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Development of Core Seismic Analysis Model of VHTR

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1. Introduction

The NHDD(Nuclear Hydrogen Development and Demonstration) project considers the prismatic block type VHTR(Very High Temperature Reactor) which uses hexagonal graphite fuel elements containing fuel compacts inside. The most part of core is composed of stacked layers of hexagonal prismatic block-shaped elements and the disarray of the components would fail to insert control rods. Thus, the dynamic response of the core structures in a seismic event is one of the major concerns in the safety design of the VHTR.

In this study, a simple beam-shaped equivalent impact model for the core components was proposed. A mathematical impact model was used to simulate the impact response using simple springs and dashpots. Experiment data of block collision test was used for the estimation of equivalent stiffness and damping. The block impact model was realized using a commercial FEM software. The analysis results were compared with experiment data.

2. Methods and Results

In this section some of the techniques used to develop the simple block impact model are described.

2.1 Simple Impact Model for Prismatic Blocks

Fig. 1 shows the details of a fuel element in the VHTR core. The fuel block is composed of graphite block and fuel materials inserted inside of the block. The block itself is a complex geometry and the characteristic length in a local area is relatively very small compared to its global size. To achieve the applicable run time of the analysis, simple impact models using rigid frame, point-mass and inertia, and equivalent impact elements attached on the proper positions of mutual collisions of blocks. MCOCO code [1] was developed in General Atomics for the analysis of the HTGR core, SONATINA code [2] was developed in JAERI, and CEA in France [3] also had their own analysis model. In even present days, the analysis of full core is a challenging task and the simple impact model is a attractive modeling scheme for the dynamic analysis.

Fig. 2(a) shows the schematic diagram of 2-D simple impact model proposed in this study. At each position of impact, a impact component is placed in which the spring and dashpot elements are connected in parallel. There is also a gap element is included not to activate the spring and damper during separation.

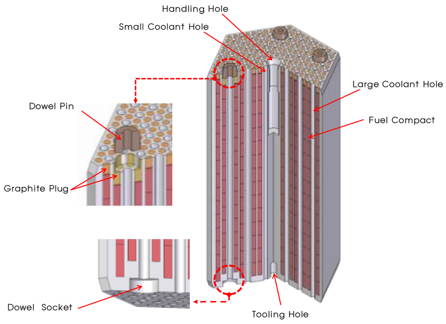
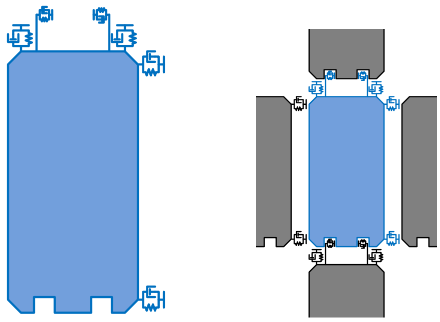


Fig. 1. Fuel element in VHTR core.



(a) Simple impact model (b) Array of simple impact models

Fig. 2. Schematic diagram of 2-D simple impact model.

The impact event usually occurs in the vicinity of block corners because of the prismatic shape of the blocks. The horizontal and vertical impact components should be placed every corners of the block but they attached to only the up and right side of the block because other blocks in bottom and left side will have the identical impact components. Fig. 2(b) shows the array of the impact models. In Voigt model for the dynamic impact analysis, the contact time and the coefficient of restitution are formulated below.

$$t_c = \pi\sqrt{\frac{M_e}{K}}, \quad CR = e^{-\pi C/\sqrt{4KM_e - C^2}} \qquad (1)$$

where,

t_c : contact time
$M_e = m_A \cdot m_B/(m_A+m_B)$
m_A, m_B : mass of objects A and B
K : interblock spring rate
CR : coefficient of restitution
C : interblock viscous damper rate

A experiment [4] conducted in General Atomics measured coefficient of restitution and contact time and they used 0.4 and 2.0 msec as a representative values for the coefficient of restitution and contact time for their MCOCO code. From those typical values measured in the experiment, interblock spring rate, K and interblock viscous damper rate, C can be calculated and those are K = 155400 N/mm^3 and C = 55.42 ton·s/mm.

2.2 Realization of the Simple Impact Model

The numerical calculation of the inherent nonlinearity, especially complex contact and impact, requires the explicit integration. A commercial explicit code, ABAQUS 6.10 [5] was used for the realization of the model and the calculation. Fig. 3 shows the simple impact model realized in ABAQUS. It has rigid beam skeleton frame and at the end of the rigid beam, impact components were simulated using CARTESIAN connector element provided in Abaqus. Because CARTESIAN connector element does not have the function of the gap element, spring rate and damper rate are required to be zero when the contact surfaces are separated. It was successful to simulate nonlinear spring rate but the nonlinear damper rate failed to work. Thus, the damper rate is still acting during the separation, and the applying nonlinear damper rate should be resolved in further study.

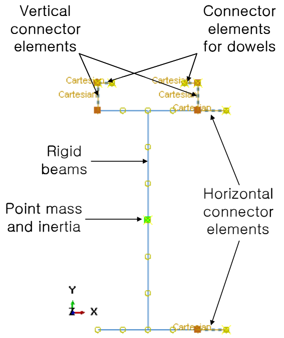
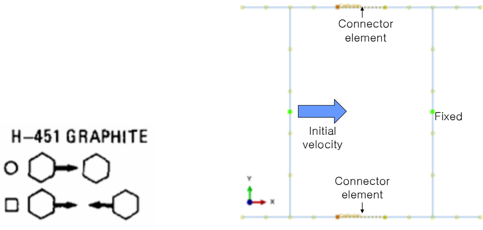


Fig. 3. Simple impact model realized in ABAQUS.

2.3 Analysis Results

The experiment [4] was simulated using the developed analytical model. Two graphite hexagonal prismatic block collided to each other in the flat surfaces as shown in the Fig. 4(a). Coefficient of restitution, contact time, and impact velocity were measured at the moment of impact. The analysis reproduced the experiment as shown in Fig. 4(b). The blocks were configured in vertical arrangement and only the horizontal connector elements were activated for the side surface impact. In the experiment, the right block also moved in some cases but only the relative velocity is meaningful in the impact analysis mathematically. Thus, only the left block moved and the right block was fixed.

The analysis results and experiment data are shown in the Fig. 5 and 6. The analysis results well matched to the mathematical theory; the coefficient of restitution and contact time are not functions of impact velocity. The contact time and coefficient of restitution were 2.09 msec and 0.402 respectively and they are almost identical to the estimation of Voigt model. The experimental results showed slight discrepancy to the theory. In one of experimental data from JAERI, which is more coincident to the theory, showed almost constant measurement as impact velocity varied.



(a) Experiment (b) Analysis

Fig. 4. Experiment configuration and analysis model for collision test.

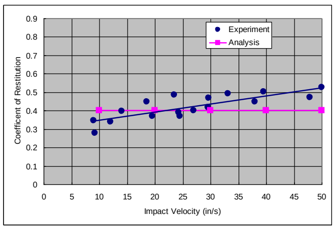


Fig. 5. Experiment and analysis results of coefficient of restitution.

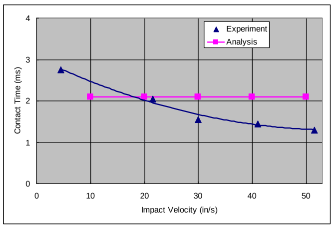


Fig. 6. Experiment and analysis results of contact time.

3. Conclusions

In this study, a simple impact model for the blocks in a VHTR core was proposed and realized using a commercial FEM software. The dynamic response of the developed model was compared with the mathematical model and the experiment data. The developed model well matched to the mathematical model.

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