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COUPLING EFFECT OF CORE-BOTTOM STRUCTURE AND CORE GRAPHITE BLOCKS IN HTTR

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Abstract : From viewpoint of aseismatic design, the graphite components in the High Temperature Engineering Test Reactor (HTTR) are separately treated as a core structure and a core-bottom structure. Thus, the coupling effect of the core structure and the core-bottom structure was clarified through experimental and analytical approach.

1. Introduction

The HTTR(1), which is one of the High Temperature Gas-cooled Reactors (HTGRs), is proceeding with the construction in Japan. The graphite components in the HTTR are considered from viewpoint of aseismatic design to be divided broadly into a core structure and a core-bottom structure (CBS). The core structure consists of many a pile of numerous hexagonal graphite blocks including fuel elements and replaceable reflectors. The CBS consists of an arrangement of hot plenum blocks (HPBs), core support posts (CSPs), and the other graphite blocks. The HPBs are combined with each other by keying systems and are supported separately by three CSPs.

The aseismatic studies of the core structure and the CBS had been done independently through experimental and analytical methods. The coupling effect of the core structure and the CBS, therefore, has not been sufficiently clarified yet.

Thus, the coupling effects of the core structure on the vibrational characteristics of the CBS, and of vice versa were investigated through experimental and analytical methods.

2. Vibrational test

The test model combining the core structure and the CBS consists of seven core columns, one HPB, and three CSP, as shown in Fig. 1. Each column is axially composed of nine hexagonal graphite blocks and one steel shielding block in full-scale. The gap width between the block and the impact plate is set up to simulate different reactor operating conditions.

To estimate the effect of CBS on vibrational behavior of core graphite blocks, the seismic tests were performed with and without the CBS; that is, HPB was fixed on the vessel to isolate the CSP vibration. Furthermore, the seismic tests were carried out with decreasing the core graphite blocks to evaluate the effect of core graphite blocks on vibrational behavior of the CBS. Table 1 shows the scope of vibration test. Horizontal and vertical uniaxial and simultaneous two-axis shaker tests were performed using a biaxial shaker facility. The model was excited by using sine waves and simulating earthquake waves: S_1, S_2 and Sv, where S_1 was the equivalent ground motion induced by the maximum possible earthquake, S_2 was the extreme design earthquake which was not supposed to actually occur and Sv was an actual vertical earthquake measured at the HTTR site. The maximum acceleration levels of S_1 and S_2 waves at the reactor pressure vessel are 1.2 and 1.9 m/s^2, respectively.

The measurement items are the relative horizontal displacement between a block and an impact plate, the impact acceleration of the block, the impact load acting on the impact plate, the shear force in a dowel by strain gages fixed around dowel pin and socket(1), the input acceleration and so on. The impact load on the HPB is measured by strain gages fixed on a support bar of the impact plate.

3. Analytical method

The SONATINA-2V code, which can estimate only the vibrational behavior of the core structure without the CBS(2), was modified by combining the vibrational model of the CBS(3) to investigate the coupling effect of the core structure and the CBS. Figure 2 shows the modified SONATINA-2V code model : the code uses an orthogonal coordinate system with a horizontal and a vertical axis, and block motions and collisions are calculated along the two axes.

The core graphite block, as shown in Fig. 2(b), is treated as a rigid body with three degrees of freedom: horizontal and vertical translation and rotation. The collision model is represented by the element of spring and viscous damper in parallel assuming that the local surface deformation of graphite block results from collision. The vibrational behavior of the CBS is described by taking account of the restoring force characteristics of the support post structure as shown in Fig. 2(c). The restoring force characteristics is represented by a bilinear spring which possesses both a positive constant for rolling motion and a negative constant for sliding motion(3).

4. Results and discussion

4.1 Effect of CBS on vibrational behavior of core graphite blocks

In order to evaluate the effect of CBS on vibrational behavior of core graphite blocks, the seismic test without the CBS was carried out, and the result was compared with one of the test including the CBS. Table 2 shows the comparison of the maximum response values between, which are required for safety evaluation of the structural integrity of the core components. As shown in the table, these maximum response values with the CBS are equal to or smaller than those of the test model without the CBS. In addition, these values are almost constant in spite of the vertical wave. It can be seen from the table that the maximum response values, which are important parameters from standpoint of asismatic design, decrease by coupling the CBS. Figure 3 shows typical time responses of block displacement in the test with and without CBS. It is clear from figure that the displacement behavior of the core graphite blocks is hardly affected by the CBS.

4.2 Effect of core graphite blocks on vibrational behavior of CBS

(1) Horizontal impact load acting on keying system

The impact force is concentrated on the keying systems of the HPBs(4). The clearance between key and keyway was simulated by adjusting the clearance between HPB and impact plate in the test model. The impact load on the HPB in the test model corresponds to that on keying system in the prototype.

The impact load acting on the HPB was examined as a function of the core weight. Figure 4(a) shows the variation of the HPB impact load when the core elevation level mounting on the CBS was changed. Both experimental and analytical impact loads were found to be almost independent of the core weight. Figure 4(b) shows the variation of the peak frequency. The peak frequency is almost independent of decrease of core weight. This is because the core weight hardly influence on the natural frequency of the CSP structure(3). It can be said from these results that the coupling effect of the core structure is almost ignored on the vibrational characteristics of the CBS.

It is confirmed from the comparison that the modified SONATINA-2V code can describe adequately the vibrational characteristics of the CBS.

(2) Impact force acting on CSP

Each HPB is supported by three CSPs. Since the CSPs are subjected to the weight of both the core graphite blocks and the HPB under normally operating condition, a compressive force acting on one CSP is equal to $W_0/3$, where W_0 denotes the weight of both core graphite blocks and one HPB. On the other hand, in a dynamic state, the compressive force of the CSP is affected by the impact force induced by the vertical and rocking motions of the HPB. In order to investigate the vertical impact force acting on the CSP, vibrational test was performed with one-third-scale model simulating the array of the graphite components in the CBS(5).

The maximum load on the CSP is expressed by $C \cdot W_0$, where C is the factor induced by the vibration behavior of the HPB. Figure 5 shows the C value response as a function of the weight mounting on the CSPs. It can be seen from Fig. 5 that the maximum impact force is in inverse proportion to the weight mounting on the CSPs, because the increase of weight reduce the rocking motions.

5. Conclusion

The main conclusions from this study are summarized as follows:

(1) The maximum response values of the core graphite blocks decrease by coupling the CBS.

(2) The maximum impact load acting on the keying system is almost independent of the vibrational behavior of the core graphite blocks.

(3) The maximum load on the CSP is expressed by $C \cdot W_0$, where C is the factor induced by the vibration behavior of the HPB, and W_0 is the weight supported by the CSPs, respectively. It can be clarified that the C value becomes small when increasing the core weight.

References

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Table 1 Scope of vibration test

Direction of excitation	Vibration mode	Main measurement item
# Uniaxial (horizontal) # Biaxial simultaneous (horizontal & vertical)	# Sine waves (maximum acc. $2m/s^2$) # Simulated earthquake S_1, S_2; horizontal Sv; vertical(earthquake at site)	# Block and HPB (displacement, acceleration) # Impact plate (impact load) # Dowel force

Table 2 Comparison of core seismic response with and without CBS

	Gap width between block and impact plate	Input earthquake	Upper shielding block impact load kN	Block displacement (4th block from the top), mm	Dowel force (2nd block from the top) kN
Without CBS	Large	S_1	24.7	13.8	1.30
		S_2	42.4	16.2	1.15
	Small	S_1	6.4	2.2	0.59
		S_2	10.6	4.6	1.09
With CBS	Large	S_1	21.2	15.7	1.33
		S_2	35.3	16.6	1.33
		S_2 + Sv	32.5	16.6	1.34
	Small	S_1	7.1	2.1	0.57
		S_2	7.8	3.7	0.98
		S_2 + Sv	12.3	3.9	1.01

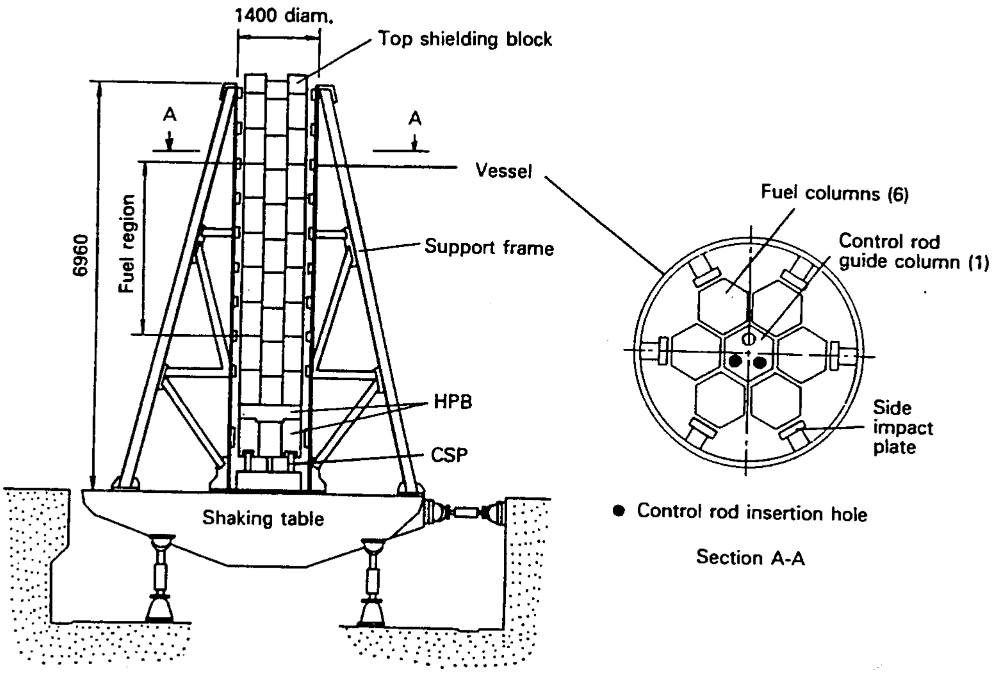
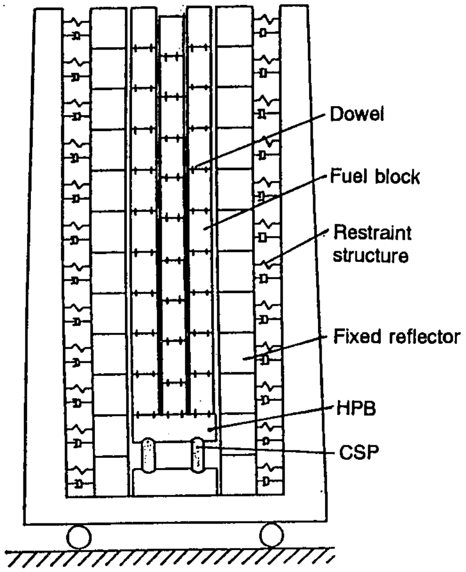
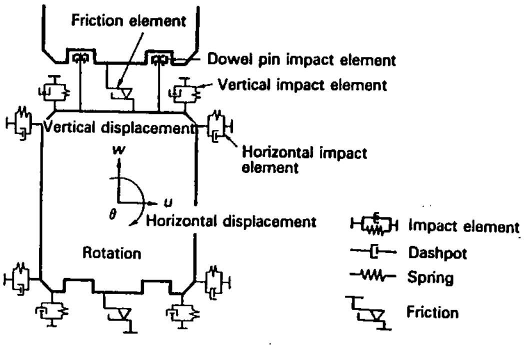


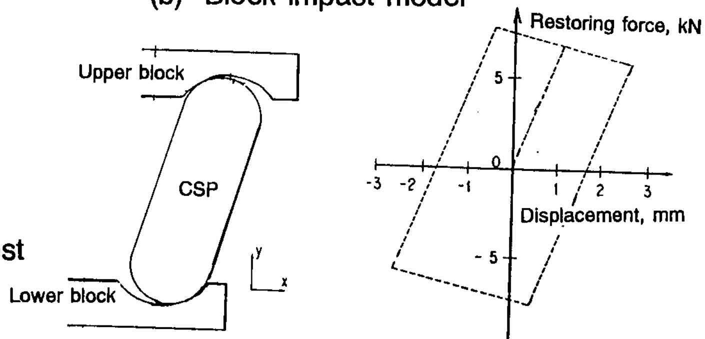
Fig.1 Experimental apparatus for full-scale seven-column test.



(a) Analytical model for seismic test

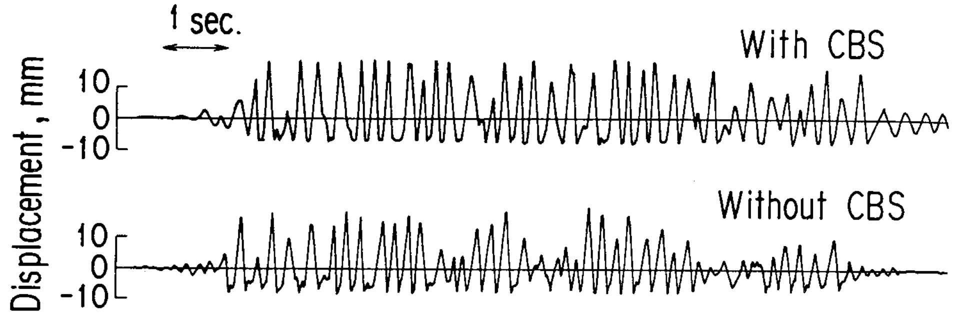


(b) Block impact model

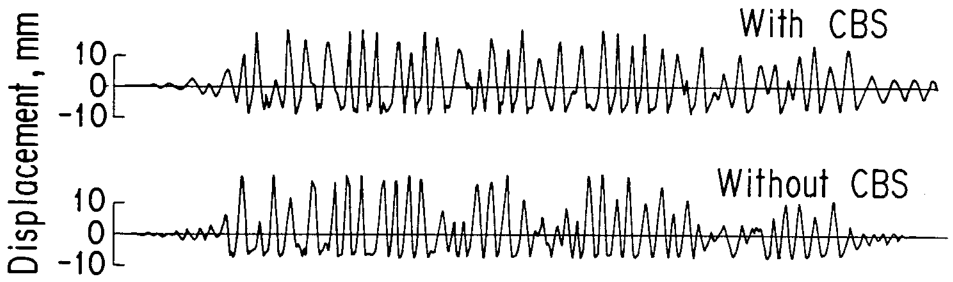


(c) Support post

Fig.2 Modified SONATINA-2V code model.

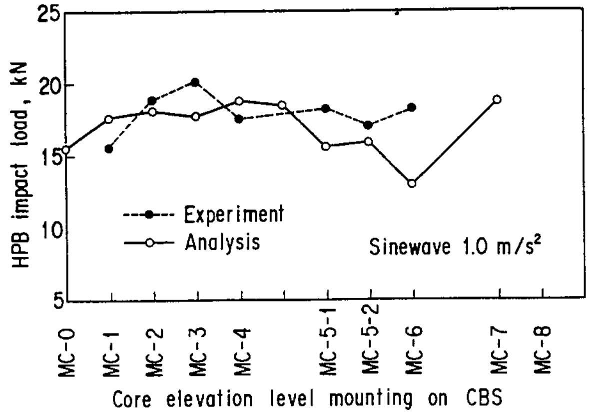


(a) 2nd block from the top

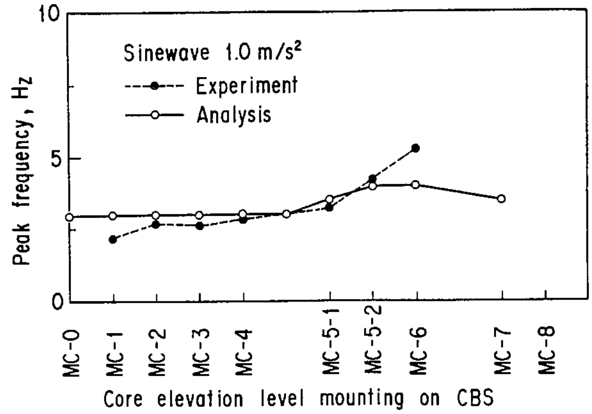


(b) 4th block from the top

Fig. 3 Comparison of block displacement with and without CBS (S_2)



(a) Impact load



(b) Peak frequency

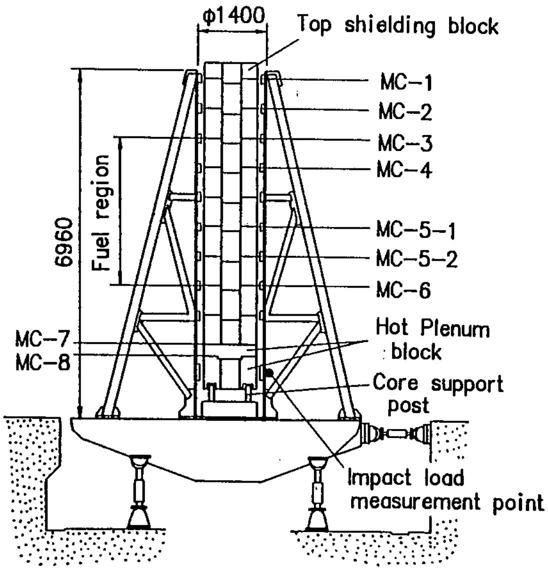


Fig.4 HPB impact load behavior as a function of core weight

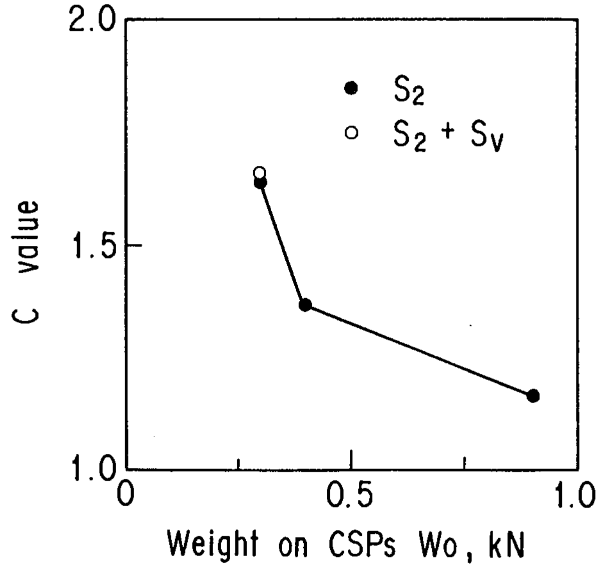


Fig. 5 C value vs. weight on CSPs