Transactions of the Korean Nuclear Society Spring Meeting
Chuncheon, Korea, May 25-26 2006

Gravity Effects on the Free Vibration of a Graphite Column

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1. Introduction

The gravity effects on the free vibration of a graphite column are studied. Graphite block is a key component of a HTGR (High Temperature Gas Cooled Reactor). The major core elements, such as the fuel blocks and neutron reflector blocks, of HTTR (High Temperature Test Reactor, Japan)[1,2] and GT-MHR (Gas Turbine-Modular Helium Reactor, USA)[3] consist of stacked hexagonal graphite blocks forming a group of columns. The vibration of the columns induced by earthquakes may lead to solid impacts between graphite blocks and structural integrity problems. The study of free vibration characteristics of the graphite block column is the first step in the core internal structure dynamic analysis.

Gravity force bring a negative stiffness term to the transverse vibration analysis of heavy long column structures, and results in natural frequency reductions[4,5]. Generally it is not considered in the not so tall structure cases, because the gravity term makes the analysis and design complicated. Therefore it is important to check whether the gravity effect is severe or not[6].

2. Graphite Block Columns

GT-MHR and HTTR are typical prismatic type gas cooled reactors. Figure 1 shows the reactor internal structures of GT-MHR and HTTR. Many columns of stacked graphite blocks are the major component of the reactors. Each column has gaps between neighboring columns and stands on the core bottom structure by itself [4, 5].

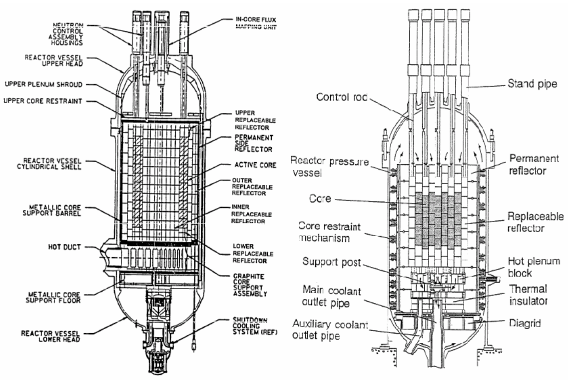

Figure 1. Reactor internals of GT-MHR and HTTR

The geometry and dimensions of the graphite fuel block of HTTR is shown in Fig. 2. It is a prismatic block with hexagonal cross section and many holes for fuel elements and handling tools. The width and the height are 360mm and 580mm, respectively.

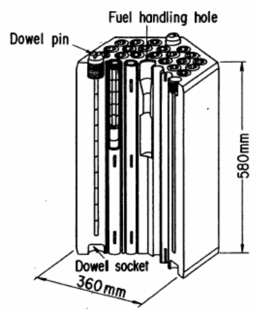

Figure 2. Geometry of graphite fuel block of HTTR

3. Equation of Motion

Governing equation of a free vibration of the general slender vertical columns is as follows (damping term is omitted):

$$\frac{\partial^2}{\partial y^2}\left(EI\frac{\partial^2 x}{\partial y^2}\right)+m\frac{\partial^2 x}{\partial t^2}+\frac{\partial}{\partial y}\left(N\frac{\partial x}{\partial y}\right)=0 \qquad (1)$$

in which EI, m, N, x and y are the flexural stiffness, the mass per unit length, the axial force, the transverse displacement of a column and the vertical coordinate, respectively. The axial force term is caused by the gravity and as follows:

$$N(y)=-mg(L-y) \qquad (2)$$

in which g is the gravitational acceleration, and L is the column height. The governing equation, Eq. (1), leads to the equation of mode shape function X(y):

$$\frac{d^2}{dy^2}\left(EI\frac{d^2 X}{dy^2}\right)+\frac{d}{dy}\left(N\frac{dX}{dy}\right)-m\omega^2 X=0 \qquad (3)$$

where X(y) is the mode shape function, w is the circular natural frequency.

The mode shape equation is an Eigen value problem with no analytical solution due to the gravity term. Numerical method can be used to obtain the mode shapes and natural frequencies of a transverse free vibration of the slender columns with gravity. Typical mode shapes obtained from a numerical analysis are presented in Fig. 3. From a series of analysis one can obtain a simple result where the gravity term does not seriously alter the mode shapes. But the natural frequency is a function of the column length and gravity.

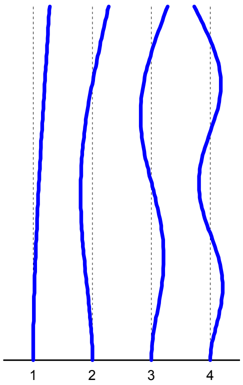

Figure 3. Typical mode shapes of the slender columns

4. Gravity Effects on the Natural Frequency

The transverse free vibration analysis of the graphite columns is performed with the commercial structural analysis code, ABAQUS. The columns have the same cross section outline and material properties as that of HTTR fuel block. The natural frequencies of the columns without gravity and with gravity are compared. And the effect of the column height is also studied. The eight cases with different heights, from 5m to 40m, are considered.

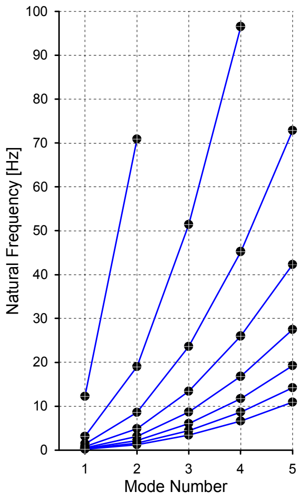

Figure 4. Natural frequencies of the graphite columns of different heights

The natural frequencies of the graphite columns without gravity and with different heights are shown in Fig. 4. The frequencies increase with the mode number. And the higher column has lower natural frequencies. The natural frequencies in the cases of with gravity are reduced, and the percent reduction ratios are shown in Fig. 5. The reduction ratios decrease with a mode number increase, and they increase with a column height increase. The frequency reduction is remarkable in the first natural frequency, and in the high tall column cases it is more drastic. In the case of the column height of 25m, the frequency reduction by gravity is not lower than 3%. And it is up to 14% when the height 40m.

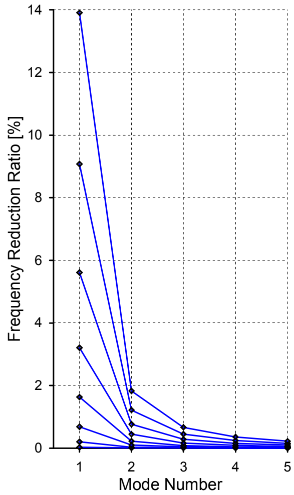

Figure 5. Percent ratios of the natural frequency reduction by the gravitational force

3. Conclusion

The effects of gravity on a free transverse vibration of graphite columns are studied. The changes in the column height do not alter the vibration mode shapes. The natural frequencies, however, decrease as the height increases and with the total weight. The gravity effect should be considered in the cases where the graphite column is higher than 20m.

ACKNOWLEDGMENT

This study was supported by the Korea Ministry of Science and Technology through its National Nuclear Technology Program.

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