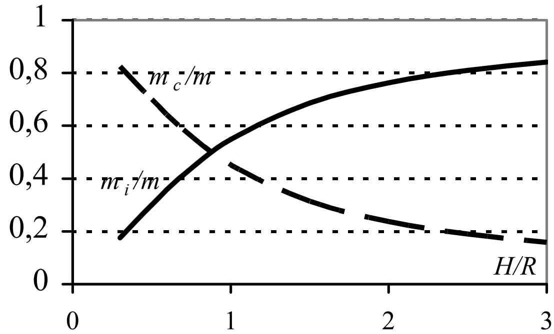

Figure 3: Impulsive and convective masses as fractions of the total liquid mass in the cylindrical tank

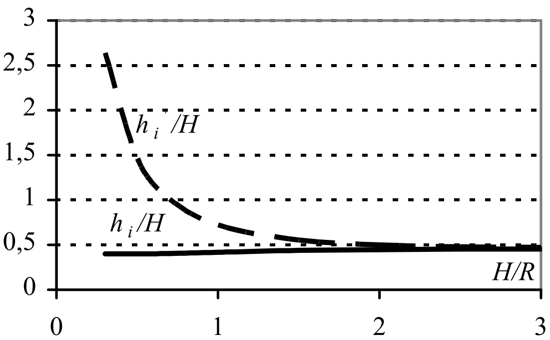

Figure 4: Impulsive heights as fraction of the height of the liquid in the cylindrical tank

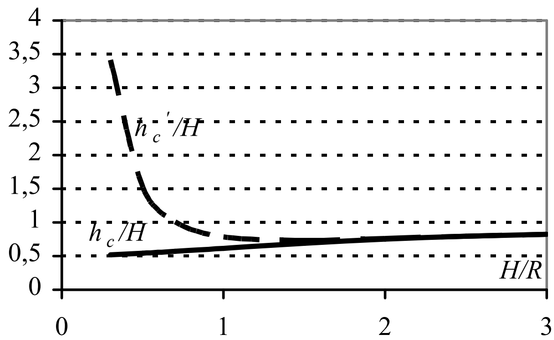

Figure 5: Convective heights as fraction of the height of the liquid in the cylindrical tank

4. NUMERICAL EXPERIMENT

A ground supported cylindrical tank of 1000 m^3 capacity has plan dimension of $2R$ = 14 m and height H_w = 7,0 m. Wall has uniform thickness s = 0,25 m. The base slab is d = 0,4 m thick. There is no roof slab on the tank.

from irregularly reinforced concrete with short steel fibers, $l = 5$cm, $d = 4$mm, $\xi = 0{,}25$. Tank is located on hard soil. The reservoir is filled with water (H_2O) to level from 0,5 m into 6,5 m. Seismic excitation is along x - direction. We consider only horizontal seismic load. Elastic response spectrum [5, 8] used for determination of impulsive spectral acceleration $S_e(T_i)$ and convective spectral acceleration $S_e(T_c)$. Elastic response spectrum is determinate for region of seismic risk is 2, category of sub-soil A, B, C and D [8]. Calculation had been realized by using [5, 8, 9] and the values m_i, m_c, h_i, $h_i^{'}$, h_c a $h_c^{'}$ were computed by using Figures 3 - 5.

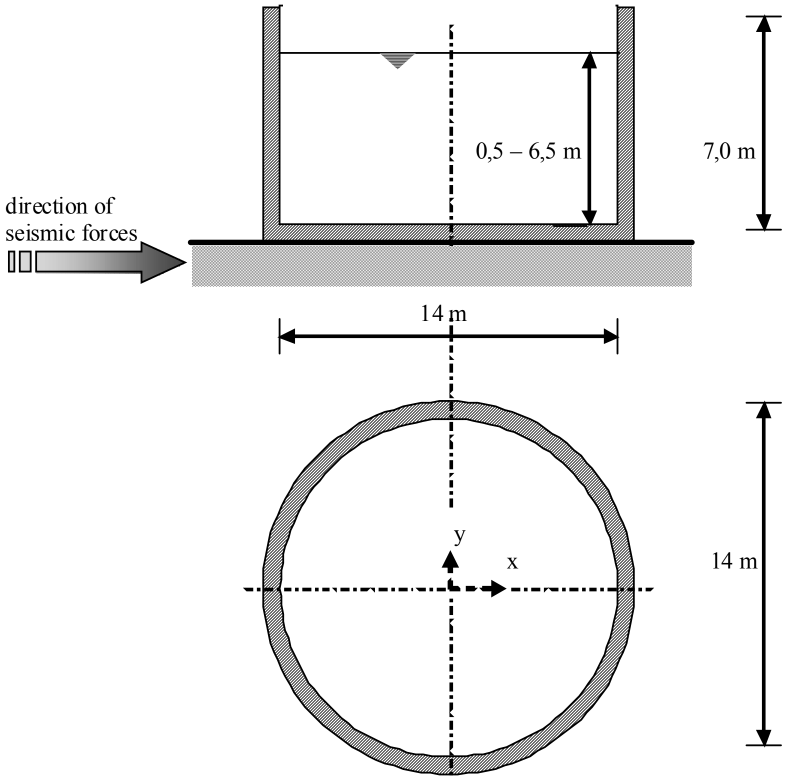

Figure 6: Details of tank geometry

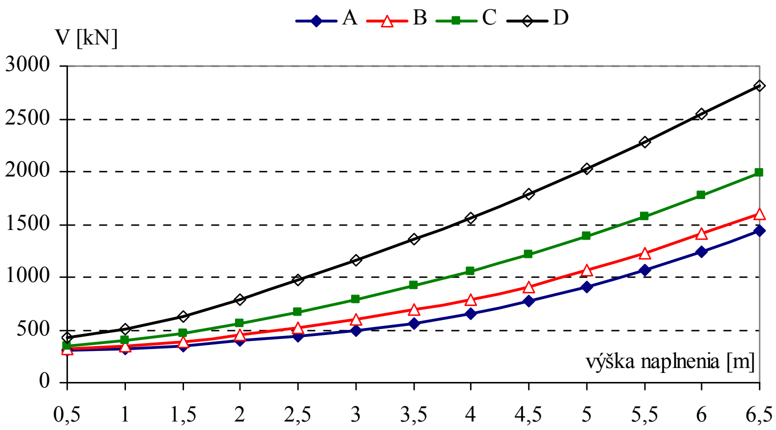

Figure 7: Total base shear at the bottom of the wall V in dependency on filling level and category of sub-soil

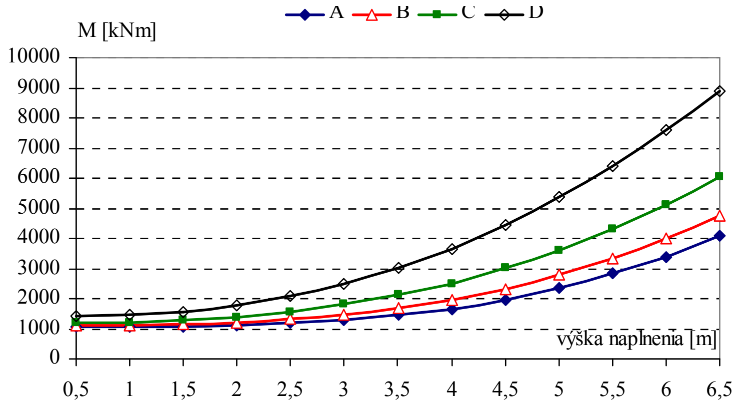

Figure 8: Total bending moment immediately above of the base plate M in dependency on filling level and category of sub-soil

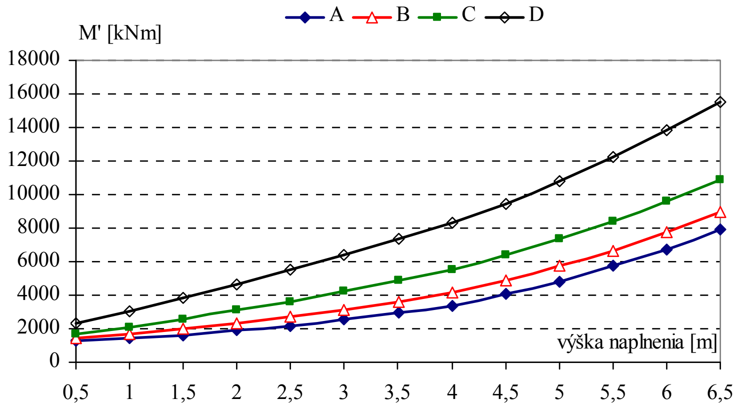

Figure 9: Total overturning moment immediately bellow of the base plate M' in dependency on filling level and category of sub-soil

5. CONCLUSION

From the Figures 7 - 9 is evident, that the maximum values of total base shears an overturning moments are getting, when the tank is completely filled with fluid. Value of total base shears and overturning moments of the reservoir fixed to the rigid foundations to stored on the more flexible sub – soil are getting to greater value.

ACKNOWLEDGEMENTS

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