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The Propagation Characteristics of The Incident and Reflected Pressures Under Steam Explosions at A Corner of The Reactor Cavity by ALE and FSI Method

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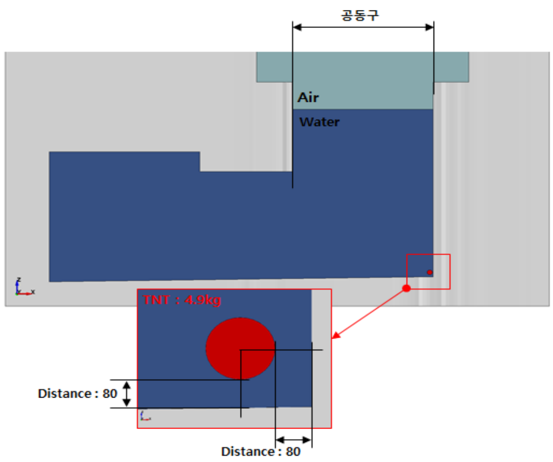
1. Introduction

In accordance with section 4.2.5 of the Safety Review Guideline for Accident Management Program [1], the structural integrity of the reactor cavity subjected to steam explosion loads should be maintained [2]. Up to date, evaluating the propagation characteristics of steam explosions in complex systems, such as walls and floors in the reactor cavity, has been regarded as an undeveloped technology [2]. In this study, a series of preliminary numerical analyses were carried out using the ALE (Arbitrary Lagrangian-Eulerian) and FSI (Fluid-Structure Interaction) methods to evaluate the propagation characteristics of the incident and reflected pressures under steam explosions at the corner of the reactor cavity [2].

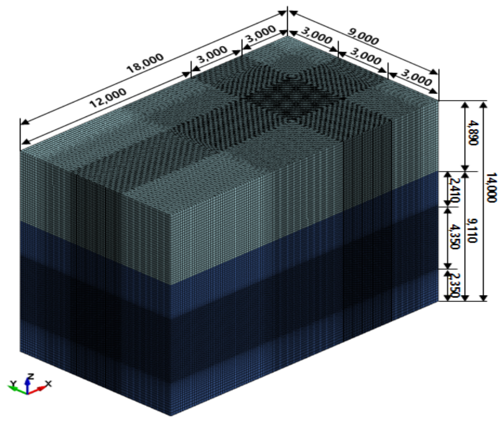
2. Finite element analysis condition

2.1 Position of the steam explosion

In the event of a severe accident, fuel-coolant interaction (FCI) is assumed to occur as a result of reactor vessel bottom failure [2]. As shown in Fig. 1(a), the steam explosion position is chosen at a corner of the reactor cavity, 80 mm from both the wall and the floor [2]. As shown in Fig. 1(b), a fluid model for cooling water was built up to a height of 9.1 m from the bottom, and a fluid model for air was built up to a height of 4.9 m from the free surface of the cooling water [2]. The near region where the steam explosion occurs in the reactor cavity was uniformly set up with a mesh size of 50 mm, and the mesh size increased as the distance from the center of the fluid models increased [2].



(a) Steam explosion position



(b) Fluid model for air and water

Fig. 1. Steam explosion position at a corner of the reactor cavity (a) and fluid model (b) [2]

2.2 Calculation of the equivalent TNT mass

The thermal energy of the molten core can be converted to mechanical energy in the form of an explosion during a steam explosion [2]. Using the relationship between the thermal energy of the molten core and the equivalent energy of TNT [2], the thermal energy of the molten core can be converted into equivalent TNT mass. Using an energy conversion ratio of 0.03%, the entire thermal energy of the molten core in the virtual cylindrical region (with the 0.118 m jet diameter and the 6.4 m height of the cooling water in the cavity) was converted into the equivalent energy of TNT, and the equivalent TNT mass was assumed to be 4.9 kg [2].

2.3 ALE and FSI method

The ALE method was used to model TNT, water, and air to numerically simulate the steam explosion pressures in the reactor cavity [2]. Moreover, using the FSI method, explosion pressures were applied to the reactor cavity structure [2]. TNT was modeled using Eulerian elements with *JWL_EOS [2]. Eulerian elements were also used to model the air and water with *EOS_LINEAR_POLYNOMIAL and *EOS_GRUNEISEN, respectively [2,3].

3. Numerical results

3.1 Incident pressures

Pressure tracers were embedded in the free field to measure the incident pressures of the steam explosion using the ALE method [2]. The peak incident pressure of the steam explosion was measured to be approximately 1386 MPa beneath the TNT charge [2]. As shown in Fig. 2, the attenuation ratio of the incident pressure was 53.2 %, 73.5 %, 77.7 %, 82.2 %, and 84.1 %, respectively, at distances of 190 mm, 290 mm, 390 mm, 490 mm, and 590 mm from the explosive charge [2]. At distances of 690 mm or more, the attenuation ratio of the incident pressure was approximately 86% or greater than that of an explosive charge [2].

3.2 Reflected pressures

The peak reflected pressure of a steam explosion was approximately 1820 MPa at the pressure tracer during a TNT explosion using the ALE & FSI method [2]. At 190 mm, 290 mm, 390 mm, 490 mm, and 590 mm away from the explosive center, the attenuation ratio of the reflected pressure was 43.5 %, 61.2 %, 68.0 %, 75.0 %, and 78.0 %, respectively, as shown in Fig. 2 [2]. At distances of 690 mm or more, the attenuation ratio of the reflected pressures was about 86% or greater than that of an explosive charge [2].

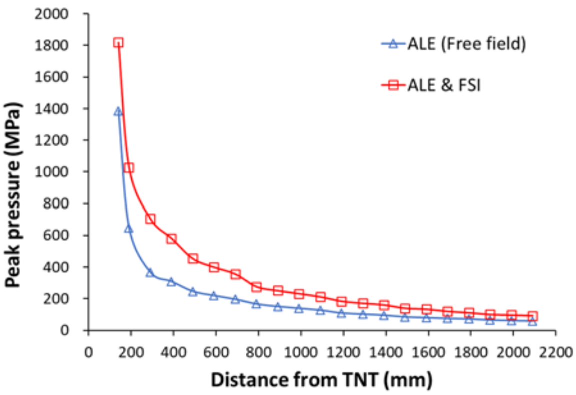


Fig. 2. Distribution of the peak incident and reflected pressures at a corner of the reactor cavity [2]

3.3. Reflection coefficients

When a structure is in the path of the explosion shock waves, the incident shock waves combine with the reflected shock waves from the target structure to produce amplified reflected pressure [2]. The reflection coefficient, defined as the ratio of reflected pressure to incident pressure, was measured and calculated from underwater explosion tests to be 1.65 to 2.09 [4]. In this study, the reflected pressures from the ALE and FSI methods were divided by the incident pressures from the ALE method to determine the reflection coefficient of the steam explosion at the corner of the reactor cavity [2]. As shown in Fig. 3, the average of the distribution of reflection coefficients is 1.67, the standard deviation is 0.13, and the variation coefficient is 7.92% [2]. The predicted distribution of the reflection coefficient closely matches the experimental data of Zhuang et al. [4].

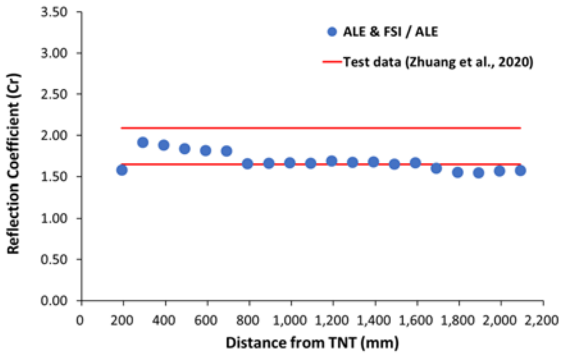


Fig. 3. Distribution of the reflection coefficient at a corner of the reactor cavity by ALE and FSI method [2]

4. Conclusions

As the shock wave propagation distance increased, the incident pressures of the steam explosion in the free field decreased rapidly, as determined by the ALE analysis. In addition, ALE and FSI analysis demonstrated that the reflected pressures of the steam explosion decreased significantly as the propagation distance of the shock wave increased. During the steam explosion, the reflected pressures on surface of the reactor cavity were approximately 1.67 times greater than the incident pressures. The calculated steam explosion pressures will be used in the future to evaluate the structural integrity of the reactor cavity.

Acknowledgements

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