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A Benchmark Study of a Seismic Analysis Program for a Single Column of a HTGR Core

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1. Introduction

A seismic analysis program, SAPCOR (Seismic Analysis of Prismatic HTGR Core), was developed in Korea Atomic Energy Research Institute. The program is used for the evaluation of deformed shapes and forces on the graphite blocks which using point-mass rigid bodies with Kelvin-Voigt impact models. Fig. 1 shows the schematic diagram of the impact mechanism of the graphite blocks of which a prismatic HTGR core is composed. In the previous studies [1-4], the program was verified using theoretical solutions and benchmark problems. To validate the program for more complicated problems, a free vibration analysis of a single column of a HTGR core was selected and the calculation results of the SAPCOR and a commercial FEM code, Abaqus, were compared in this study.

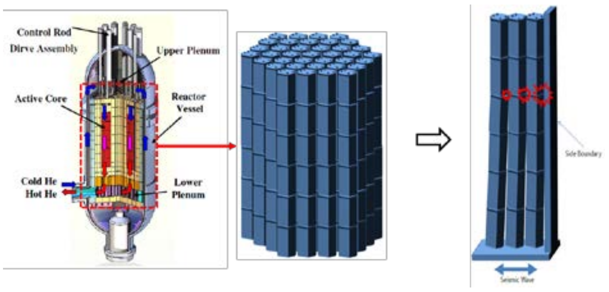
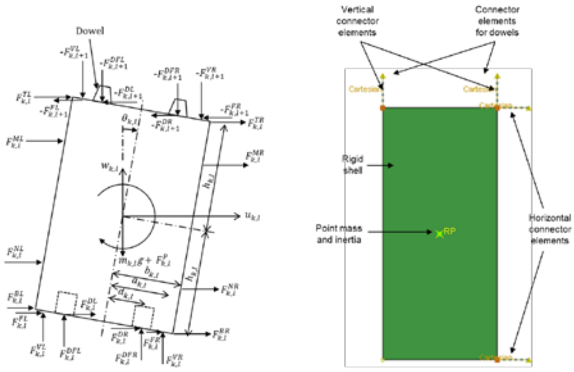


Fig. 1. Collision of blocks in a prismatic HTGR core.

2. Methods and Results

2.1 Point-Mass Model of a Graphite Block

A point-mass rigid body model was developed in the previous study [1]. Fig. 2 (a) shows the developed analysis model. Fig. 2 (b) shows the Abaqus model which is equivalent to the model of this study. Two models are much similar to each other because they use rigid bodies with point-mases and spring-damper systems to simulate the impact response of the block at the anticipated impact locations. Abaqus uses a special element called "Connector" to implement the spring-damper system. A "Connector" is a line element between two nodes which are located at the anticipated locations of impact. Therefore, the connector are rotated as the two nodes are dislocated by the block movements. This undesirable rotation of the connector may cause relatively large errors on force estimations. The SAPCOR does not use pre-specified connection between any two points, but it calculates the real penetrations by impact at the corresponding impact locations. Therefore, the SAPCOR is expected to calculate the impact forces more precisely.



(a) SAPCOR (b) Abaqus

Fig. 2. Seismic analysis models.

The governing equations of the SAPCOR model are shown below:

$$
\begin{aligned}
m_{k,l}\ddot{u}_{k,l} = {} & F^{TL}_{k,l} + F^{ML}_{k,l} + F^{NL}_{k,l} + F^{BL}_{k,l} + F^{TR}_{k,l} + F^{MR}_{k,l} + F^{NR}_{k,l} + F^{BR}_{k,l} + F^{FL}_{k,l} + F^{FR}_{k,l} - F^{FL}_{k,l+1} \\
& - F^{FR}_{k,l+1} + F^{DL}_{k,l} + F^{DR}_{k,l} - F^{DL}_{k,l+1} - F^{DR}_{k,l+1} \\
m_{k,l}\ddot{w}_{k,l} = {} & F^{VL}_{k,l} + F^{VR}_{k,l} - F^{VL}_{k,l+1} - F^{VR}_{k,l+1} + F^{DFL}_{k,l} + F^{DFR}_{k,l} - F^{DFL}_{k,l+1} - F^{DFR}_{k,l+1} - m_{k,l}g \\
& - F^{P}_{k,l} \\
I_{k,l}\ddot{\theta}_{k,l} = {} & M^{TL}_{k,l} + M^{ML}_{k,l} + M^{NL}_{k,l} + M^{BL}_{k,l} + M^{TR}_{k,l} + M^{MR}_{k,l} + M^{NR}_{k,l} + M^{BR}_{k,l} + M^{FL}_{k,l} + M^{FR}_{k,l} \\
& + M^{FL}_{k,l+1} + M^{FR}_{k,l+1} + M^{DL}_{k,l} + M^{DR}_{k,l} + M^{DL}_{k,l+1} + M^{DR}_{k,l+1} + M^{VL}_{k,l} + M^{VR}_{k,l} \\
& + M^{VL}_{k,l+1} + M^{VR}_{k,l+1} + M^{DFL}_{k,l} + M^{DFR}_{k,l} + M^{DFL}_{k,l+1} + M^{DFR}_{k,l+1} + M^{W}_{k,l} + M^{P}_{k,l}
\end{aligned}
\tag{1}
$$

Theses ordinary second-order differentiation equations are solved by Runge-Kutta or the ODEPACK library (a collection of Fortran solvers for the initial value problems of ordinary equation systems) which are selected in the user input, while the Abaqus uses its unique explicit FEM solver.

2.2 Free Vibration of a Single Column of Blocks

A single column made of 13 blocks were selected and its response was analyzed under a free vibration condition by the SAPCOR and the Abaqus. The initial shape and the analysis parameters are shown in Table 1. The top block has different mass and moment of inertia and is fixed horizontally to provide the constraint on top.

Table 1. Analysis parameters of a single columns of blocks.

Param	Unit	Normal Blocks	Top Block
b	cm	7.23	
a	cm	7.23	
d	cm	5.2	
h	cm	14.23	
m	kgf·s^2/cm	0.00628	0.00918
I	kgf·s^2·cm	0.524	1.36
K_V	kgf/cm	2.50E+04	
C_V	kgf·s/cm	1.77	
K_D	kgf/cm	1.55E+04	
C_D	kgf·s/cm	4.2	
δ_D	cm	0.025	

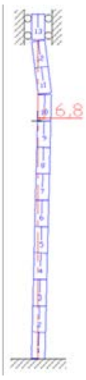


Fig. 3 shows the deformed shapes of the blocks for the first three maximum displacements of blocks. The SAPCOR and the Abaqus results are almost same. Fig. 4 shows the displacement of the every second block from the bottom. The graph shows that the SAPCOR and the Abaqus gave almost same results for the first two periods of the vibration. However, two programs have slightly different estimations of the block displacements after that.

3. Conclusions

In this study, free vibration response of a single column of graphite blocks to validate the SAPCOR by benchmarking with a commercial program, Abaqus. Two programs gave almost same results for the first two periods of the vibration of the block columns. After that, slight differences were found. A more detailed investigation of the calculation results will be done to improve the SAPCOR program.

REFERENCES

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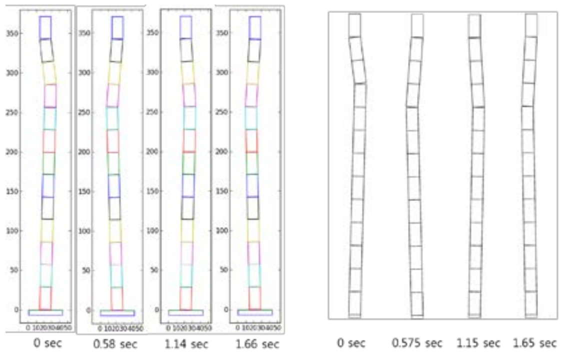

(a) SAPCOR (b) Abaqus

Fig. 3. Deformed shapes of block column.

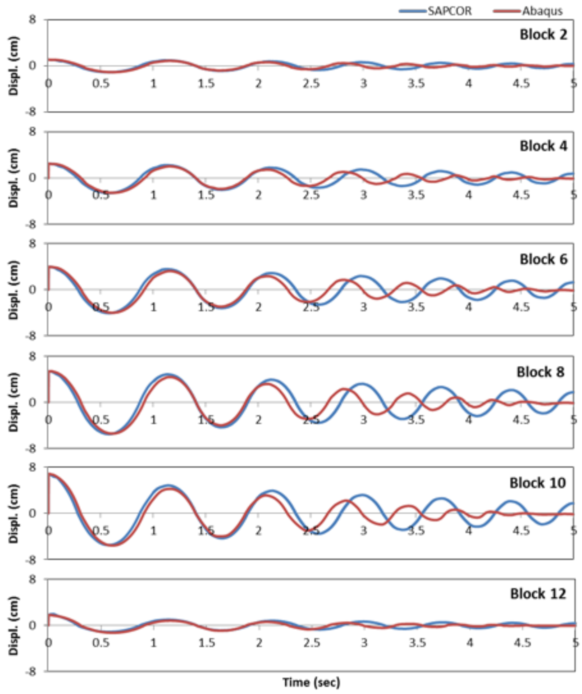

Fig. 4. Displacements of selected blocks.