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A preliminary study on seismic behavior of the graphite reflector in molten salt reactor

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ABSTRACT

Graphite reflector submerged in molten salt in TMSR has important influences on the evaluation of structural stability of the reflector and the safety of the reactor because of the collision and fluid–solid interaction. In this paper, an approach is proposed for simulating the non-linear responses of the reflector under seismic excitation. And then, with this approach, a finite element model of the reflector in TMSR is built to investigate its dynamic characteristics and the seismic time history responses. From the results of the seismic time history analysis, the displacements of the control rod channel, which are required for the evaluation the safety of the reactor, are obtained as the boundary condition for the control rod drop test. At the same time, the impact forces between the components are provided that is required for the stress evaluation of graphite components.

1. Introduction

The graphite reflector submerged in the molten salt plays an important role in the Thorium-based Molten Salt Reactor (Jiang et al., 2012) (TMSR) as neutron moderator and bearing load structure. The reflector consists of a large number of bricks, keys and pins with a narrow gap space between the adjacent components. Therefore, the collisions between the components caused by earthquake are important influencing factors on structural safety of the core. The collisions of multi-body structure and fluid–solid interaction are two aspects to represent in seismic analysis in TMSR. For the collisions of multi-body structure, there are many studies on the numerical analysis and experiments. Iyoku et al. (2004) developed a 2D code SONATINA-2V to calculate bottom structure and tested the displacement of components in high temperature engineering test reactor (HTTR); Hongkun et al. (2012) proposed an efficient 3D approach by using ABAQUS software for simulating the complicated responses of the reflector in high temperature gas-cooled reactors (HTR) under earthquake loads; Shi et al. (xxxx) tested the static intensity of the dowel, Jin et al. (xxxx) and Jin et al. (2014) calculated and tested the collision of graphite bricks to obtained the equivalent stiffness and damping coefficient; furthermore, Sun et al. (xxxx) tested double layer of HTR-PM graphite structure under earthquake loads, the results show the double-layer model kept its basic structural, and damping of the double-layer model was obtained; Duncan et al. (xxxx) also developed a finite element model by using LS-DYNA software that represents the seismic response of each graphite brick in advanced gas-cooled reactor (AGR); Kim and Lee (2002) analyzed the reflector with super element by using MSC software in Korean next generation reactor (KNGR). At present, many studies focus on the collision with rigid body-spring model in gas coolant, however, the researches on the graphite reflector with regard to fluid–solid interaction are less reported.

In the aspect of fluid–solid interaction analysis, a simple approach using additional mass is often used because a long computing time caused by highly nonlinear multi-field is needed in time history analysis. Koo and Lee (2004) developed a numerical application for applying the additional mass matrix for a 7-ducts core system to investigate the fluid effects, the fluid coupling terms can significantly affect the impact responses of the ducts. Valentin et al. (2014) studied the additional mass of a disk submerged in water experimentally and numerically using structural–acoustic simulations, the effect of the radial gap is significant and should be considered when calculating natural frequencies of submerged and confined structures. Zhao et al. (1996) analyzed the nonlinear impact and frictional motion responses including fluid–structure coupling effects of spent fuel storage with finite element model, the fluid–structure-interaction effects can be taken into account using the additional mass based on potential theory.

In this paper, a new simulation method based on rigid body-spring model and additional mass is brought forward to perform the seismic analysis of the reflector in molten salt. Firstly, a rigid body-spring model with additional mass of the reflector in TMSR is built by using ANSYS software, and the additional mass is calculated with a three bricks model. Then, the seismic dynamic response of the reflector is analyzed using the new method under earthquake loads. Finally, the

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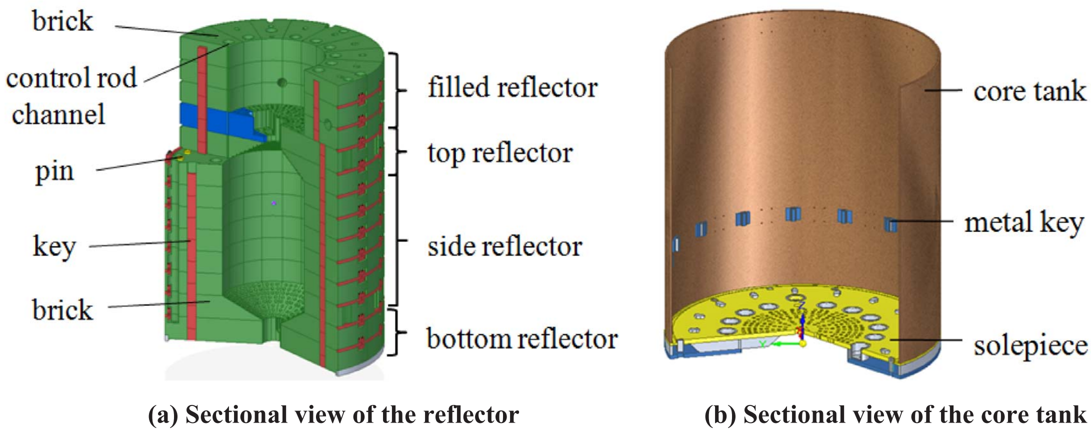

Fig. 1. Reflector structure in TMSR.

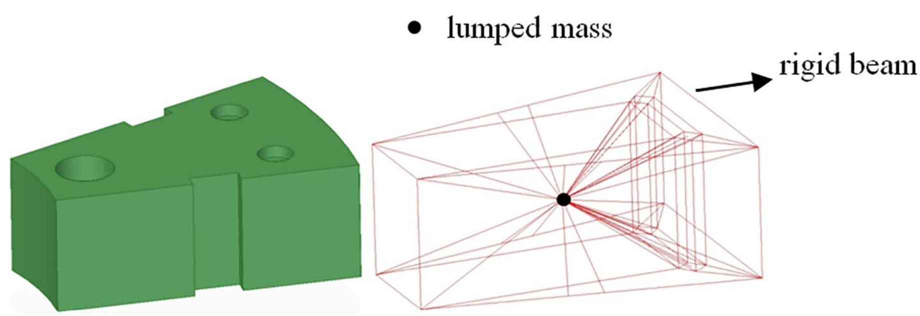

Fig. 2. Structural and rigid body of brick.

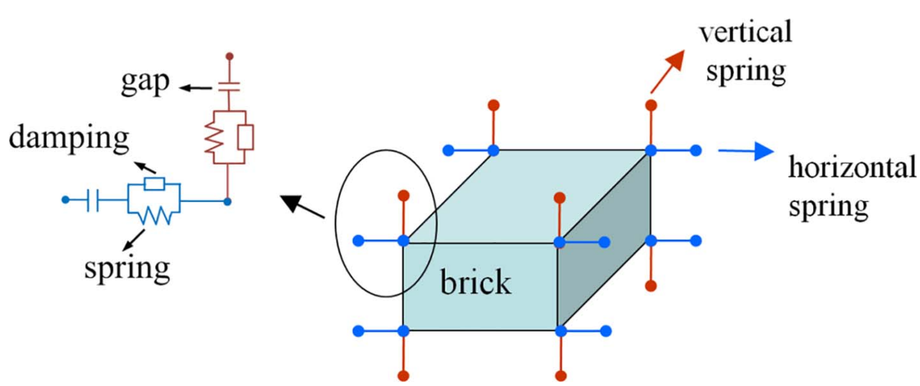

Fig. 3. Layout of spring to simulate collisions between bricks.

results of seismic analysis are represented such as the dynamic characteristics and the seismic time history response.

2. Rigid body-spring model

The reflector is divided into bottom reflector, side reflector, top reflector and filled reflector, as shown in Fig. 1(a). Bricks are the major components that make up the basic structure of reflector. Pins and keys are used for limiting the displacement of bricks. The control rod channel offers the space for the control rod going up and down. The structure has 13 layers and each layer has 16 bricks. Fig. 1(b) shows the sectional view of core tank which is the support of the reflector. The solepiece of the core tank is used for supporting the reflector, the metal key and the core tank are used for limiting the displacement of the reflector and ensuring the structural integrity.

Referring to seismic analysis of reflector in HTGR Hongkun et al. (2012); the reflector in TMSR can also be revealed by rigid body-spring model. The rigid body of the brick is built by lumped mass and rigid beams. The lumped mass locates on the center of gravity of the brick, the rigid beams outline the profile of brick, as shown in Fig. 2.

The spring system in rigid body-spring model contains spring, damping and gap to present collision between bricks. There are two different forms of collision, one is the direct collision between bricks, the other one is the pin or key transfers the collision force between bricks.

Fig. 3 shows the layout of vertical and horizontal spring systems to simulate direct collisions between bricks. Obviously, the purpose of the vertical spring systems are to transfer the gravitational force and vertical impact force from the above or below bricks, and the horizontal spring systems are used to transfer the horizontal impact force from the sideward bricks.

Fig. 4 shows the simplified model of key which is a linker located between two adjacent bricks in the same layer. The spring system of key is similar as the horizontal spring system.

Fig. 5 shows the simplified model of pin which is another linker that keeps the bricks aligned within a column by restricting the horizontal