ANALYSIS OF CYLINDRICAL COMPOSITE SHELL STRUCTURE

Kotrasová Kamila, Kormaníková Eva
Faculty of Civil Engineering, Technical University of Košice, Slovak Republic, kamila.kotrasova@tuke.sk, eva.kormanikova@tuke.sk

Introduction

Ground-supported tanks are used to store a variety of liquids. During earthquake activity the liquid exerts impulsive and convective pressures (sloshing) on the walls and bottom of the rectangular tank. 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.

Properties of irregularly reinforced composite with short fibers

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

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

where

η_L and η_T are described in [1],

l is length of the fiber, d is diameter of the cross section, ξ is fiber volume fraction, ζ_E depends on the shape of cross section of the fiber.

For the modulus of elasticity for irregularly reinforced composite with short fibers we can write the empirical equation [1]

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

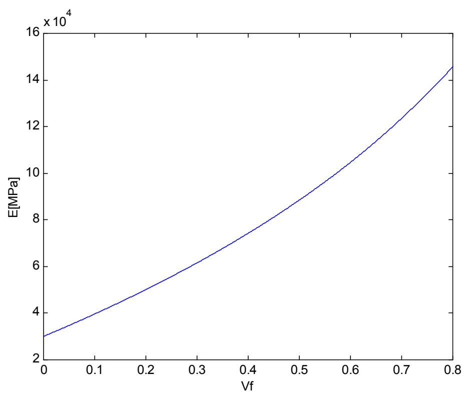

Figure 1: Modulus of elasticity as a function of fiber volume fraction (matrix E = 30GPa, ν = 0.2 and fibers E = 210GPa, ν = 0.3)

Cylindrical composite liquid storage tanks during earthquake

Seismic design of liquid storage tanks has been adopted in 错误！未找到引用源。. When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic effects on the tank wall and the tank base, in addition to the hydrostatic effect. Dynamic analysis of a liquid–filled tank may be carried out using the concept of generalized single – degree – of freedom (SDOF) systems representing impulsive and convective modes of vibration of the tank – liquid system. For practical applications, only the first convective mode of vibration needs to be considered in the analysis (Figure 2). The impulsive mass of liquid mi is rigidly attached to tank wall at height h_i. Similarly convective mass m_C is attached to the tank wall at height h_C by a spring of stiffness k_C. The mass, height and natural period of each SDOF system are obtained by the methods described in [2].

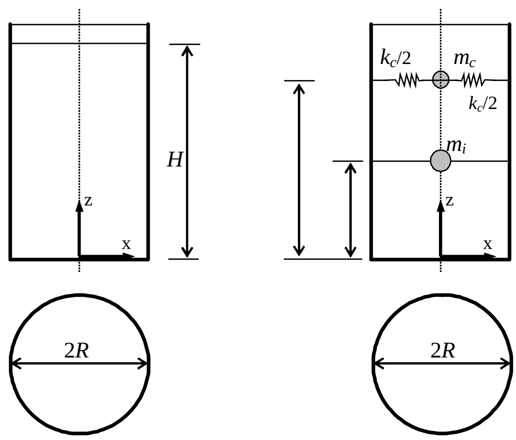

Figure 2: Two single degree of freedom systems for ground supported cylindrical tank

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. Most tanks have 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 radius of tank.

For a ground supported cylindrical tank, in which the wall is rigidly connected with the base slab, time period of impulse mode of vibration T_i [s] is given by

$$T_i = C_i \frac{H\sqrt{\rho}}{\sqrt{t/R}\sqrt{E}}$$

where C_i is coefficient of time period for impulsive mode. Value of C_i can be obtained from table in [2]. H is maximum depth of liquid, R is inner radius of circular tank, t is thickness of tank wall, E is modulus of elasticity of tank wall, and ρ is mass density of liquid. Time period of convective mode, in seconds, is given by

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

C_c is coefficient of time period for convective mode. Value of C_c can be obtained from table in 错误！未找到引用源。.

Seismic coefficient $S_e(T)$ will be calculated separately for impulsive $S_e(T_i)$ and convective mode $S_e(T_c)$. The impulsive horizontal seismic coefficient is obtained from 2 percent damped elastic response spectrum for steel or pre-stressed concrete tanks and 5 percent damped elastic response spectrum for concrete and masonry tanks. The convective seismic coefficient is obtained from 0.5 percent damped elastic response spectrum [3].

Total base shear of ground supported tank at the bottom of the wall can be obtained by combining the overturning moment in impulsive and convective mode:

$$V = (m_i + m_w + m_r)S_e(T_i) + (m_c)S_e(T_c)$$

Total base shear given by base shear in impulsive mode and base shear in convective mode at the bottom of base slab

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

where m_i is impulsive mass of water, m_c is convective mass of water, m_w is mass of tank wall, m_b is mass of base slab and m_r is mass of roof of tank. Base moment of ground supported tank at the bottom of the wall is given by base moment in impulsive mode and base moment in convective mode

$$M = (m_i h_i + m_w h_w + m_r h_r)S_e(T_i) + (m_c h_c)S_e(T_c)$$

Overturning moment can be obtained by combining the overturning moment in impulsive and convective mode to be used for checking the tank stability at the bottom of base slab/plate, and is given by

$$M^{'} = \left(m_i h_i^{'} + m_w h_w^{'} + m_r h_r^{'} + m_b(t_b/2)\right)S_e(T_i) + \\ + (m_c h_c^{'})S_e(T_c)$$

Example

A ground supported cylindrical tank has plan dimension of $D = 2R = 3$ m and height $H_t = 4.0$ m, wall has uniform thickness $t = 0.10$ m. The reservoir is filled with water (H_2O) to level $H_w = 3.5$ m. The base slab is $t_b = 0.2$ m thick. There is no roof slab on the tank. Tank is made from irregularly reinforced concrete with short steel fibers, l = 5cm, d = 4mm, $\xi = 0.25$. We consider only horizontal seismic load. Seismic excitation is along the x - direction. Elastic response spectrum is determined for region of seismic risk 2, category of sub-soil A, B, C and D 错误！未找到引用源。. Calculation had been realized by using 错误！未找到引用源。 and the values m_i, m_c, h_i, $h_i^{'}$, h_c a $h_c^{'}$ can be obtained from the table, which is published in 错误！未找到引用源。.

	A	B	C	D
V [kN]	57.81	67.99	88.80	128.93
V' [kN]	67.12	77.73	99.28	141.50
M [kNm]	96.58	121.46	172.98	268.12
M' [kNm]	118.93	146.50	203.41	309.62

Table 1: Comparison of base shear V and bending moment M at the bottom of the wall of reservoirs and of total base shear V' and total overturning moment M' at the bottom of base slab of reservoirs only caused by influence of seismic loading

Conclusions

In this case, where slightness of tanks is H/R = 2.33, substantial amount of mass - 80 % participates in impulsive and 20 % participates in convective mode. In the Table 1 are comparisons of base shear V and bending moment M only caused by influence of seismic loading at the bottom of the wall of reservoirs and of total base shear V' and total overturning moment M' only caused by influence of seismic loading at the bottom of base slab of reservoirs for diferent category of sub-soil.

Acknowledgement

This research has been supported by the Ministry of Education of the Slovak Republic under the Research Project VEGA No.: 1/4202/07.

References

[1] AGARWAL,B.D., BROUTMAN, L.J.: Vláknové kompozity, Praha, 1987

[2] EN 1998-4: 2006 Eurocode 8. Design of structures for earthquake resistance. Part 4:

Silos, tanks and pipelines. CEN, Brussels, 2006.
[3] STN 73 0036 Seizmické zaťaženia stavebných konštrukcií.