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Effect of Explosive Region Modeling on Steam Explosion Analyses by TNT Model

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1. Introduction

Steam explosion may occur in nuclear power plants due to molten fuel-coolant interaction when the ERVC (External Reactor Vessel Cooling) strategy fails[1,2]. This phenomenon can threat the integrity of reactor cavity, penetration piping and support structures as well as major components. Even though extensive researches have been performed to predict the influence of the steam explosion, it remains to be one of possible hazards due to complexity of physical phenomena and harsh thermal-hydraulic conditions.

The object of the present study is to examine effect of geometry and volume of explosive region under a representative steam explosion condition. Structural evaluation of reinforced concrete and components is performed by TNT (trinitrotoluene) model through steam explosion analyses and their results are discussed.

2. Numerical Analysis

2.1 Structural models

Fig. 1 depicts the FE model of reinforced concrete structure and components with structural geometry used for the steam explosion analyses. The steel liner plate was modeled by employing shell elements and merged with the concrete. Vertical and horizontal rebars embedded in the concrete were modeled by using beam elements. Element types of each component depicted in the figure were employed from general-purpose commercial program element library[3].

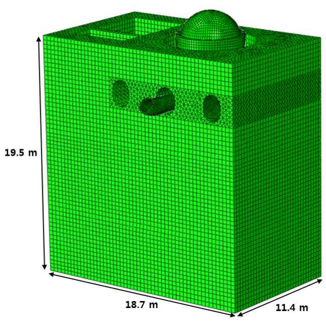


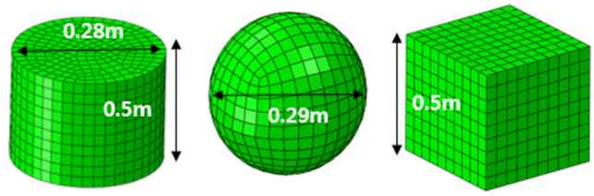
Fig. 1 FE model and structural geometry

2.2 Explosive models

The air and explosive regions were set by using the Eulerian modeling technique. The Eulerian and Lagrangian elements can interact with each other through the general contact defined between air, explosive region and reactor cavity. The air was modeled with the same size as the reactor cavity as shown Fig. 1 and generated by Eulerian continuum three dimensional eight node reduced integration elements (EC3D8R) with 153,140 elements and 162,162 nodes. Fig 2 represents the explosive regions. To compare the pressure histories the explosion region was modeled as cylinder, sphere and cube having the same volume. In addition, to investigate effect of explosion magnitude, 1.5 and 2 times higher volumes were also considered such as 0.13 m^2, 0.195 m^2 and 0.25 m^2. The explosive region was simulated by using Jones Wilkins Lee Equation-Of-State (JWL EOS). In this model, the pressure (P) - density (ρ) relationship can be represented as the sum of functions as follows[3];

$$P = A\left(1 - \frac{\omega\rho}{R_1\rho_0}\right)e^{-R_1\frac{\rho_0}{\rho}} + B\left(1 - \frac{\omega\rho}{R_2}\right)e^{-R_2\frac{\rho_0}{\rho}} + \omega\rho E_m \quad (1)$$

where ρ_0 is the initial density of explosive material. The parameters A, B, R_1, R_2 and ω are material constants. E_m is the initial specific energy.



(a) Cylinder (b) Sphere (c) Cube

Fig. 2 Eulerian FE model of explosive regions

2.3 Analysis conditions

Five analysis conditions examine effect of the geometry and volume are summarized in Table I. Only SVF (Side Vessel Failure) was considered taking into account focusing effect. In the previous study, pressure histories due to steam explosion were calculated from CFD model[4]. In the present study, a pressure history of steam explosion was newly calculated from JWL EOS by using the TNT model and relevant parameters were determined by trial and error technique[5]. The pressures obtained from CFD and TNT models were comparable within the maximum difference of 0.1% approximately.

Table I: Analysis conditions

Case	Failure mode	Geometry	Volume (m^2)
1	SVF	Cylinder	0.130
2		Sphere	
3		Cube	
4			0.195
5			0.260

3. Analysis Results

Table II compares the maximum von Mises stresses of reinforced concrete, liner plate, RPV and anchor bolts. All the stresses at the concrete were sufficiently lower than its compressive strength. On the other hand, maximum stresses at the rebar exceeded their yield strength but less than ultimate tensile strength. From the viewpoint of geometry effect, von Mises stress of the cube in Case 3 was the highest and the difference with those of the cylinder and cube was 10%, approximately. Figs. 2 and 3 show von Mises stress distributions obtained in Case 3 and Case 5, respectively. When the volume was increase 2 times, von-Mises stress of the reinforced structure and components increased up to 25% and the difference of von Mises stresses between Case 3 and Case 4 was 16%, approximately

Table II: Maximum von Mises stresses

Case	Concrete (MPa)	Rebar (MPa)	Liner plate (MPa)	RPV (MPa)	Anchor bolts (MPa)
1	21.65	510.63	342.58	251.13	230.98
2	22.01	513.25	345.21	260.52	232.67
3	23.18	516.87	350.25	266.74	235.34
4	25.25	530.25	380.58	284.51	240.52
5	28.23	546.21	410.52	310.25	245.25

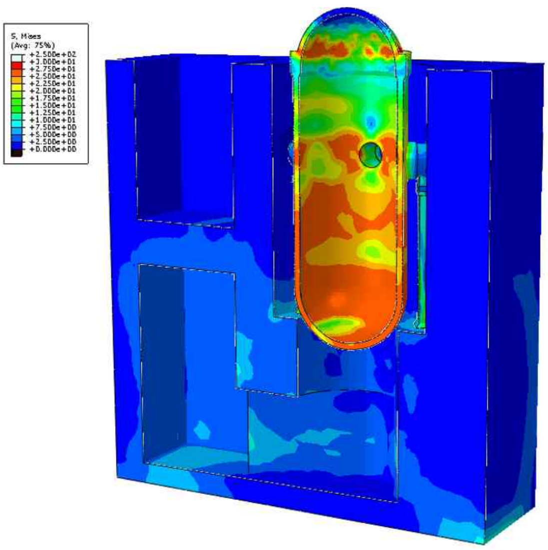


Fig. 2 von Mises stress distribution (Case 3)

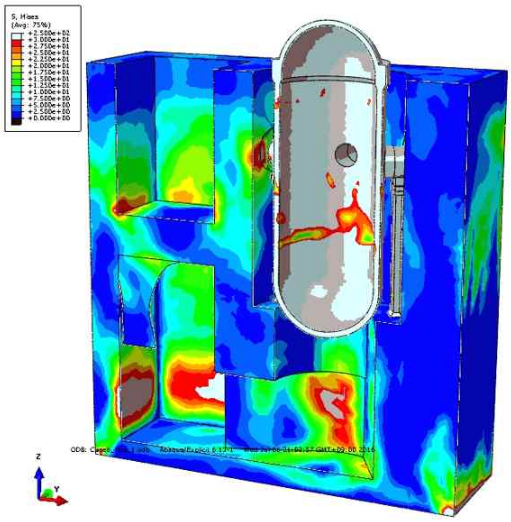


Fig. 3 von Mises stress distribution (Case 5)

4. Conclusion

In this study, comparative numerical analyses were carried out to examine effect of geometry and volume of explosive regions under a typical steam explosion condition and the following conclusions were derived.
(1) The highest von Mises stress was calculated in the cube, among three geometries, so that it was recommended for conservative steam explosion analyses.
(2) As the increase of steam explosion load by 1.5 and 2 times higher volume, von Mises stresses on the structures increased by 16 and 25%, respectively.

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