Hydrodynamic Loads on Oil Storage Tanks with Interior Semi-Porous Barriers under Earthquakes

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1. Introduction Estimation of the hydrodynamic loading on cylindrical oil storage tanks during earthquakes is of fundamental importance in the anti-seismic design. A reduced two-dimensional source distribution method and sub-region matching technique are developed for the prediction of three dimensional hydrodynamic forces on oil storage tanks of arbitrary sections with interior semi-porous barriers of different configurations under earthquake excitations.

2. Formulation and Solution Procedure of the Problem As shown in Fig.1, the oil tank, rigidly connected to the ground, may have interior vertical semi-porous barriers of various configurations in order to reduce the hydrodynamic response. Shown also in Fig.1 a Cartesian coordinate system $oxyz$ with the origin on the tank bottom and the oz axis pointing vertically upward through the sectional center. The fluid depth in the tank is H. We consider first the case of the oil tank rigidly oscillating under the action of horizontal seismic ground motions and assume the seismic displacement to be expressed as $x = x_0 \exp(-i\omega t)$, in which x_0 denotes the amplitude of the seismic displacement and ω the oscillating frequency. x_0 is regarded as small enough and ω large enough so that we may let the body surface condition be satisfied on the mean position of the body surface and the influence of the surface gravity waves be neglected. The whole fluid domain may be divided into several sub-regions according to the configuration of the barriers, as depicted in Fig.1. With the usual assumptions of ideal and incompressible fluid and irrotational flow for time-harmonic motions, a velocity potential may be introduced to describe the fluid motion in each i-th sub-region, corresponding to the seismic waves, i.e.

$$\Phi^{(i)}(x,y,z,t) = \phi^{(i)}(x,y,z)e^{-i\omega t} \text{ and } \phi^{(i)}(x,y,z) = \sum_{m=1}^{\infty}\phi_m^{(i)}(x,y)\cos k_m z,\ k_m = \frac{2m-1}{2H}\pi, m = 1,2,\cdots,\infty .$$

The superscript (i) denotes the variables corresponding to the i-th sub-region. On the interior semi-porous thin barriers, the fluid flow passing through the barrier is assumed to obey the Darcy's law (Taylor, 1956). Hence, the porous velocity W perpendicular to the barrier is linearly proportional to the pressure difference across the common barrier between the i-th and j-th sub-regions, i.e.

$$W_{ij}(x,y,z) = i\omega G\left[\phi^{(j)}(x,y,z) - \phi^{(i)}(x,y,z)\right].$$

The porosity parameter is defined as $G = \rho\gamma/\mu$, ρ is the density of the fluid in the tank, μ is the coefficient of dynamic viscosity and γ is a material constant with dimension of length. $\phi_m^{(i)}$ may be represented by the source and sink distribution on the sectional contour C_i of the i-th sub-region, i.e.

$$\phi_m^{(i)}(P) = \frac{1}{4\pi}\int_{C_i}\sigma_m^{(i)}(Q)G_m(P,Q)dl \cdot$$

The fundamental source solution may be taken as (Miao and Liu, 1992) $G_m(P,Q) = 2K_0(k_m r)$, in which $P(x,y)$ and $Q(\xi,\eta)$ denote the field point and source point, respectively, and r is the distance between them. The coupling effects of the interior fluid in different sub-regions are taken into account by matching of the potentials of different sub-regions on their common boundaries which gives a complete fluid motion behavior in the tank and hence the hydrodynamic loading on the tank wall. A integral equation can be formed by imposing the corresponding boundary conditions and the matching conditions, and be solved by discretization technique. Each sub-region girth may be divided and approximated into a number of linear segments. The source distribution strength is assumed constant on each segment and the integral equation is satisfied at the middle of each segment. Once the source strength is solved, the velocity potential at any point P in the fluid domain can be determined, the hydrodynamic pressure and hydrodynamic forces on the tank wall.

3. Computational Results and Analysis Systematic calculations for the hydrodynamic loads on various tanks with semi-porous barriers are carried out with the present method, which has been widely validated by comparison of the calculated results with the corresponding analytical results. Fig.2 shows the hydrodynamic force per unit length on circular tanks of different fluid heights with concentric semi-porous barriers of radius 0.3a (a=1.0 as non-dimensional scaled, ω =10.0 and G=1.0).

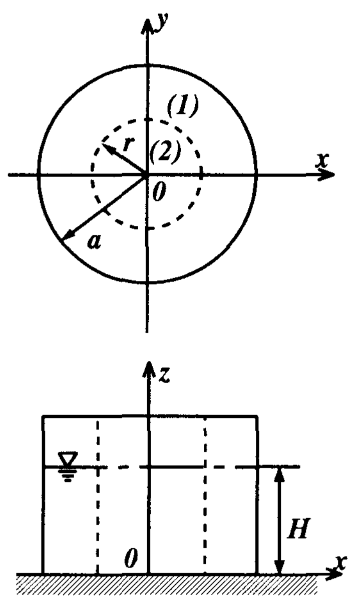

Fig.1 A cylindrical oil storage tank with interior vertical semi-porous barriers

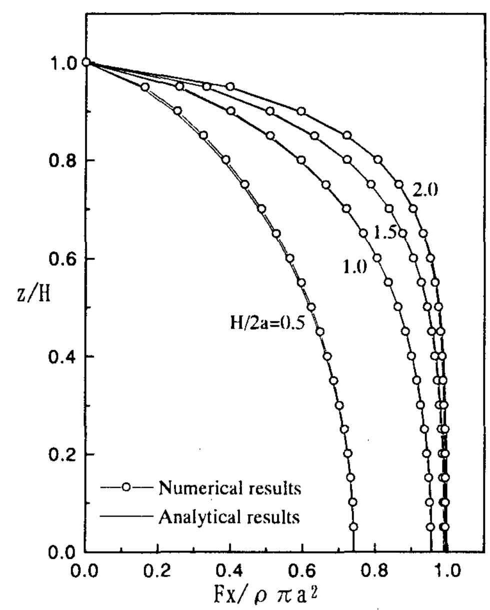

Fig.2 The hydrodynamic force per unit length on circular tanks with a concentric semi-porous barrier (r=0.3a)

4. Concluding Remarks A clear view on the influence of semi-porous barriers to the loading of tanks during earthquakes is obtained by the systematic computational results. Contrary to one's intuitive expectations, it is shown that semi-porous barriers usually give less influence to the total force on the tank at high frequency while the hydrodynamic pressure distribution on the tank wall may be changed. The present study also offers a theoretical method to count for the hydrodynamic loads for oil storage tanks of arbitrary sections with interior semi-porous barriers of different configurations under earthquakes, which will be useful for the corresponding anti-seismic design for oil storage tanks and similar structures. The method can be easily extended to include the effects of the elastic vibrations of the tank.

References

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