Experimental Studies on Seismic Vibration Phenomena of FBR Core Components

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Summary

This paper deals with vibration behaviours in a cluster of components with hexagonal cross section in a limited area under dynamic excitation due to seismic events.

A seismic analysis of the Fast Breeder Reactor Core is a complicated problem, which includes the dynamic interaction with many components of different vibrational behaviours.

The core components are assumed to be elastic beams fixed at the lower part and free at the top.

They have first mode resonant frequencies in the same components as earthquake wave predominant frequencies and are arranged in the barrel with small gaps between them.

When strong earthquake excitation is applied to the barrel, the cluster of components displace to geometrical limits in the barrel and collisions will occur between adjacent components as a result of their relative motion, because of the small gaps between components.

For these reasons, a non-linear analysis with components collision is necessary to predict the seismic response in the cluster of components.

It is hoped to establish a relatively simple calculation model with lower degrees of freedom within the range where the phenomena cannot be mistaken.

In order to clarify the complicated seismic response of components, experiments were carried out under two situations.

Single row components tests and grouped components tests were carried out in a fluid region with actual components.

The followings became clear after studying the experimental results.

(1) Relation between input acceleration and components displacement distribution.
(2) Relation between input acceleration and predominant vibrational frequencies in response time history.
(3) Differences in behaviour between single row model and grouped model.

1 Introduction

In the course of FBR development, evaluation of its safety to withstand an earthquake is one of the important problems for FBR plant design.

This paper relates to the FBR Core Components. The FBR core components consist of core fuel assemblies, radial blanket assemblies and neutron shield assemblies. They are assumed to be elastic beams immersed in a fluid region, supported at the lower end plug and free at the top.

Studies on dynamic response with interactions between a cluster of beams and fluid subjected to dynamic forces caused by support acceleration due to earthquake, have been conducted analytically and experimentally.1)

The FBR core components have first mode resonant frequencies, same as earthquake wave perdominant frequencies. They are arranged in a limited area in the barrel with small gaps between them.

During strong earthquake excitation, the cluster of components displace to geometrical limits in the barrel and collisions could occur between adjacent components as a result of their relative motion. For these reasons, aseismic analysis of core components is a complicated non-linear problem, which includes collision vibration and fluid interaction. In actual core design, it is difficult to include hundreds of components in numerical calculation. In order to develop an applicable analytical method for practical treatment, it is necessary to clarify the complicated seismic response of components experimentally. So, forced vibration tests using actual components were conducted "in air" and "in water".

2 Vibration Tests

In an actual core, hundreds of components with hexagonal cross section are arranged closely in a barrel. In these experiments, single row apparatus with 29 components simulated all components in a core central row and 7 group row apparatus with 37 components in core center were made. The test apparatus was put on a large-sized shaking table and excited.

The test apparatus are shown in Fig. 1 ∿ Fig. 2. Fig. 1 shows the single row test apparatus - a water tank 4800 mm in height and 300 mm x 3835 mm sectional area. It can accomodate 29 components in a row and can be excited in the direction of the row. The test apparatus must have as high a natural frequency as possible, so as not to affect the vibration characteristics of test components when it is charged with these components and filled with water. The first mode natural frequency of test apparatus is 50 Hz or above.

Although measurement devices are not shown in Fig. 1, this test apparatus includes a frame having the mounting seat for displacement transducers for measuring displacement of the component upper part, and load cell mounting seat for measuring the collision force between pad parts of the component at both ends of the row. Further strain distribution in components and acceleration at component top and middle part were measured.

Fig. 2 shows the group test apparatus - a water tank with 4860 mm height and 1050 mm diameter. It can accomodate 37 components. The concept embodied here is the same for a single row test.

The reason to make two different apparatus configuration is to understand details about the phenomena regarding a single row and group row, and finally to conclude that the single row analysis represents in design, including that margin.

Single row tests with 29 Components

In this test, the tank in which 17 core fuel assemblies, 4 radial blanket assemblies and 8 neutron shield assemblies were arranged in a line, was put on the shaking table and excited.

Fig. 3 shows the acceleration response curves for the component top in water against sinusoidal sweep waves. This example shows the response of center component in the single row. These figures have taken input levels as a parameter. The frequency range is up to 20 Hz considering the earthquake predominant frequencies. As is clear from Fig. 3, the response curves have two predominant peaks that correspond to 1st mode and 2nd mode natural frequencies in the single row.

The frequency that gives the maximum response corresponding to the 1st mode, varies with input acceleration level. This is a particular phenomena in beam vibration system with gaps. There is a natural frequency which come from the relation between gaps and input acceleration level. The peak at 3 Hz is the natural frequency for a component linear system without the presence of collision.

The frequency at 17.5 Hz that gives the 2nd mode does not vary with input acceleration. In general, the same as the 1st mode, the 2nd mode frequency also depends on the input acceleration. But, it can be considered constant value in practical application because the 2nd mode frequency is higher than the 1st mode, the displacement is small compared with gaps and the collision effect does not appear conspicuously.

Fig. 4 shows the change in 1st mode natural frequency under sinusoidal excitation. In Fig. 4, the difference in frequency between in-air and in-water values comes from the fluid forces, that is, added mass. The frequency change ratio as the cluster vibration to the input level is the same between in-air and in-water excitation. This means the frequency change by collision effect is the same for the in-air and in-water conditions. The response displacement time history by earthquake wave excitation is shown in Fig. 5 in order to show the behavior of all components in the water. The response was measured at the top of each component. The components move in the same phase. At the time when maximum displacement appears, a 3 Hz is predominant in the response and the predominant frequency of core vessel vibration mode is also included.

Fig. 6 shows the strain response time history of component. In Fig. 6, needless to say this corresponds to displacement response, the 3 Hz is predominant at the lower part, a 12 Hz included in the input waveform at the middle part and the high frequency component due to collision at the upper part.

Grouped tests with 37 components

Vibration tests were conducted with a hexagonal section of 37 actual core fuel assemblies. Fig. 7 shows the change in 1st mode natural frequency and the single row test results comparison with grouped tests results in air excitation in order to except the fluid effects. The horizontal axis of the figure means the acceleration divided by total gaps value in the row. As is clear from Fig. 7, the change in frequency due to input acceleration is the same in the single row tests and grouped tests.

Fig. 8 shows the relation between input acceleration and components displacement. The components vibrate in a limited area, which restricts the displacement.

Here, the displacement amplitude x at the top component, with no local deformation due to collision considered, is:

$$\begin{array}{ll} x > 0 & G\cdot(N + 1 - M) \\ x < 0 & G \cdot M \end{array} \qquad (1)$$

where, N shows the number of components, M shows the Mth component and G shows the initial gap. The natural frequency for component is comparatively low. Therefore when an earthquake occures, each component easily displaces to the full in the gap.

In this test where input acceleration level is 400 gal, the response displacement reaches the geometrical limit. Thus, the collision will occur between adjacent components. The extreme components behavior is that all components lean to one side.

Component response is influenced by the following factors;

(i) Input acceleration ($\ddot{u}_i$)

(ii) Damping ratio (h_i)

(iii) Participation factor by fluid (β_i)

The component displacement response x_i becomes as follows,

$$x_i = F(\ddot{u}_i, \beta_i, h_i) \qquad (2)$$

i = s Single row tests

i = c Group tests

The response is in proportion to $\ddot{u}_i$ and β_i.

Therefore,

$$\frac{F(h_s)}{F(h_c)} = \frac{x_s}{x_c} \cdot \frac{\ddot{u}_c}{\ddot{u}_s} \cdot \frac{\beta_c}{\beta_s} \qquad (3)$$

$F(h_s)$ and $F(h_c)$ are monotone decreasing functions. From tests results, x_s and x_c are geometrical limit displacement for each test, and at that time input acceleration levels are $\ddot{u}_s$ and $\ddot{u}_c$. β_c and β_s can be obtained from the relation of frequency between in-air and in water excitation.

$\ddot{u}_c$ = 400 gal, $\ddot{u}_s$ = 800 gal

x_c = 4.9 mm, x_s = 20.3 mm

β_c = 0.43, β_s = 0.6

Substituting these value into eq. (3),

$$\frac{F(h_s)}{F(h_c)} = 1.48$$

This result means that the damping ratio in group tests is larger than that in single row tests under the consideration of fluid forces.

3 Discussion

For an analytical model from design standpoints, the following discussions concerning points encountered on applying the tests are listed from the tests results.

(1) Vibration system with predominant frequency increasing phenomena for the components, accompanying the input acceleration increase, will be expressed and modeled using the gap elements and collision spring.

(2) From the results in the in-air excitation and the in-water excitation, added mass due to fluid force is to be considered, and components interaction by fluid and collision forces, are to be included.

(3) For stress evaluation concerning component bending, a component itself should have a sufficient degree of freedom to allow estimating the 2nd vibration mode.

(4) For strength evaluation of collision part, the collision inpulse is to be obtained.

So, concrete expressions are;

(1) The collision parts between components are replaced by equivalent spring and damper with initial gaps, and collision force value comes from their deformation.

(2) The fluid effect and coupling between components are replaced by fluid inertia forces. In this manner, the treatment of fluid will be easy and it is sufficient to change the mass matrix as required. Based on the above assumption, a computer analysis code is being developed at present.

4 Conclusion

For aseismic design of FBR core components, vibration tests were conducted, in order to determine their complicated behavior and summarize the process of vibration analytical model determination.

When core component vibration in a fluid region during an earthquake are calculated, it is not practical to consider all components in a core cluster also with the present numerical calculation techniques.

After studying the test results, it can be found that the single row vibration model gives a practical representation regarding a component cluster, under the consideration of fluid forces and damping.

5 Acknowledgement

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Reference

[1] T. J. Moran, "An Assumed Mode Approach to Fast Reactor Core Seismic Analysis" ANL-CT-76-33 June 1976

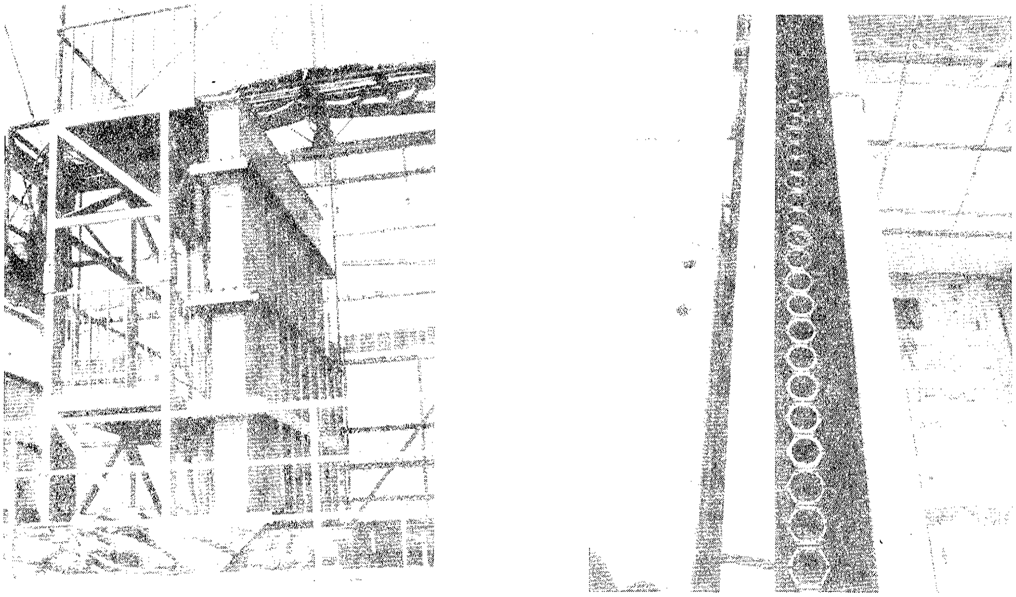

Fig. 1 SINGLE ROW TEST APPARATUS

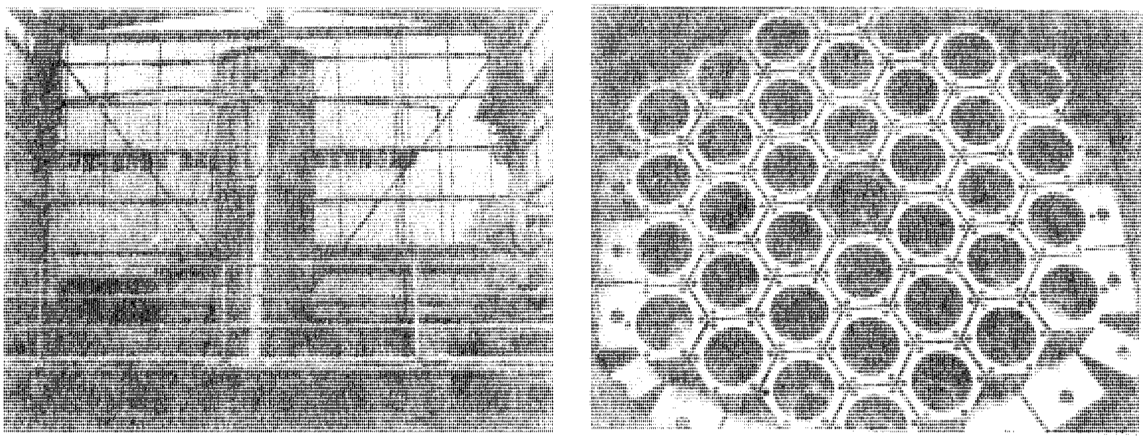

Fig. 2 GROUP TEST APPARATUS

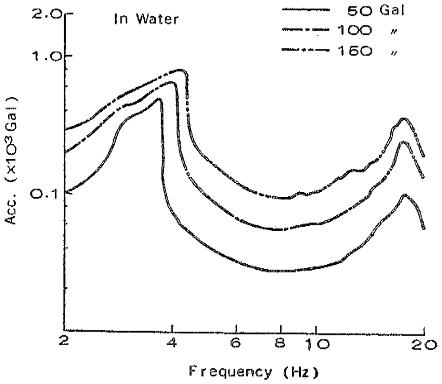

Fig.3 RESPONSE CURVES OF COMPONENT(SINGLE ROW MODEL)

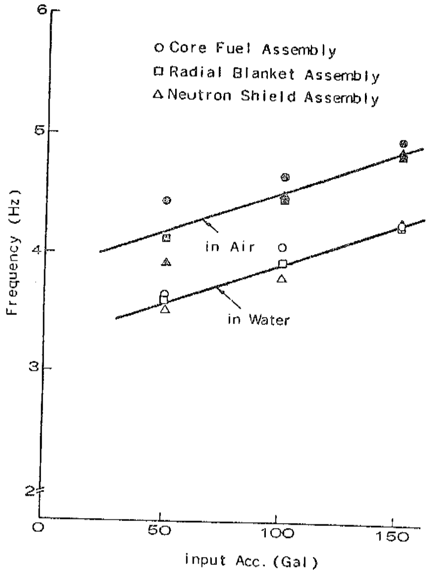

Fig.4 FREQUENCY GIVEN MAXIMUM RESPONSE UNDER SINUSOIDAL EXCITATION (SINGLE ROW MODEL)

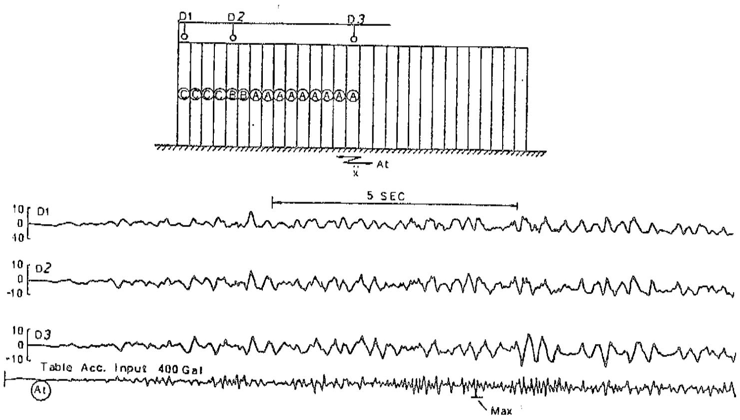

Fig.5 DISPLACEMENT TIME HISTORY OF COMPONENTS UNDER EARTHQUAKE WAVE EXCITATION (SINGLE ROW MODEL)

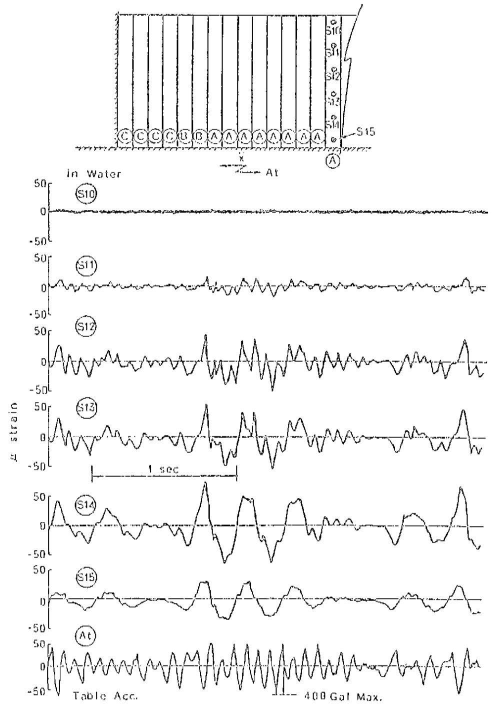

Fig.6 STRAIN TIME HISTORY OF COMPONENT UNDER EARTHQUAKE WAVE EXCITATION (SINGLE ROW MODEL)

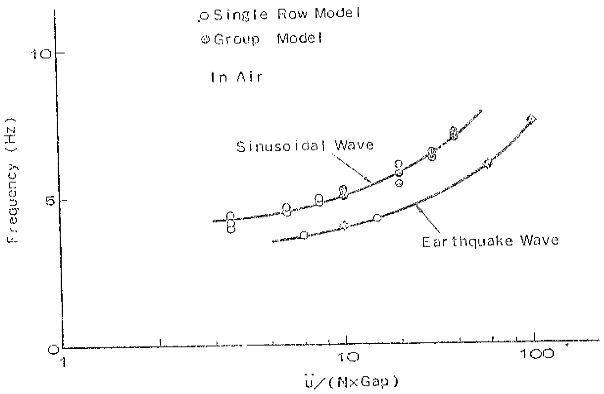

Fig.7 RELATION BETWEEN INPUT ACCELERATION AND PREDOMINANT FREQUENCY

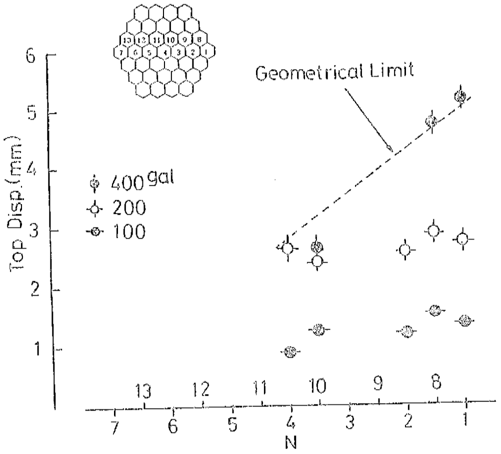

Fig.8 DISPLACEMENT OF COMPONENTS UNDER EARTHQUAKE WAVE EXCITATION IN GROUP MODEL