Transactions, SMiRT-22
San Francisco, California, USA - August 18-23, 2013
Division IX (include assigned division number from I to X)

DYNAMIC ANALYSIS OF POOL DOOR IN WATER

Kang Soo Kim [1], Kyeong Hoon Jeong [1], In Soo Koo [1]

[1] Principal Researcher, Korea Atomic Energy Research Institute, (kskim5@kaeri.re.kr)

1 ABSTRACT

The pool tank of the research reactor has a pool door, which is located between the reactor pool and the service pool. It is used to separate the reactor pool from the service pool for the maintenance and/or removal of the equipment either in the reactor pool or in the service pool. The pool door consists of stainless steel plates supported by the structural steel frames and the sealing component. Also, it is contacted with the water in the pool tank.

The pool door shall be designed considering the deadweight and the hydrostatic load of the water pressure. Also, it shall be designed to withstand loads induced by a seismic event.

In this paper, the natural frequency for the free vibration of the rectangular plate in contact with the water is obtained using the ANSYS code. This result was compared with that of the theoretical analysis. Also, the impulsive force and convective force of the pool tank during an earthquake were calculated for an estimation of the structural integrity of the pool door.

2 INTRODUCTION

The configuration of the pool door is shown in Figure 1. The FEM analysis and theoretical calculation by the formula were performed to evaluate the natural frequency for the pool door in the water. The results from the two methods were compared.

The types of loads considered for the design of the pool door are dead loads, hydrostatic loads, hydrodynamic loads, and seismic loads. The hydrodynamic loads are the loads resulting from the oscillation of the water of the service pool during seismic events. That is, the impulsive force and convective force of the pool tank during an earthquake were calculated for the estimation of the structural integrity of the pool door. The seismic loads are the loads experienced by the system during the SSE. The effect of these loads is evaluated using the floor response spectrum (SSE, 7% damping) curves. The equivalent static analysis for the seismic loads is performed. The static loads, hydrodynamic loads, and seismic loads are then combined for the stress calculation.

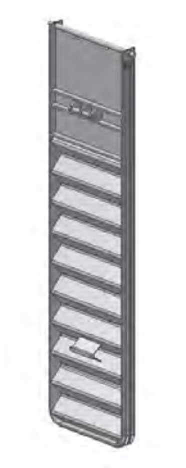

Figure 1 Configuration of the pool door

3 METHODS AND RESULTS

3.1 Natural Frequency by FEM

The natural frequencies of the pool door were obtained from an analysis using the ANSYS code. The pool door was modeled using the SHELL 63 element, and the water in the pool was modeled using the FLUID80 element. The finite element model by the ANSYS code is shown in Figure 2. All structural steel shall conform to the ASTM Specification, A240-TP304L.

The size of each component is as follows;
Plate : 1.58x6.19x 0.0811(m), t=8.11(cm)
Service pool : 1.58x7.43x 4.9(m).
Reactor pool : 1.58x4.57x 4.9(m).

The boundary condition at the plate edge is assumed to be completely simply supported (S-S-S-S).

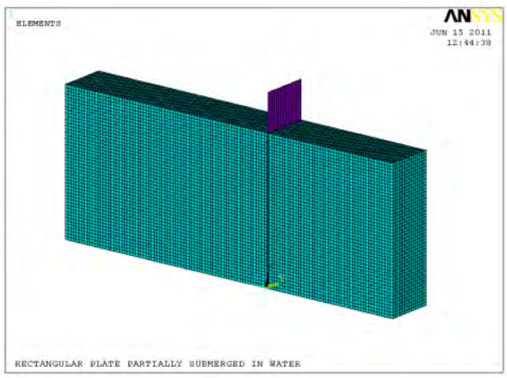

Figure 2 ANSYS model for the pool door

The results of the modal analysis are as follows.

Table 1: Results of modal analysis.

Mode	Natural frequency (Hz)
1	33.96
2	55.78
3	82.07
4	114.14
5	151.14

The deformed shapes of the 1st, 2nd, 3rd and 4th mode are shown in Figure 3, 4, 5, and 6, respectively.

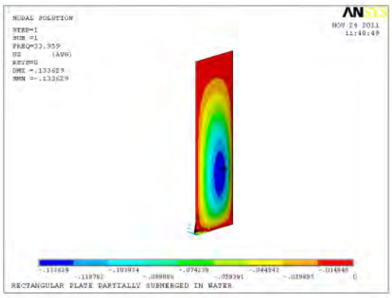

Figure 3 The 1st mode of the pool door

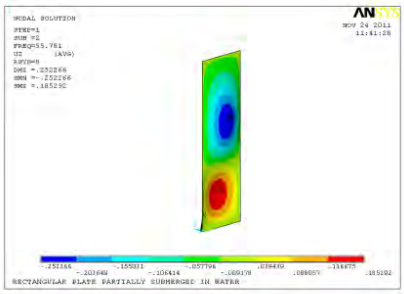

Figure 4 The 2nd mode of the pool door

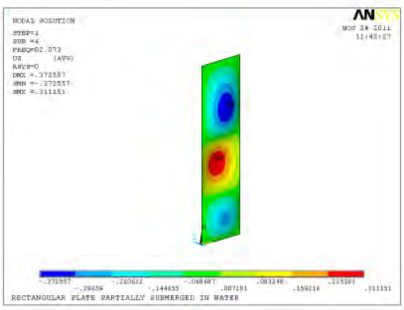

Figure 5 The 3rd mode of the pool door

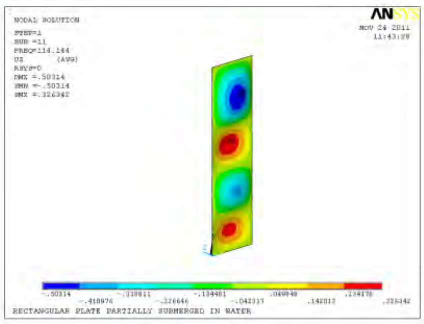

Figure 6 The 4th mode of the pool door

3.2 Theoretical calculation by formula

The total inertia moments for each component of the pool door are

$I = [(3x\ 24^3)/12]\ x\ 2 + (152x\ 2.1^3)/12 \fallingdotseq 7029.3\ cm^4$

The equivalent thickness of the pool door was calculated as follows.

$t = \sqrt[3]{(12\ x\ I)/158} = \sqrt[3]{(12\ x\ 7029.3)/158} = 8.11\ (cm)$

The added mass for rectangular plates with one side exposed to water [Robert D. Blevins (1979)].

$A_p = \alpha_{ij}\beta\rho ab^2$, $\alpha_{ij} = (\int z_{ij}\ dA)^2/(2ab\int z_{ij}^2\ dA)$,

where z_{ij} is the dimensionless mode shape.
A = ab =the area of the pool door contacted in the water.
α_{ij} = function of the modal indices and the boundary conditions on the plate
β = aspect ratio dependent factor.

a/b	0.1	0.2	0.3	0.4	0.5	0.6
β=0	0.30	0.42	0.58	0.65	0.72	0.78

$a/b = 108/485 \fallingdotseq 0.22$

$\therefore\ \beta = 0.452$

α_{11} is obtained from the table below.

i	j	α_{ij}	
		C-C-C-C	S-S-S-S
1	1	0.3452	0.8106
1	2	0.0000	0.0000
1	3	0.1512	0.2702
1	5	0.0962	0.1620

where C-C-C-C indicates completely clamped edges and S-S-S-S indicates completely simply supported edges.

$\therefore\ \alpha_{11} = 0.8106$

The natural frequencies of the pool door were obtained from the following equation [Robert D. Blevins (1979)].

$f_{xij} = [\lambda_{ij}^2/(2\ \pi b^2)]\ x\ [(Et^3)/\{12\ \gamma(1-\nu^2)\}]^{0.5}$,

where $\lambda_{ij}^2 = \pi^2[i^2 + j^2(b/a)^2] = \pi^2[1^2 + (619/152)^2] \fallingdotseq 173.5$

$\therefore\ f_{x11} = [173.5/(2\ \pi\ x\ 619^2)]\ x\ [(1.937\ x10^6 x\ 8.11^3)/\{12\ x\ 0.000392877(1-0.272^2)\}]^{0.5} \fallingdotseq 35.1$ Hz

Therefore, it was found that the results from the theoretical calculation can predict the finite element analysis results well, and the pool door can be assumed as a rigid body in the seismic analysis, since its fundamental natural frequency exceeds 33 Hz.

3.3 Dynamic Analysis

The calculation has been performed to evaluate the structural adequacy of the pool door for the required design loadings. The static and dynamic analysis is used for a structural evaluation. The equivalent static analysis is employed as a dynamic analysis method.

Since the pool door of Figure 1 is located between the reactor pool and the service pool, the impulsive force and convective force of the service pool during an earthquake must be calculated for that of the pool door. When a tank containing a fluid of weight W is accelerated in a horizontal direction, a certain portion of the fluid acts as if it were a solid mass of weight W_0 in rigid contact with the walls. Assuming that the tank moves as a rigid body, with the bottom and walls undergoing the same acceleration, the mass then exerts a maximum horizontal force directly proportional to the maximum acceleration of the tank bottom. This force is identified as an impulsive force, P_0. The acceleration also induces oscillations of the fluid, contributing additional dynamic pressures on the walls and bottom, in which a certain portion of the fluid, of weight W_1, responds as if it were a solid oscillating mass flexibly connected to the walls. Again assuming that the tank itself behaves as a rigid body, the maximum amplitude, A_1, of the horizontal excursions of the mass relative to the walls determines both the maximum vertical displacement, d_{max}, of the water surface (slosh height) and the horizontal force exerted on the walls. This force is defined as a convective force, P_1, since it involves fluid motion . The United States Atomic Energy Commission (1963) The pool door is located between the reactor pool and the service pool. The water depth is 10 m.

All components of the pool door are classified as a safety class NNS, seismic category II, and quality class T. The types of loads considered are dead loads, hydrostatic loads, hydrodynamic loads, and seismic loads. The seismic loads are the loads experienced by the system during the SSE. The effect of these loads is evaluated using the floor response spectrum (SSE, 7% damping) curves. For example, Figure 7 is the E-W FRS of the top area of the reactor pool (SSE, 2%, 3%, 4%, 5%, 7%, 10% damping).

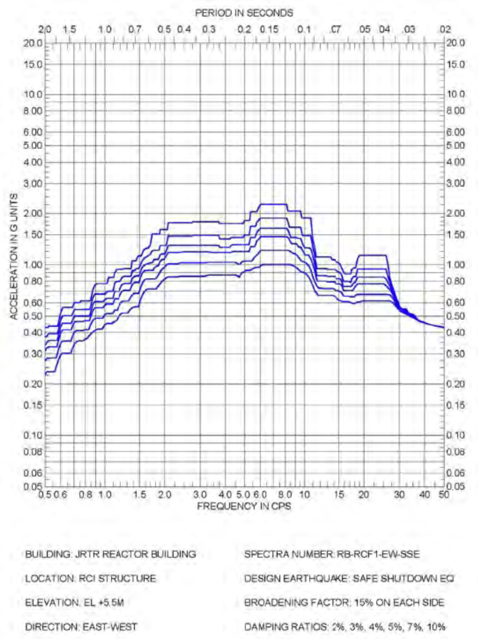

Figure 7 E-W FRS of the top area of the reactor pool (SSE, 2%, 3%, 4%, 5%, 7%, 10% damping)

3.4 Material and Property

All loads bearing structural steel shall conform to ASTM Specification A240-TP 304L. The yield stress, tensile stress and allowable stress for ASTM A240-TP 304L are as follows. ASTM

Table 2. Material property of A240-TP 304L

Material Property	**ASTM A 240-TP 304L**
Modulus of Elasticity	1.952E+11 N/m^2
Poisson's Ratio	0.30
Mass Density	7900 kg/m^3
Yield Strength (σ_y)	172 MPa
Tensile Strength (σ_u)	483 MPa
Allowable Stress (σ_a)	1.0 σ_a (115 MPa), 1.6 σ_a (184 MPa)

3.5 Stress Analysis

As shown in Figure 8, the service pool is Non-Slender.

h/l = 16.076/11.483 = 1.4

Since the h/l value is smaller than 1.5, this is a non-slender tank.

ImpulsiveForce (P_0) and Convective Force (P_1) are calculated by the fomula [United States Atomic Energy Commission (1963)].

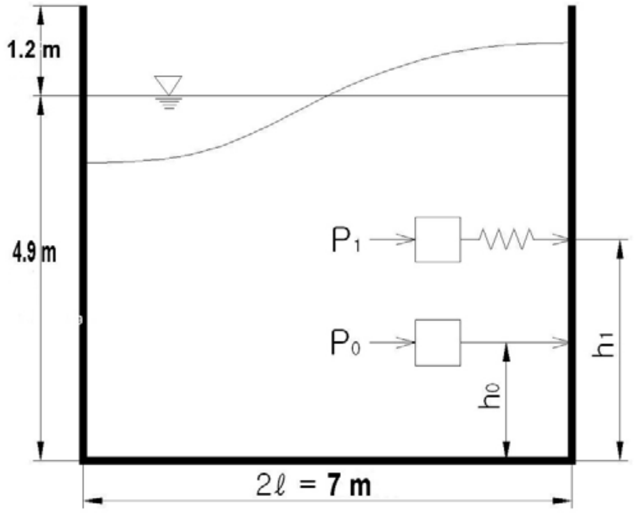

Figure 8 Dynamic model for non-slender tank

For an equivalent static analysis, horizontal acceleration (0.52g) is applied and vertical acceleration (0.45g) is applied.

- Fx=Horizontal seismic loads = HSL= ma = 1.5x3000 x 0.52 g = 22932 (N)
- Fz =Horizontal seismic loads = HSL= ma = 1.5x3000 x 0.52 g = 22932 (N)
- Fy =Vertical seismic loads = VSL= ma = 1.5x3000 x 0.45 g = 19845 (N)

After the load combination, the loads are calculated are follows.

Fy = Dead Load+ Vertical seismic load=29400+19845=49245(N)

Fx= Horizontal seismic load=22932 (N)

Fz= Hydrostatic Load+ Hydrodynamic Load +Horizontal seismic load=185886+18350(Convective Force) + 128878(Impulsive Force) + 22932=356046(N)

The maximum load applied to the pool door is

$F = \sqrt{F_v^2 + F_y^2 + F_z^2} = \sqrt{49245^2 + 22932^2 + 356046^2} \fallingdotseq 360166$ (N)

This load is applied to each component of the pool door for the stress analysis. Results of the static and seismic analysis for each component of the pool door were lower than the design limits for the given material.

CONCLUSION

Comparing the results of ANSYS with those of the theoretical estimation for calculating the natural frequencies of the pool door, two results show good agreement. It was observed that the 1st mode of the pool door is 33.96 Hz. Since the fundamental natural frequency of the pool door exceeds 33 Hz, we can regard the pool door as a rigid body. The stress analysis for each component of the pool door was performed against the given loads including the seismic load. Since the stresses for the analysis results were lower than the design limits for the given material, the structure integrity for the given dimension of the pool door was confirmed.

ACKNOWLEDGEMENTS

This work has been carried out under the nuclear R & D program supported by the Ministry of Education, Science and Technology, Korea.

REFERENCES

Annual Book of ASTM, American Society for Testing Materials.

Robert D. Blevins (1979) “Formulas for natural frequency and mode shape”

United States Atomic Energy Commission (1963) TID-7204 Nuclear Reactors and Earthquakes, Chapter 6 Dynamic Pressure on Fluid Containerst.