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Achievements in the Past and New Directions of Seismic Analysis for Graphite Block Structures of VHTR

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1. Introduction

The reactor core of HTGR (High Temperature Gas-cooled Reactor) with prismatic fuel blocks employs a number of stacked graphite blocks. Getting the basic understanding of the dynamics of a block was first tried in 60's, and in the field of nuclear engineering the seismic characteristics of stacked block structures for HTGR core had been key issues in 70s and 80s for the structural integrity and the plant safety. After that little interest has been shown to that area, but it will be more important area soon because of the growing need of VHTR system. This paper summarizes the achievements of the seismic study of stacked block structures in the past and the studies in other fields, and the author proposes a new study direction for progress.

2. A Classical Study of a Simple Block

It was Housner[1] who first provide in 1963 the basic and systematic understanding on the rocking response of a rigid block with a linearized equation of motion of a rocking block. It was shown that the rocking period is a function of the angular displacement of a block. Figure 1 shows a rocking block considered and the period of block rocking with amplitude of angle.

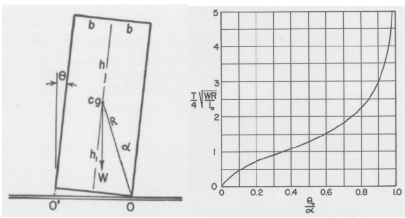

Figure 1. A rocking block model and period of rocking [1]

3. Achievements for HTGR

3.1 Seismic Analysis and Tests for HTGR Core Design

In 1975 T. H. Lee presented his work[2] in which a method had been developed for analyzing the nonlinear response of a column consisting of stacked prismatic fuel blocks of HTGR. The neighboring fuel blocks are constrained by dowel pins and dowel sockets by each other. In the work he developed two different models; the first one is a rigid block model with rigid dowel and the other one with flexible dowel. Figure 2 shows the column of stacked fuel blocks and a model of the flexible dowel model with friction. Through a long hand-labor he derived the equation of motions for cases, and obtained the numerical results for both free vibration and forced vibration. In his work with a column of stacked blocks, he showed the feasibility of numerical study for multi-column of stacked blocks.

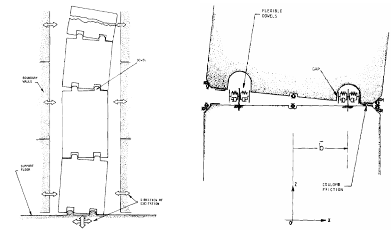

Figure 2. Stacked fuel blocks and flexible dowel model [2]

Seismic test results of one-fifth scale planar array models of HTGR core structure are presented by B. E. Olsen, A. J. Neylan and W. Gorholt, and the numerical analysis results are presented in 1976[3]. Basic test data describing the phenomena of impact between single and multiple graphite blocks was used as primary input the analytical models.

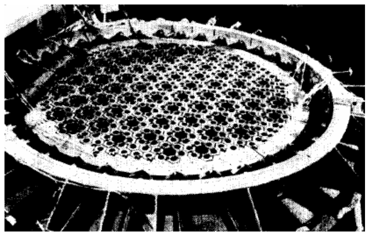

Figure 3. One-fifth scale full-array test model [3]

3.2 Seismic Analysis and Tests for HTTR Core Design

In 1979 T. Ikushima and T. Nakazawa presented their work results[4] of seismic analysis of a column consisting of the stacked fuel blocks of HTTR and compared to the seismic test results of a half scale column model. The numerical model is similar to that of the Lee's study[2], but the parameters in their analysis are from scaled model tests and the results are verified.

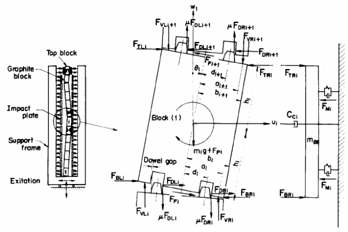

Figure 4. Column model and forces acting on a block [4]

JAEA started their own program of seismic analyses and tests for HTTR in 70s. The seismic tests of a single column half scale model was conducted in 1976, a seven columns model in 1977, a vertical two dimensional model from 1978 to 1979, a horizontal two dimensional model, and some other models and cases. The brief overview of the seismic test results are introduced in Ref. [5].

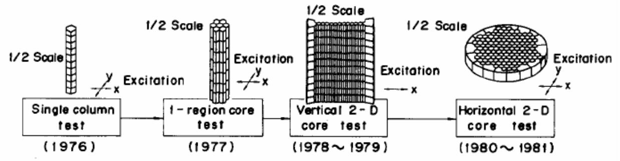

Figure 5. Core seismic test program for HTGR in Japan [5]

3.3 Seismic Analysis and Tests for AGR Core Design

The AGR core is a more complex engineering structure by virtue of its geometry and arrangement than that of HTGR. In 1986 K. M. Ahmed, J. V. Parker and D. E. Proffitt presented work results[6] of seismic analysis and compared to the test results. After that K. M. Ahmed presented long summary of the seismic analysis and test results of AGR system, Ref. [7].

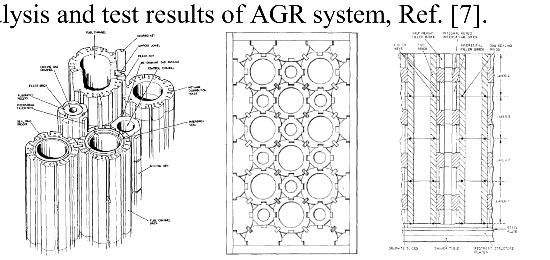
Figure 6. AGR core blocks and one of seismic test models [7]

4. Studies in other fields

4.1 Random Rocking Response of a Block

While the most of authors in the field of block dynamics focused on the deterministic methodology, some challenging researchers have focused on the random response analyses. A significant work on stochastic analysis has been done by Pol D. Spanos and Aik-Sion Koh[8], they considered a rocking block on the Winkler foundation. After their works some other researchers have studied new techniques to solve the nonlinearity problems of block impacts on the base.

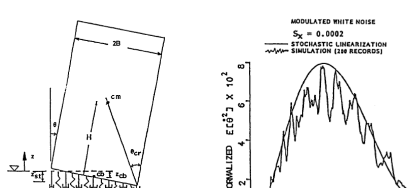

Figure 7. Linear model and stochastic results [8]

4.2 Nonlinear Rocking Response of a Block

S. J. Hogan considered the dynamics of a slender rigid block mounted on a vibrating rigid table with side walls[9]. The governing equation is quite simple, but nevertheless it shows complex nonlinear dynamics and gives many types of solutions.

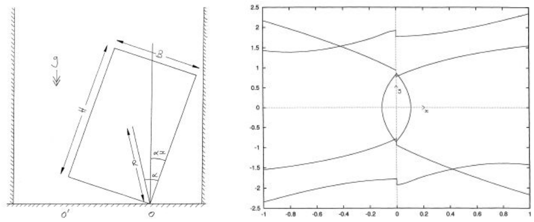
Figure 8. A block model and a solution on phase plane

3. Conclusion

There are long history of trials and achievements concerning the seismic analysis of the block type structures starting early 1960s. In the field of nuclear engineering there were the deterministic analysis approaches in the past, and now it is required to adopt new method, such as stochastic and probabilistic methodology, and nonlinear dynamic analysis methods, from other fields of engineering to get more reliable design methods for VHTR system.

ACKNOWLEDGMENTS

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