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Pebble Bed Loads onto Reflector Walls

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1. Introduction

The Pebble Bed Modular Reactor (PBMR) [1] is a High Temperature Gas-cooled Reactor. The annular space formed by the centre and side graphite reflectors of the PBMR contains a large number of graphite fuel spheres for a reactor core. In the PBMR design, the centre reflector column structure (Fig. 1) is a newly introduced design concept and its loading conditions are not fully understood. Qualitative review of the loads onto the side and centre reflector walls by pebble bed is the aim of this work. The safety under earthquake loadings and the static loadings by the pebbles is considered.

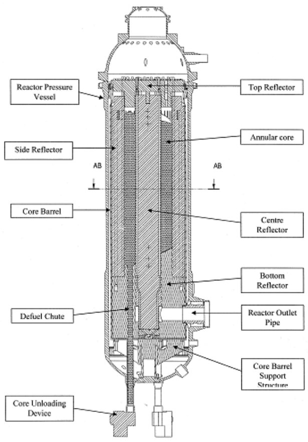

Figure 1. Vertical section view of the PBMR

2. Earthquake loadings by pebble beds

2.1. Seismic test for HTR

The dynamic response behavior of pebble beds under earthquake loadings was also an important issue of the well known German pebble bed reactor HTR that has no centre reflector column.

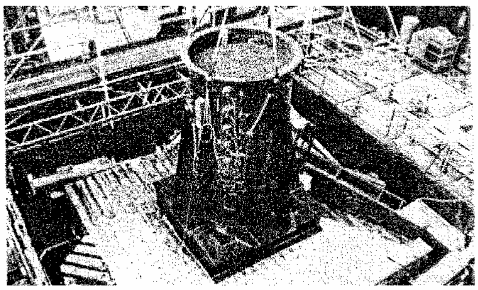

Figure 2. Test model and test facility for HTR

Scale models of the pebble bed was tested on the vibrational test facility SAMSON at HRB-Julich[2], see Fig. 2. The main concerns were dynamic behavior of the pebble bed, and sloshing of pebbles at the core surface. The test specimen consists of a cylindrical vessel of 1.5m in diameter and 1.5m in height. The pebble bed is composed of 10, 30, 60mm diameter graphite spheres. The excitations are sinusoidal between 0.5 and 90Hz with acceleration levels between 0.2 and 1.5g. The selected test results are summarized below.

Even under high acceleration, sloshing of the pebble bed surface does not occur. The pebble bed does not behave like a liquid. The dynamic magnification factors are strictly limited. Excessive resonances were not detected. The maximum magnitude is reached in the range of 40 to 60Hz. The pebble bed core undergoes a minor packing fraction increase under seismic loads, less than 5% from initial values of 0.59~0.62. But the static pressure after shaking is about 17% higher than before.

2.2. Dynamic pressure in PBMR

Based on the earlier research result that the dynamic pressure magnification in the pool type pebble bed reactor, HTR, occurs in the higher frequency range than earthquakes, one can say that the pebble bed behaves like a rigid medium under earthquakes.

The behavior of the pebble bed of PBMR can be predicted by simple analogy. The simple model of the pool type pebble bed is shown in Fig. 3.

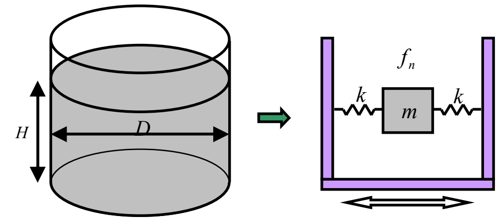

Figure 3. Simple model of the pebble bed of HTR

The natural frequency of the bed has the relation to the geometric parameters as follow;

$$f_n \propto \sqrt{\frac{1}{AD}} \qquad (1)$$

where A is the cross section area of the bed, and D is the diameter.

The simple model of the annular type pebble bed like the PBMR is shown in Fig. 4. And the frequency is as follow;

$$\bar{f}_n \propto \sqrt{\frac{1}{A(D_o - D_i)}} \qquad (2)$$

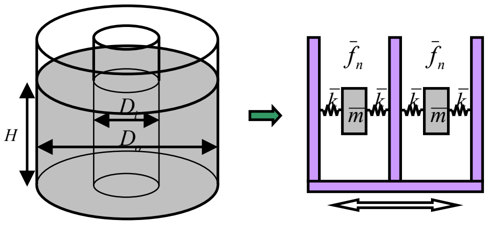

Figure 4. Simple model of the pebble bed of HTR

From the equation (1) and (2), one can simply conclude that the natural frequency of the annular type pebble bed will be higher than that of the pool type one, and so the dynamic pressure effects will be shifted to the higher frequency range. The dynamic pressure by earthquake loadings onto the side and centre reflector walls of PBMR is not important loading condition.

2.2. Static pressure in PBMR

The mean static pressure on the reflector walls of the pebble bed type reactors can be predicted by the Janssen's formula. The German engineer H.A. Janssen is a pioneer in the field of granular material science[3]. His famous paper published in German in 1985 reporting the results of novel experiments, Fig. 5, and studies have been citied by many researchers.

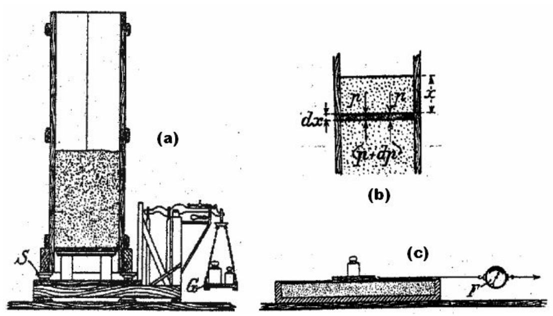

Figure 3. Janssen's experiments

Based on his experiments, Janssen drives a governing equation for the vertical pressure in the granular bed in a silo as follow;

$$\frac{dp_v}{dx} + \frac{sK}{A} p_v = \rho_b g \qquad (3)$$

And the vertical pressure is as follow;

$$p_v(x) = \frac{A\rho_b g}{sK}\left[1 - \exp\left(-\frac{Ks}{A}x\right)\right] \qquad (4)$$

Based on the equation above, one can drive an equation for horizontal mean static pressure on the reflector walls of PBMR as follow;

$$p_h(x) = \frac{\alpha_p (D_o - D_i)}{4\mu_w} \rho_p g \left[1 - \exp\left(-\frac{4K}{D_o - D_i}x\right)\right] \qquad (5)$$

where α_p, μ_w, ρ_p, .D_o, D_i, g, and K are packing fraction, wall friction coefficient, pebble density, diameter of side reflector wall, diameter of centre reflector wall, gravitational acceleration, and Janssen coefficient respectively. The downward vertical coordinate x starts from the free surface of the pebble bed. The mean static pressure on the wall is proportional to the packing fraction.

The Ref. [4] concludes from careful experiments that the packing fraction of a granular bed can be changed by the vibrating loads. Fig. 4 shows typical results of the experiments.

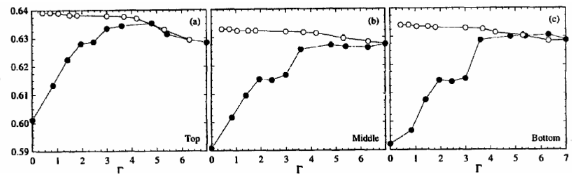

Figure 4. Change of packing fraction by vibrating loads

The result shows that the packing fraction is uniformly increased through the depth and converses within 0.62~0.64 by vibrating base excitations. This result also confirms the results of the Ref. [1], that there was minor increase of packing fraction after earthquake loadings.

The excessive increase of the static pressure, 17% in Ref. [1], was caused by the stress fluctuation in a granular bed, Ref. [5].

7. Conclusions

The dynamic load and the static loads onto the side and centre reflector walls of the PBMR are discussed. The dynamic load onto the reflector walls of PBMR by the pebble bed under earthquakes will be not so severe. The static load increase by the increase of packing fraction after earthquakes will be less than 5%. However, the stress fluctuation in the pebble bed shall be carefully considered in the design of pebble bed reactors.

ACKNOWLEDGMENT

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