Water Pressure Distributions on Pool Door for Research Reactor

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1. Introduction

One or two pool door(s) can be installed in the pool of a research reactor to be able to drain the pool water for maintenance of the reactor. The reactor pool water can be drained after the installation of the pool door. The service pool maintains its water level by using the pool door when the reactor pool is drained. The pressure induced by the service pool water acts on the pool door. The hydrostatic pressure is considered in design of the pool door. Sloshing motion of the pool water imposes dynamic pressures on the pool wall and the pool door during earthquake. The dynamic pressures are also considered in seismic design of the pool door. The dynamic water pressures are calculated with simple formula. [1, 2] In this work, we introduce the formula of TID-7024 report and ACI 350.3 standard. Static and dynamic pressure distributions on the pool door are evaluated by using the formula. The structural integrity of the pool door under the water pressure distribution is investigated through the finite element analysis.

2. Water Pressure Distributions

2.1 TID-7024 Formula

The horizontal dynamic forces acting on the pool wall are calculated in the TID-7024 report. [1] These forces can be separated into impulsive and convective parts. The impulsive force is as follows.

Equivalent weight of water to produce the impulsive and convective forces on the pool door, W_i and W_c, are obtained from following equations,

$$W_i = 1.15W\frac{H}{L}\tanh\left(0.866\frac{L}{H}\right) \tag{1}$$

$$W_c = 0.264W\frac{L}{H}\tanh\left(3.16\frac{H}{L}\right) \tag{2}$$

where L is length of rectangular pool wall, H is height of water surface above the bottom of the pool, and W is the equivalent weight of pool water.

The impulsive and convective forces act at the heights from the bottom of the pool, h_i and h_c, which are obtained from following equations.

$$h_i = 0.375H \tag{3}$$

$$h_c = H\left(1-\frac{\cosh\left(3.16\frac{H}{L}\right)-1}{3.16\frac{H}{L}\sinh\left(3.16\frac{H}{L}\right)}\right) \tag{4}$$

The impulsive force, P_i, is obtained from

$$P_i = \frac{\dot{u}_0 W_i}{g} \tag{5}$$

where $\dot{u}_0$ is zero period acceleration.

The natural frequency, ω, is obtained from

$$\omega^2 = \frac{3.16g}{L}\tanh\left(3.16\frac{H}{L}\right) \tag{6}$$

where g is acceleration of gravity. The angle of free oscillation, θ_h, at the water surface is obtained from following equation

$$\theta_h = 3.16\frac{A_1}{L}\tanh\left(3.16\frac{H}{L}\right) \tag{7}$$

where A_1 is the maximum amplitude of the displacement. The convective force, P_c, is

$$P_c = W_c\theta_h \sin\omega t\ . \tag{8}$$

2.2 Spectral Acceleration Approach

Equation 9 shows the mutual relationships of pseudo values; displacement, velocity and acceleration

$$A_1 = S_D = \frac{S_V}{\omega} = \frac{S_A}{\omega^2} \tag{9}$$

where S_A is the spectral acceleration for the natural frequency of pool water, ω, and 0.5% critical damping. Using Eqs. 6-9, θ_h and P_c are re-written as

$$\theta_h = \frac{\omega^2}{g}A_1 = \frac{\omega^2}{g}\frac{S_A}{\omega^2} = \frac{S_A}{g} \tag{10}$$

$$P_c = \frac{S_A W_c}{g}\sin\omega t \tag{11}$$

2.3 ACI 350.3 Formula

In ACI 350.3 standards [2], W_i, W_c, h_i, and h_c are same as those in Eqs. 1-4. The impulsive and convective forces are obtained from following equations,

$$P_i = C_i I \frac{W_i}{R_i},\ P_c = C_c I \frac{W_c}{R_c} \qquad (12)$$

where I is importance factor ($1.0 \le I \le 1.5$), R_i and R_c are response modification factors ($1.5 \le R_i \le 3.25$ and $R_c = 1.0$), and C_i and C_c are seismic response coefficients, which designate the profile of the design response spectrum at periods, T_i and T_c. T_i is the natural period of oscillation of the pool wall considering impulsive component. T_i is assumed to be very short for concrete wall or pool door. In this case, $C_i = \dot{u}_0 / g$. T_c is the natural period of the first mode of sloshing. T_c is calculated in the same manner as Eq. 6. The calculations of impulsive and convective forces in ACI 350.3 are essentially same as those in TID-7024. However, importance and modification factors adopted in ACI 350.3 make differences in values of dynamic forces.

Vertical distributions of the impulsive and convective forces, P_{iy} and P_{cy}, may be assumed as linear function of the height from the bottom, y.

$$P_{iy} = \frac{P_i}{H^2}\left[2H - 3h_i - \left(3H - 6h_i\right)\frac{y}{H}\right] \qquad (13)$$

$$P_{cy} = \frac{P_c}{H^2}\left[2H - 3h_c - \left(3H - 6h_c\right)\frac{y}{H}\right] \qquad (14)$$

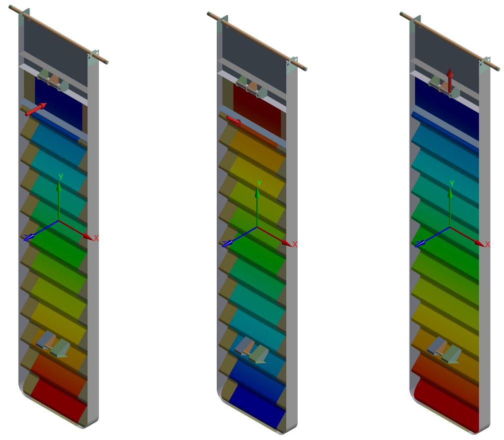
Horizontal distributions of the impulsive and convective pressures, p_{iy} and p_{cy} are

$$p_{iy} = \frac{P_{iy}}{B},\ p_{cy} = \frac{P_{cy}}{B} \qquad (15)$$

where B is the wall width.

2.4 Water Pressure Distributions

Distributions of the water pressures acting on the pool door are shown in Fig. 1. As the height from bottom, y, increases from 0 to 6 m (from pool door bottom to pool surface), the impulsive pressure decreases from 27.0 kPa to 3.86 kPa, but the convective pressure increases from 3.01 kPa to 12.8 kPa. The hydrostatic pressure decreases from 58.8 kPa to zero as y increases from 0 to 6 m. Net pressure is 88.8 kPa at the pool door bottom (y=0) and 16.7 kPa at the pool surface (y=6 m).



(a) (b) (c)

Fig. 1. Water pressure distributions on the pool door: (a) impulsive pressure, (b) convective pressure, and (c) hydrostatic pressure. Contours indicate pressure value. Red color means higher pressure and blue color means lower pressure.

The hydrostatic pressure acts on one side of the pool door, but the impulsive and convective pressures do not act on entire face of the pool door. The pool door is installed in slot of the pool gate between the reactor pool and the service pool. Dynamic effects of pool water are negligible in the pool gate slot. Only hydrodynamic pressure is considered for both ends of the pool door.

3. Structural Analysis Results

3.1 Finite Element Model

A finite element model is prepared for the structural analysis of the pool door by using the software, Ansys Mechanical [3], as shown in Fig. 2. SOLID186 elements are used for cylindrical bars and SHELL181 elements are used for plate components. Total number of nodes and elements are 50,264 and 29,261.

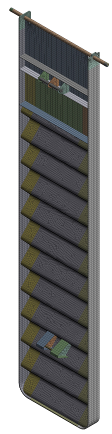
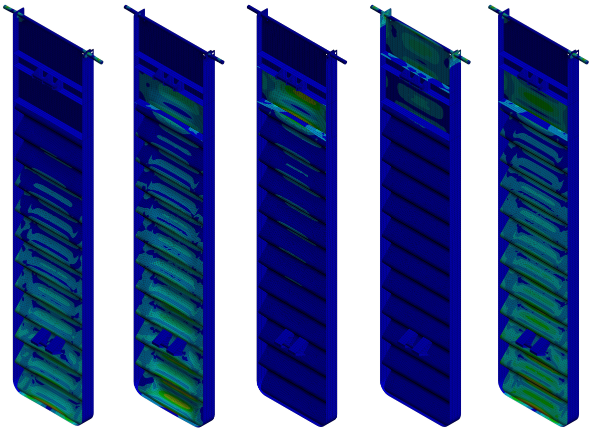


Fig. 2. Finite element model of the pool door.

3.2 Structural Analysis Results

A structural analysis is carried out with the water pressure distributions. The von Mises stress distributions under various load conditions are shown in Fig. 3. Static loads in Fig.3(a) mean the gravitational load and air pressure in the inflatable gasket. Figures 3(b) and 3(c) indicate stress distribution under the impulsive and convective pressures. Responses under seismic loads in Fig.3(d) are evaluated through a response spectrum method. All loads are considered in Fig. 3(e). The maximum stresses are 82.6 MPa, 31.7 MPa, 48.0 MPa, 2.6 MPa, and 93.6 MPa for each load condition. The maximum stress of 93.6 MPa occurs at the pool door bottom under the total loads in Fig. 3(e). The water pressure is also maximum at the bottom. The stress distributions are consistent with the water pressure distributions.



(a) (b) (c) (d) (e)

Fig. 3. Stress distributions under various load conditions: (a) static loads + hydrostatic pressure, (b) impulsive pressure, (c) convective pressure, (d) seismic loads, and (e) total loads.

4. Conclusions

Static and dynamic pressure distributions on the pool door are evaluated by using the formula from TID-7024 report and ACI 350.3 standard. We modify the formula by using the spectral acceleration. Configurations of the pool door, the pool and the pool gate are considered in the calculation of static, impulsive, and convective pressures. The structural integrity of the pool door under static and seismic loads with the water pressure condition is investigated through the finite element analysis. The stress distributions are consistent with the water pressure distributions. Further, water pressure distributions will be investigated by using the CFD method and will be compared to the results from formula.

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