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Structural Design of Pool Door for Research Reactor

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1. Introduction

The pool door is installed at the pool gate to isolate the reactor pool from the service pool during maintenance of the reactor. A rod at the top of the pool door is for lifting and installation at the pool gate. Stainless steel plates are supported by the rod and side frames. The plates block water of the service pool and inflatable gaskets seal the gap between the plate frame and the pool gate wall. The pool door is designed as a seismic category II structure to maintain its structural integrity during a safe shutdown earthquake (SSE). In this work, structural design factors such as rod diameter and plate thickness are verified through the finite element analyses. All results are compared with the design criteria of KEPIC SND [1] and MNF [2] codes.

2. Methods and Results

2.1 Methods

A finite element model of the pool door is shown in Fig. 1. BEAM188 elements are used for the rods and SHELL181 elements are used for the plates. The total number of nodes and elements are 25,467 and 25,461, respectively.

Fig. 1. Finite element model of pool door.

Dead loads and hydrostatic load are considered in the load combination for normal condition. The dead loads include total weight of the pool door and pressure of air in the inflatable gaskets. The total weight depends on the rod diameter and the plate thickness. The design value of air pressure is 1.5 bar. For a conservative design, low and over pressures (0 and 3 bar) are also considered. The hydrostatic load is caused by the service pool water.

Extreme environmental condition considers hydrodynamic loads and seismic loads as well as the dead loads and the hydrostatic load. The hydrodynamic loads are calculated in the previous work [3]. While impulsive parts of the hydrodynamic forces are generated by the motion of the pool wall structure including the pool door during earthquake, convective parts are caused by the sloshing motion of the pool water. The impulsive forces are calculated using zero period acceleration of the floor response spectrum (FRS). The convective forces depend on the natural frequency of the pool water. The structural responses to the seismic loads are evaluated by using a response spectrum analysis.

2.2 Rod Design

The rod with circular cross section is shown in Fig. 2. The rod withstands most of the vertical loads and is regarded as a flexural member. The vertical loads in the normal condition are the gravitational load, the vertical component of the hydrostatic force on corrugate plates, and the gasket air pressure on the bottom plate. The design of the rod should satisfy the bending stress criteria of the KEPIC SND [1].

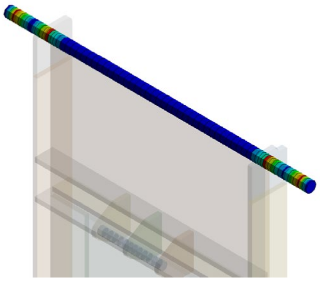
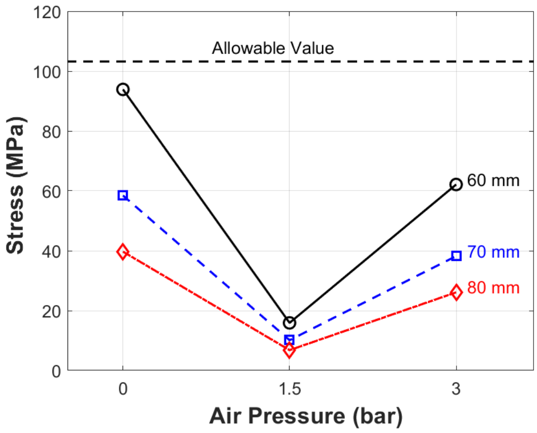


Fig. 2. Distribution of bending stress in the rod.

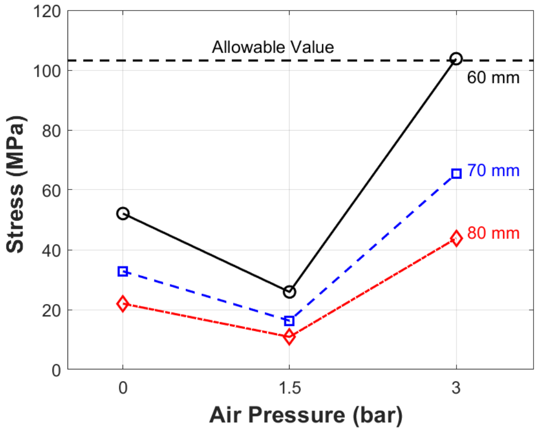
Fig. 3(a) shows the bending stresses in the rods with different diameters of 60, 70, and 80 mm for the pool door with total weight of w=2.7 ton. The bending stress decreases as the rod diameter increases. The bending stresses are 91%, 15%, and 60% of the allowable value when the diameter increases from d=60 mm to 80 mm, and the air pressure is p= 0. This means that the design margin of the rod with diameter of d=60 mm is only 9% before the gasket is inflated.

We consider a reduction of the total weight. The case of the total weight of w= 1.2 ton is shown in Fig. 3(b).

The bending stress excesses the allowable value when w=1.2 ton, d=60 mm, and p=3 bar. This result indicates the rod of d=60 mm is not safe for the case of gasket overpressure. The rod of d=70 mm has 35% design margin when w=1.2 ton and p=3 bar. The rod diameter of d=70 mm is chosen.



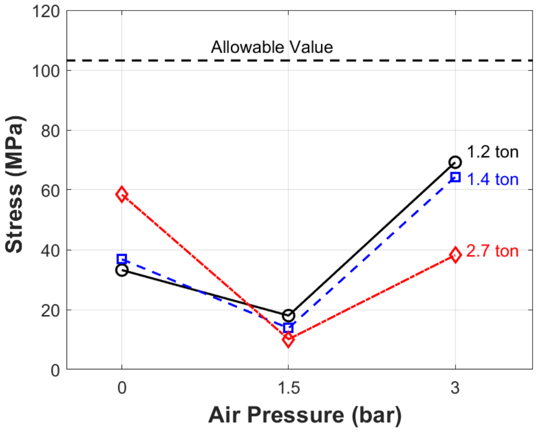
(a) Bending stress vs. rod diameter / total weight 2.7 ton



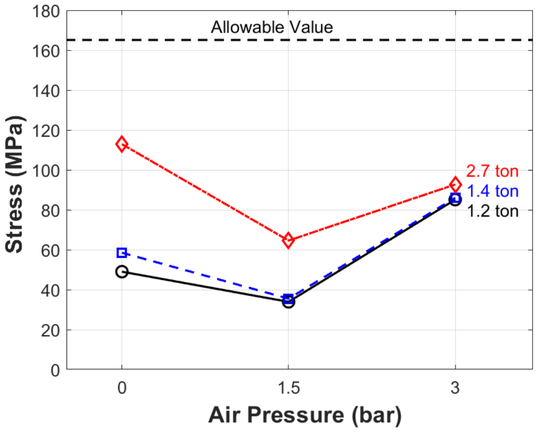
(b) Bending stress vs. rod diameter / total weight 1.2 ton

Fig. 3. Bending stresses as function of air pressure for rod diameters of 60, 70, and 80 mm and total weights of (a) 2.7 ton and (b) 1.2 ton.

Bending stresses in the rod of d=70 mm under the normal and extreme environmental conditions are shown in Fig. 4(a) and 4(b). Total weights of w=1.2, 1.4, and 2.7 ton are considered. The rods with d=70 mm satisfy the stress criteria in all cases considered. However, the tendency is different. Under the normal condition, the bending stress is higher for heavier weights when p=0, but the relationship between the bending stress and weight is the opposite when p=1.5 and 3 bar. Under the extreme environmental condition, the case of w=2.7 ton is the worst at all pressures. This is because seismic loads increase when the mass attached to the rod increases. The minimum design margins of the rod of d=70 mm are 33%, 38%, and 32%, respectively, for the total weight of w=1.2, 1.4, and 2.7 ton.



(a) Bending stress / normal condition



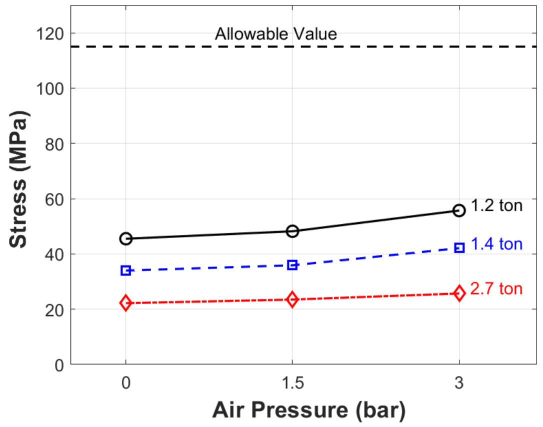
(b) Bending stress / extreme environmental condition

Fig. 4. Bending stresses as function of air pressure for rod diameter of 70 mm and total weights of 1.2, 1.4, and 2.7 ton under (a) normal condition and (b) extreme environmental condition.

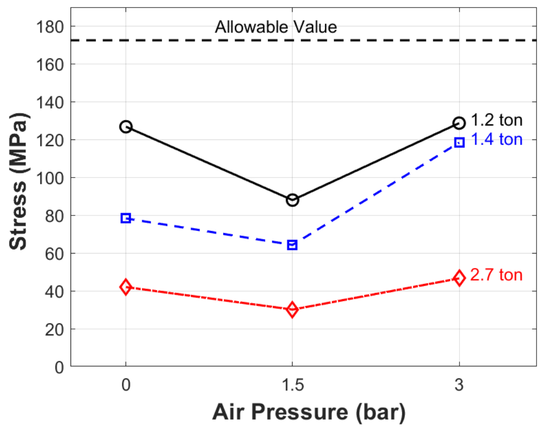
2.3 Plate Design

The plates should be designed to withstand the water pressures. The decrease in the total weight reduces the plate thickness. Total weight of w=2.7 ton corresponds to the plate thickness of t=12 and 30 mm, w=1.4 ton to t=8 and 16 mm, and w=1.2 ton to t=6 and 16 mm. The design of the plates follows the stress criteria of the KEPIC MNF [2]. Membrane and bending stresses in the plates are evaluated for the normal condition and membrane and bending stress intensities are evaluated for the extreme environmental condition. In all cases in the Fig. 5, the stresses in plates satisfy the MNF criteria. In most cases, the stress of the plate increases as the thickness decreases. An exception is the case with p=0 under extreme environmental condition in Fig. 5(c). The membrane stress intensity of w=2.7 ton is larger than that for w=1.4 ton, but the stress intensity of w=2.7

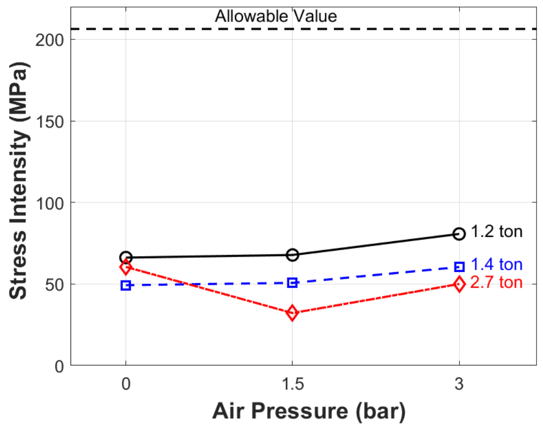
ton is only 29.3% of the allowable value. The minimum design margins of plates are 25%, 31%, and 71%, respectively, for the total weight of w=1.2, 1.4 and 2.7 ton.



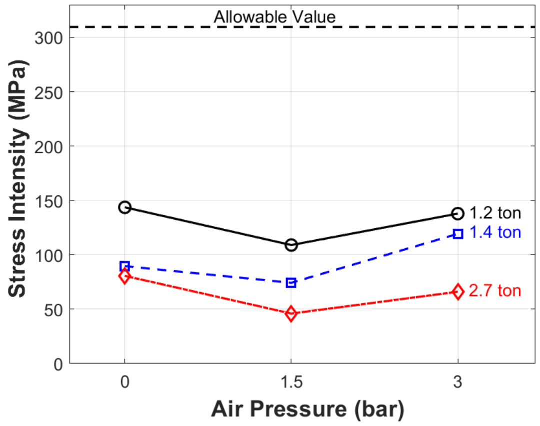
(a) Membrane stress / normal condition



(b) Membrane + bending stress / normal condition



(c) Membrane stress intensity / extreme environmental condition



(d) Membrane + bending stress intensity / extreme environmental condition

Fig. 5. Stresses in plate structure as function of air pressure for total masses of 1.2, 1.4, and 2.7 ton: (a) membrane stress and (b) membrane plus bending stress for normal condition and; (c) membrane stress intensity and (d) membrane plus bending stress intensity for extreme environmental condition.

3. Conclusions

Structural analyses of the pool door are performed with various design factors and conditions. Stresses in the rod and plates are evaluated and compared with the KEPIC code criteria to verify the design. Small diameter of the rod does not satisfy the safety criteria with possible cases. The weight reduction increases the design margin of the rod, but decreases that for the plate. The plate thickness should be carefully chosen in consideration of the advantages of weight reduction and the safety.

Acknowledgements

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REFERENCES

[1] Korea Electric Power Industry Code, SND, Safety-Related Steel Structures for Nuclear Facilities, Korea Electric Association, 2005.
[2] Korea Electric Power Industry Code, MNF, Supports, Korea Electric Association, 2006.
[3] K. Jung, T. Kim, J. Oh, Water Pressure Distributions on Pool door for Research Reactor, Korean Nuclear Society Spring Meeting, 2021.