Safety Assessment of CANDU Type Containment Building under Negative Internal Pressure

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1. Introduction

In March, 2011, Fukushima Daichi nuclear power plants experienced a long term station blackout (SBO) and severe core damages and released a large amount of radioactive materials outside of the plants. After this accident Nuclear Safety and Security Commission (NSSC) decided to install a filtered containment venting system (CFVS) at all the operating nuclear power plants in Korea. To comply with NSSC's request, Wolsong Unit 1 has installed a CFVS. During the operation of CFVS, it was expected that the containment building will be experience a negative pressure loading condition with the maximum load of -100 kPa(g) [1]. The containment for CANada Deuterium Uranium (CANDU) type plant is not design to withstand against the negative pressure. Therefore, the integrity and safety of CANDU type containment building should be verified with the ultimate negative pressure capacity analysis. In this study, the ultimate capacity of negative pressure of CANDU type containment building was evaluated by using the finite element analysis method. From the analysis results, it was founded that the CANDU type containment building have a safety margin of 850 kPa(g) in the viewpoint of concrete compressive stress under negative pressure loading.

2. Assessment of Negative Pressure Loading

The station blackout accident is selected to assess the negative pressure loading during the containment vacuum strategy in CANDU type plant. When the containment pressure exceeds the design pressure of the containment building, i.e. 124 kPa(g), the operator opens CFVS isolation valves. Then steam and air in the containment flows out to the environment through the CFVS and the containment pressure decreases. Operator closes CFVS isolation valves if the containment pressure drops below 50 kPa(g). The containment pressure oscillates between the open and the close set pressure of the CFVS as shown in Fig. 1. This oscillation continues until the containment fails by an over-pressurization after a reactor vault failure. During this pressure oscillation, the local air coolers (LACs) are assumed recovered and start an operation at 180,000 seconds (50 hours after SBO occurred). The operation of LACs condenses the steam in the containment atmosphere and decreases the containment pressure. A lot of air is expelled with steam from the containment atmosphere when the CFVS isolation valves are open. So the condense of steam by LACs results in the vacuum in the containment as shown Fig. 1. The containment for CANDU type plant is not design to withstand against the negative pressure, but it may maintain its integrity up to the -15 kPa(g)[2]. The degree of the negative pressure depends on when LACs start to operate and how many LACs are operating. In Fig. 1 the containment pressure behavior are shown 12 LACs start to operate at 180,000 second. The negative pressure is almost -100 kPa(g). This negative pressure may results the problem in the containment integrity or safety. Therefore, the containment pressure controlled to maintain near the atmospheric pressure by either LACs stop to operate or open the CFVS isolation valves when the containment pressure becomes negative. However, if the containment integrity and safety under negative pressure will be verified, the more aggressive CFVS and LACs operation strategy can be used.

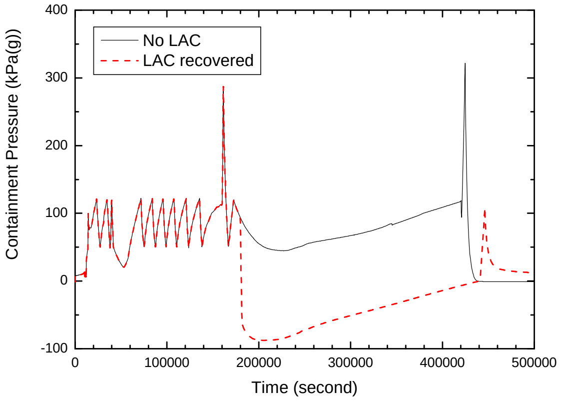

Fig. 1. Containment pressure history with a filtered containment venting system (CFVS) operation with respect to the local air coolers (LAC) recover.

3. Negative Pressure Capacity Assessment

To verify the safety of containment building under a negative pressure, the ultimate negative pressure capacity analysis using finite element analysis should be required. For the modeling of containment buildings, there exists a burdening process on the modeling of tendons at the hatch area since their geometry is somewhat complicated. In this study, we adopted a program which can automatically generate the coordination of the tendon components around the dome and wall areas. The FE-based general-purpose structural analysis program, ABAQUS [3], was adopted as an analysis tool and developed models were implemented into the input files. We modeled the CANDU type containments as 3D FE models. For the modeling of the containment wall, dome, buttress and slab, solid elements were used. The reinforcement bars and tendons were modeled using embedded surface and truss elements, respectively. The material nonlinearity of the concrete was implemented by introducing the concrete damaged plasticity model [3]. The tri-linear plasticity model and piecewise linear stress-strain model were used for the material nonlinearity of steel rebars and tendons, respectively.

Fig. 2 shows the deformed shape & stress contour for finite element model of CANDU type containment building under negative internal pressure loading of -100 kPa(g). From the Fig. 2, we can find that the critical point under a negative internal pressure loading is the top of the dome of the containment building. The expected failure mode is the crushing of the concrete under excessive compressive stress.

From the results of previous studies on ultimate internal pressure capacity analysis [4], the compressive strength of Wolsong Unit 1 containment building was estimated as 37.8 MPa, which is about 8.0% larger than design concrete strength, 35.0 MPa.

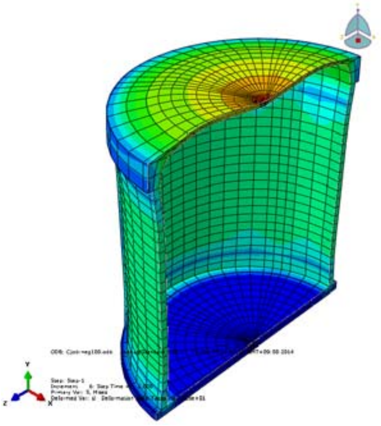

Fig. 2. Deformed shape & stress contour for finite element model of CANDU type containment building under negative pressure loading (-100 kPa(g)).

Fig. 3 depicts the internal pressure – concrete stress response curve at the critical point, i.e., top of the dome of CANDU type containment building. Under the negative pressure loading of -100 kPa(g), the compressive stress response of concrete was about 13.0 MPa, which is about 2.7 and 2.9 times smaller than the design and estimated actual concrete strength, respectively. From the Fig. 3, we can also find that the ultimate negative pressure capacity is -950 kPa(g), and the safety margin for negative pressure is about -850 kPa(g) for the present CFVS operating strategy. From the previous study, the margin for positive ultimate pressure capacity was about 250 kPa(g). With these results, we can conclude that the CANDU type containment building has relatively enough safety margin against to the negative pressure loading especially compare to that of ordinary internal pressure loading.

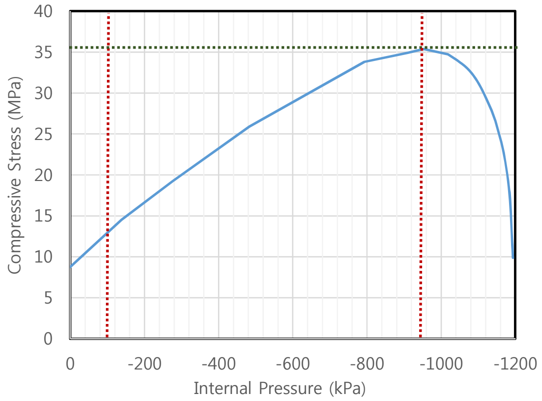

Fig. 3 the internal pressure – concrete stress response curve at the critical point, i.e., top of the dome of CANDU type containment building.

4. Conclusions

In this study, the ultimate capacity of negative pressure of CANDU type containment building was evaluated by using the finite element analysis method. The critical point under a negative internal pressure loading was the top of the dome of the containment building. The expected failure mode was the crushing of the concrete under excessive compressive stress. From the analysis results, it was founded that the CANDU type containment building have a safety margin of 850 kPa(g) in the viewpoint of concrete compressive stress under negative pressure loading. With the safety verification results and ultimate capacity information for negative pressure loading, it can be expected that more effective and aggressive CFVS operation strategy will be possible.

Acknowledgement

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