The 2016 World Congress on
The 2016 Structures Congress (Structures16)
Jeju Island, Korea, August 28-September 1, 2016

Analysis of the Shell Structure under Extreme Load

*Joon-Ki Hong[1)] and Thomas Kang[2)]

[1), 2)] *Department of Architecture & Architectural Engineering,*
Seoul National University, Seoul, Korea
[2)] *tkang@snu.ac.kr*

ABSTRACT

For containment structures, accidents caused by extreme environmental conditions should be considered even if it is highly improbable. Therefore all containment structures should observe the design code meticulously. As a role of preventing release of radiological materials, containment structures should resist beyond the design pressure. The main purpose of this study is to characterize the response of the reactor building with an analysis when a containment structure is under 0.7 MPa. The analysis is conducted using ETABS 2015. It is concluded that structural behavior of the containment structure can be analyzed using the tensile force and bending moment at various points, and that the critical point is located at 11 m in height of the modeled full-scale shell structure.

1. INTRODUCTION

The three-mile island accident happened in the United States in 1979. In 1986, the Chernobyl disaster occurred. Recently, the explosion of a nuclear plant caused by the earthquake in Fukushima, Japan occurred in 2011. After these accidents, anxieties about structural safety of nuclear power plant (NPP) structures are stretched to the world. During the design of nuclear containment structures, nuclear structural engineers should consider various loading cases although it is highly improbable. For many kinds of accidents, severe accidents in the NPP structures are related to the loss of coolant accident (LOCA). In the event of a severe accident, radioactive materials are released, coinciding with increasing internal pressure level beyond the design pressure. Consequently, the NPP structure should perform a role as a radiation shield.

In general, NPP structures are typically comprised of main buildings, appurtenances, and foundation. The NPP structures are designated separately as safety-related or non-safety-related components. Reactor buildings and auxiliary buildings are classified as safety-related components constructed as concrete

[1)] Graduate Student
[2)] Associate Professor

structures. The reactor buildings consist of pressure boundary parts, such as cylindrical wall, hemispherical dome-shape roof and foundation slab, and internal structures which are not belonged to the pressure boundary parts. While the structures included in pressure boundary parts are designed complying with KEPIC SNB, concrete structures which are not classified in the boundary parts should conform to KEPIC SNC (KEPIC, 2010a; KEPIC, 2010b; Moon, 2014). In the U.S., design basis and combinations are addressed in the ASME Boiler and Pressure Vessel Code (BPVC) to construct nuclear containment buildings, where loads are divided into service load and factored load categories. Particularly, severe environmental loads, extreme environmental loads, and abnormal loads are involved in the factored load category. Based on the load cases, load combinations and load factors are defined in the ASME code (ACI-ASME Joint Committee, 2015).

A typical research to evaluate the structural capacity about internal pressure was the overpressurization test of a 1:4 scale containment conducted by Sandia National Laboratories. By performing the static pneumatic overpressurization test at ambient temperature, the structural response of the containment to and beyond the design pressure was observed and measured, including the failure modes (Hessheimer, 2003). Akbar and Gupta (1986) studied the reinforced concrete containment behavior under dead load, internal pressure, and earthquake.

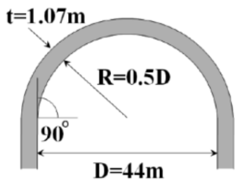
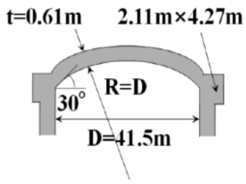
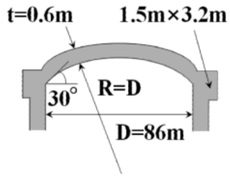
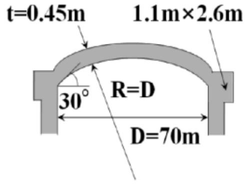
In this study, a containment shell structure subjected to 0.7 MPa of internal pressure is considered. The main purpose of this study is to characterize the behavior when the containment structure is under the extreme internal pressure. Using ETABS 2015 and LS-DYNA, finite element programs, the structural analysis is conducted (CSI, 2015).

2. ANALYSIS MODEL

2.1 Computational Model

Representative types of containment buildings are summarized in Table 1 (Jeon, 2000). In particular, methods of generating nuclear energy are classified as Pressurized Water Reactor (PWR) and Pressurized Heavy Water Reactor (PHWR). The PWR method is employed on the OPR-1000 such as Kori, Hanbit, and Hanul plants. It has a hemispherical dome and cylindrical wall constructed by adopting unbonded prestressed concrete. The PWHR method was applied to the Wolsong plant, where a partially spherical dome was applied on the top of the building. The design pressure was approximately 0.41 MPa and 0.12 MPa, respectively (Kwak, 2004). In Korea, the PWR method was adopted for most of the NPP structures except for 4 units. In this respect, the OPR-1000 is established as a computational model to study a response to internal pressure in this paper.

Table 1 Types of Containment Structures (Jeon, 2000)

Structure	Nuclear Containment Building		LNG Storage Tank	
	OPR-1000[1)]	CANDU[2)]	Tongyeoung	Incheon
Shape of Dome and Ring Beam				
Ring Beam	X	O	O	O

[1)] Optimized Power Reactor 1000 MWe
[2)] Canada Deuterium Uranium

As shown in Fig. 1, a computational containment structure in ETABS 2015 is consisted of cylindrical wall, which has a 22 m radius and 44 m elevation, and a hemispherical dome on the top of the building. The wall and dome thickness is 1.22 m.

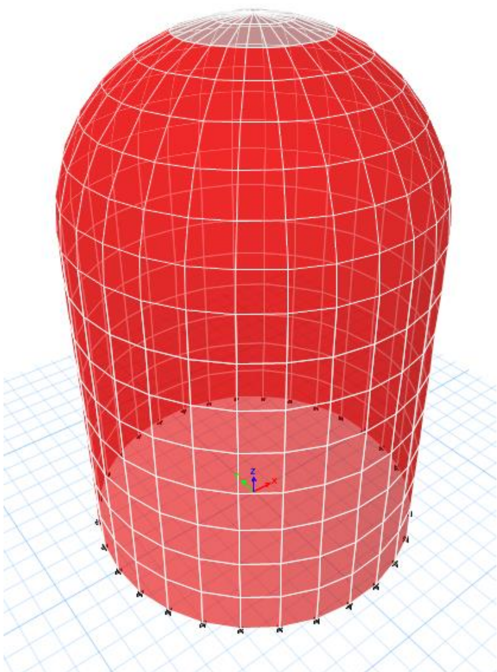


Fig. 1 Computational Shell Structure Model in ETABS 2015

Material properties for concrete are summarized in Table 2 (Lee, 2011). The

Table 3 General Information of Representative Elements

Height (m)	Shell Object	Unique Name
66.0	F153	213
65.6	F123	183
64.3	W513	153
62.3	W483	123
59.6	W453	93
56.2	W423	60
52.4	W393	33
48.3	W363	3
44.0	W567	409
38.5	W567	410
33.0	W567	411
27.5	W567	412
22.0	W567	413
16.5	W567	414
11.0	W567	415
5.5	W567	416

Figure 2 shows comparisons of the tensile forces or stresses between circumferential and longitudinal directions under design internal pressure. For the tensile force, the maximum force is obtained at 11 m elevation in the circumferential direction. Generally, the circumferential force or stress is larger than that in the longitudinal direction.

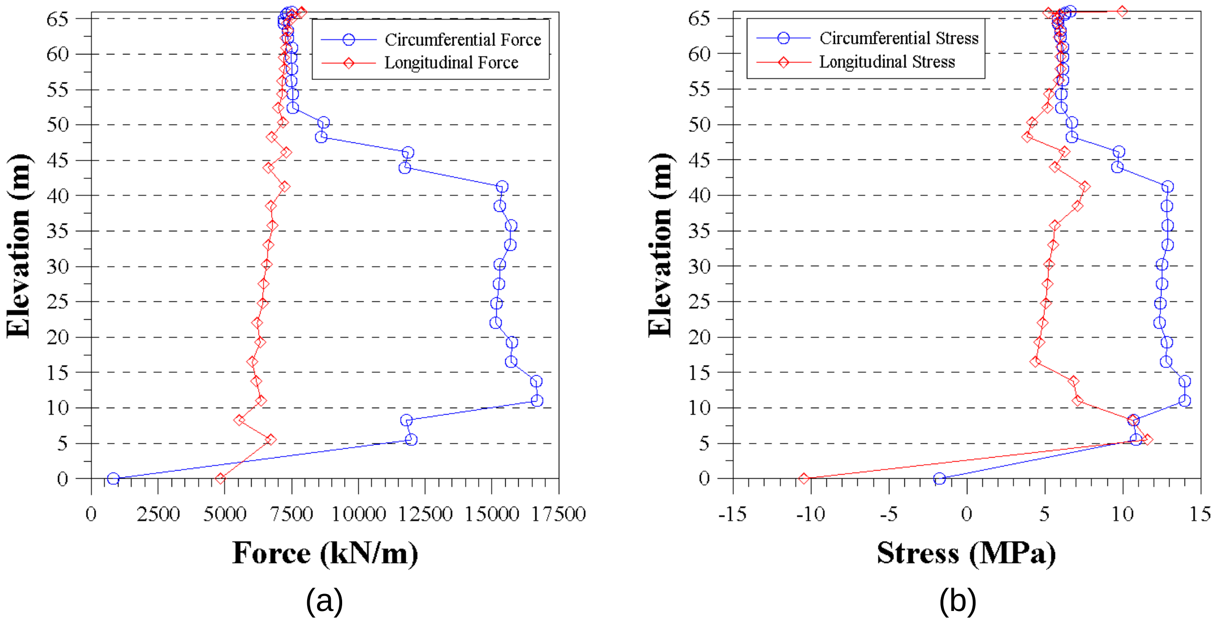


Fig. 2 (a) Tensile Force, (b) Stress