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Dynamic Analysis Models and Analysis Examples for Stacked Graphite Fuel Blocks of a VHTR Using a Commercial Structural Analysis Code

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1. Introduction

Prismatic type gas cooled reactors has many columns of stacked graphite fuel blocks as its reactor core structure. An earthquake loading on the stacked blocks causes rocking responses and solid impacts between them, and may lead to structural integrity problems, because the blocks are not fully constrained and have gaps between neighboring blocks. The dynamic analysis of block structures has a long history. In the historically early stages of the structural and dynamic analysis of the stacked graphite fuel blocks, the special computers of high computing power with the dedicated computer programs were needed for the analyses to make short the computational time and to reduce the cost. At the present days, the computational power of personal computers has been remarkably increased and the commercial codes for structural analyses provide many useful modeling procedures and analysis options. The purpose of this paper is to introduce the finite element models and the analysis examples of the stacked graphite fuel blocks of a prismatic type gas-cooled reactor performed on a personal computer using the commercial structural analysis code, ABAQUS. This study is for the seismic analysis of reactor internal structures of the prismatic type gas-cooled reactors, and this paper is about the first step of our works.

2. Classical Models for the Dynamic Analysis

The GT-MHR (USA) and HTTR (Japan) are the well known gas-cooled reactor systems having the reactor core structures composed of the columns of the stacked prismatic graphite blocks, see Figure 1.

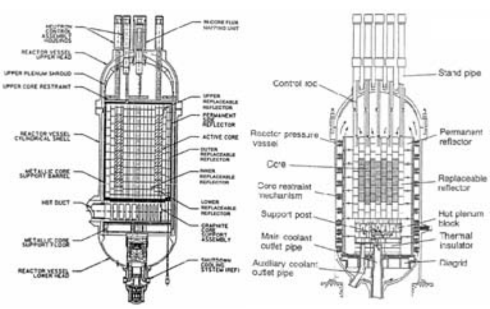

Fig. 1. Schematics of the reactor internal structures of the GT-MHR and the HTTR

The vertically neighboring fuel blocks are constrained by dowel pins and dowel sockets by each other. And each column has gaps between neighboring columns and stands on the core bottom structure by itself. The cross section of the prismatic block is a hexagonal one with many holes for fuel elements, coolant pathways, and handling tools.

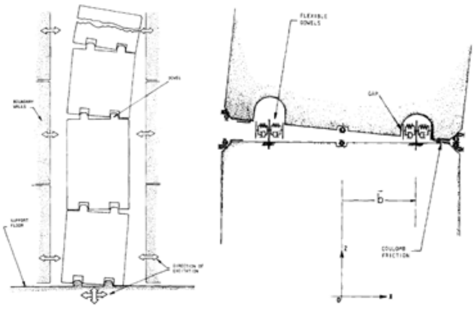

Fig. 2. Schematics of stacked fuel block model for the GT-MHR

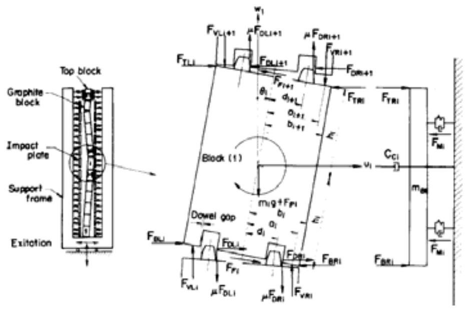

Fig. 3. Schematics of stacked fuel block model for the HTTR

In 1975, T.H. Lee presented a methodology for analyzing the nonlinear response of a column of stacked prismatic fuel blocks for GT-MHR [1]. In 1979 T. Ikushima and T. Nakazawa presented their work results on a seismic analysis of a column of stacked prismatic fuel blocks for HTTR[2]. They made and used the dedicated computer programs for the analyses. Figure 2 and Figure 3 are the schematics of the models they developed.

3. Models and Analyses with Commercial Code for the Dynamic Analysis

The commercial structural analysis code, such as ABAQUS, provides many useful options for modeling and structural analysis. The FE models of the stacked prismatic graphite blocks were developed using the ABAQUS/Explicit Ver. 6.8 and the simple examples of dynamic response analyses were conducted.

Figure 4 shows the outer geometry of the graphite fuel blocks and the FE model for the analysis. The internal holes for the fuel pellets and the coolant path are not considered in this model yet. The size and material properties of the graphite block considered are the same with of the HTTR fuel blocks.

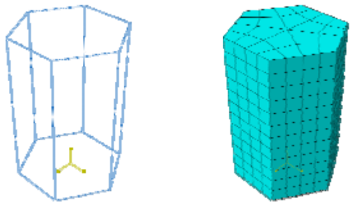

Fig. 4. The geometry and FE model of the graphite block

To verify the contact modeling and dynamic analysis options of the ABAQUS/Explicit, the simplest case is considered at the first, that a single block falling on a rigid floor is modeled and analyzed. Figure 5 shows the model and the results where the first sub-figure shows the block initially in the air and the subsequent sub-figures shows the block bouncing motions on the floor and the color contours are showing stress levels. The analyses with the more complex geometry and with the oscillating floor conditions are shown in the subsequent figures.

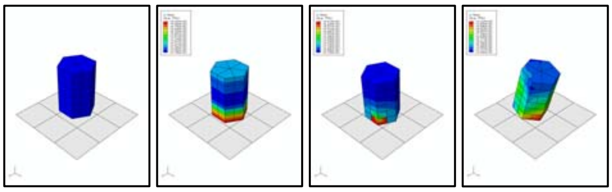

Fig. 4. The bouncing motions of the single graphite block on the rigid floor

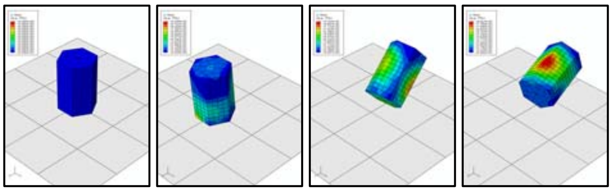

Fig. 5. The turn-over motions of the single graphite block on the horizontally oscillating rigid floor

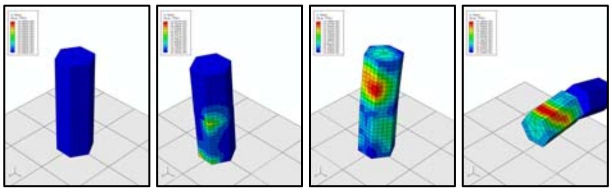

Fig. 6. The turn-over motions of the simply stacked graphite blocks on the horizontally oscillating rigid floor

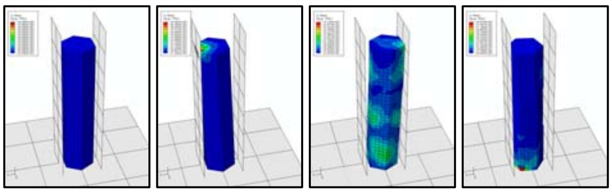

Fig. 7. The bouncing motions of the stacked three-story graphite blocks between the rigid walls horizontally oscillating with the rigid floor

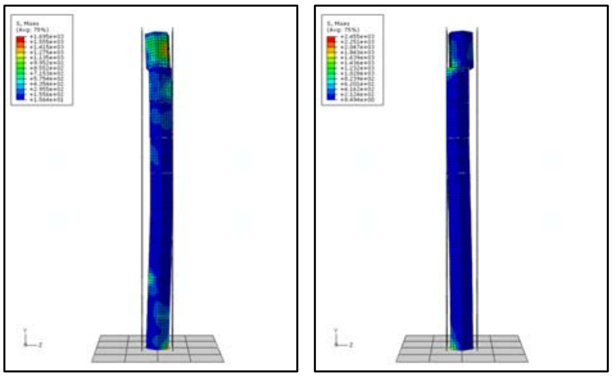

Fig. 8. The bouncing motions of the single column of stacked nine-story graphite blocks between the rigid walls horizontally oscillating with the rigid floor

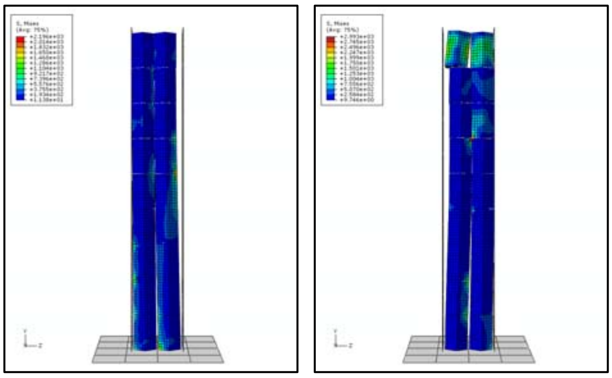

Fig. 9. The bouncing motions of the twin column of stacked nine-story graphite blocks between the rigid walls horizontally oscillating with the rigid floor

In the calculations, the ABAUQS/Explicit uses the penalty method to consider the contact motions in which the contact stiffness and the energy loss by hard contact and the friction force are considered.

3. Conclusions

Dynamic analysis models and simple example results for the stacked graphite block structures using the commercial structural analysis code ABAQUS are introduced and the results show reasonable trends. The models introduced in this paper are not complete yet, but they will be improved and reported with details in the later papers.

ACKNOWLEDGMENTS

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REFERENCES

[1] T. H. Lee, “Nonlinear Dynamic Analysis of a Stacked Fuel Column Subjected to Boundary Motion,” Nuclear Engineering and Design, Vol. 32, pp. 337-350, 1975.
[2] T. Ikushima and T. Nakazawa, “A Seismic Analysis Method for a Block Column Gas-Cooled Reactor core, Nuclear Engineering and Design,” Vol. 55, p. 331-342, 1979.