Predicting the Pressures of Shock Waves Caused by A Steam Explosion in the Reactor Cavity using ALE and FSI Method

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1. Introduction

In the event of a severe accident, if the core molten in the reactor vessel is not effectively cooled, the reactor vessel may be damaged and fuel-coolant interaction (FCI) may occur as the core molten is discharged into the cooling water in the reactor cavity [1]. If the walls and base slab of the reactor cavity are damaged by steam explosion loads, radioactive materials may leak. Additionally, as the reactor vessel is lifted up, the pipe lines connecting to it may deform, resulting in a loss of leak-tightness in the containment building [1]. In this study, a series of numerical simulations were carried out to predict the pressure of shock waves caused by a steam explosion in the reactor cavity using ALE and FSI method [1].

2. FE analysis condition

2.1 Steam explosion position

Fuel-coolant interaction (FCI) is assumed to occur as a result of bottom failure of the reactor vessel in the event of a severe accident. The steam explosion position is chosen near the base slab of the reactor cavity, 80 mm from the floor in the vertical direction, as shown in Fig. 1 [1].

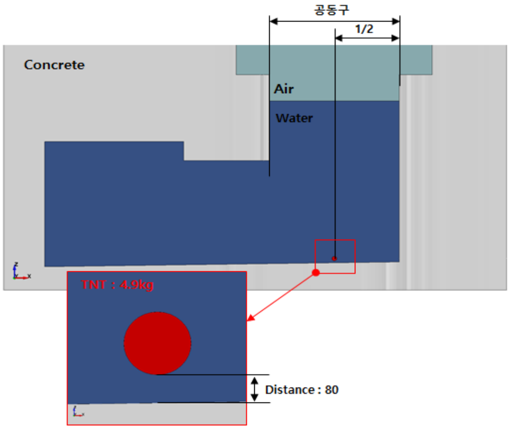

Fig. 1. Steam explosion position in reactor cavity [1]

2.2 Equivalent TNT mass

During a steam explosion, the thermal energy of the molten core is converted into mechanical energy in the form of an explosion [1]. The thermal energy of the molten core can be converted to equivalent TNT mass through the relationship between the thermal energy of the molten core and the equivalent energy of TNT [1]. Using the energy conversion ratio of 0.03 %, all of the thermal energy of the core molten in the virtual cylindrical region (with the 0.118 m jet diameter and the 6.4 m height of the cooling water in cavity) is converted into equivalent energy of TNT, and the equivalent TNT mass is assumed to be 4.9 kg [1].

2.3 ALE & FSI method

To numerically simulate the steam explosion pressures in the reactor cavity, the Arbitrary Lagrangian-Eulerian (ALE) method was used to model TNT, water, and air [1]. Additionally, the explosive pressures were applied to the reactor cavity structure using the fluid-structure interaction (FSI) method [1]. As illustrated in Fig. 1, TNT was modeled using Eulerian elements with *JWL EOS [1]. As shown in Fig. 2, air and water were modeled using Eulerian elements using *EOS LINEAR-POLYNOMIAL and *EOS GRUNEISEN [1,2].

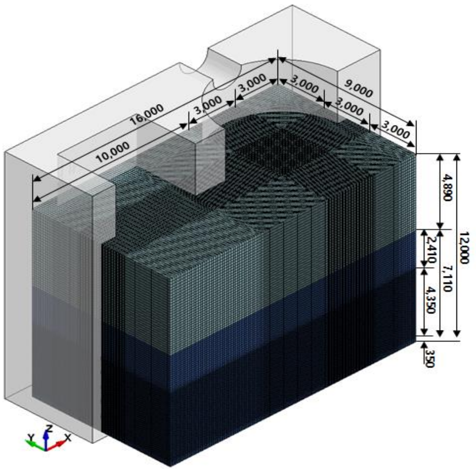

Fig. 2. FE modeling of the fluid (air and water) [1]

3. FE simulation results

3.1 Incident pressures in the free-field

Using the ALE method, pressure tracers were embedded to measure the incident pressures of the steam explosion shock waves in the free field [1]. As illustrated in Fig. 3, the peak incident pressure of the steam explosion shock wave was measured to be 1390 MPa beneath the TNT charge [1]. At distances of 100 mm, 200 mm, 300 mm, 400 mm, and 500 mm from the explosive charge, the incident pressure was 37.3 %, 28.7 %, 20.3 %, 15.4 %, and 12.3 % of the peak value [1]. The incident pressures were 10% or less than that of an explosive charge at distances of 600 mm or more [1].

3.2 Reflected pressure in the reactor cavity

As illustrated in Fig. 3, the peak reflected pressure of steam explosion shock wave was measured as 1950 MPa at the pressure tracer under the TNT explosion by the ALE & FSI method [1]. The reflected pressure was 43.3 %, 32.5 %, 23.9 %, 18.4 %, and 14.7 % of the central explosion pressure of 1950 MPa at 100 mm, 200 mm, 300 mm, 400 mm, and 500 mm away from the explosive, respectively [1]. The reflected pressures were 12.3% or less than that of an explosive charge at distances of 600 mm or more [1].

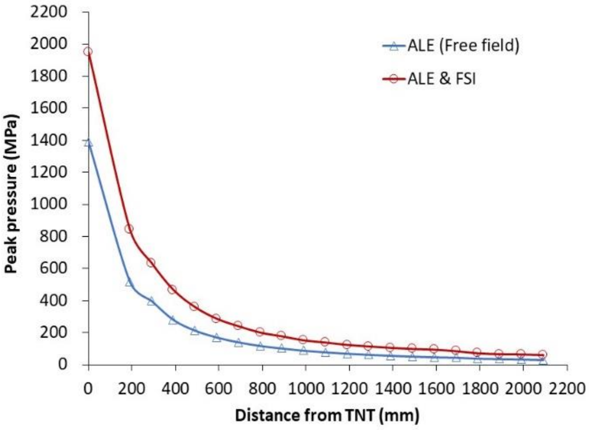

Fig. 3. Distribution of peak incident and reflected pressures using ALE and FSI method [1]

3.3. Reflection coefficient

When a structure is located in the path of the explosion shock waves, the incident shock waves merge with the reflected shock waves from the target structure, resulting in an amplified reflected pressure [1]. For underwater explosions, the amplification ratio of the reflected pressure to the incident pressure, referred to as the reflection coefficient, is approximately 2 [3,4]. To determine the reflection coefficient of the steam explosion, the reflected pressures from the ALE and FSI methods were divided by the incident pressures from the ALE method [1]. Table 1 summarizes the final results. The average of the distribution of reflection coefficients is 1.74, the standard deviation is 0.12, and the variation coefficient is 6.89 % [1].

Table. Summary of the reflection coefficient [1]

Distance from TNT (mm)	**Reflection coefficient**
Bottom	1.40
100	1.45
200	1.65
300	1.72
400	1.74
500	1.72
600	1.86
700	1.80
800	1.64
900	1.80
1000	1.80
1100	1.81
1200	1.92
1300	1.90
1400	1.56
1500	1.57
1600	1.59
1700	1.59
1800	1.66
1900	1.65
2000	1.55

4. Conclusions

According to the ALE analysis, the incident pressures of the steam explosion shock waves in the free field were rapidly attenuated as the shock wave propagation distance increased. Additionally, ALE and FSI analyses showed that the reflected pressures of the steam explosion shock waves were significantly attenuated as the shock wave propagation distance increased. During the steam explosion, the reflected pressures on the surface of the reactor cavity was 1.74 times greater than the incident pressures. In the future, the structural integrity of the reactor cavity will be evaluated using the calculated steam explosion pressures.

Acknowledgements

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