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A conceptual study on vertical seismic isolation for fast reactor components

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ABSTRACT: In a base isolated plant, the vertical component of an earthquake ground motion is directly transmitted to the upper structure, while the horizontal components sufficiently reduced. Hence, if one can combine a vertical seismic isolation at equipment level with base isolation, the plant may be three dimensionally freed from seismic load, which will substantially enhance plant safety and economy. From this point of view, a structural concept of vertical isolation system has been pursued.

1. VERTICAL ISOLATION SYSTEM -A CONCEPTUAL DESIGN-

The success of horizontal base isolation can chiefly be attributed to the use of laminated rubber bearings which have flexibility in shear deformation and high rigidity in vertical load supporting direction. In the vertical isolation system, on the other hand, the direction of isolation is the same as that of gravitation. This is the most distinctive feature of the vertical isolation system and one has to use vertically flexible isolation device while supporting the static weight of its object, which is the main cause of engineering difficulty in developing a realistic vertical isolation system. It is essential to avoid excessive static deflection (settlement) during installation and undesired rocking response to the horizontal excitation. The isolation device is therefore required to have a carefully tuned flexibility in the vertical direction while keeping a sufficient rigidity in the other degrees of freedom. The device is, from safety aspect, also required to maintain supporting capability even its failure is postulated. In addition, it should be avoided that excessive relative displacement be imposed to primary piping systems that connect the major components.

As a promising solution to the above requirements inherent to the vertical isolation system, a concept that the author calls "common deck isolation system" is proposed, see Fig. 1. Here, the idea is that the reactor vessel and the major primary components are suspended from a flat circular slab structure (common deck) inside the reactor containment vessel. This common deck is then supported by a couple of vertical isolation devices installed around each component. The isolation device adopted in the present study, as is shown in Fig. 2, basically consists of a set of large bore dish springs that surround the body of each component. These dish springs are, in connection with the movable inner cylinder and the upper ring, compressed downward when the upper structure moves downward, and compressed upward when the upper structure moves upward. In this way, the dish springs always remain in a stable compressed state. The dish springs are sized and combined in parallel and/or series so that the desired fundamental frequency and necessary stroke are achieved.

Since in this system the isolated structure is basically a flat plate and the offset between its center of gravity and supported location is small, only marginal rocking response is intrinsically expected. This unnecessitates any additional support against rocking. It also contributes to suppressing the rocking motion that a few number of large bore dish springs are utilized. One of the other advantages of this system is that no relative displacement is subjected to the primary piping systems since there occurs no relative motion among the components suspended from the common deck. It should also be noted that the dish springs can maintain their capability for the static weight support of the isolated structure even in an ultimate state of deformation and no catastrophic failure is expected.

2. ANALYSIS

2.1 Vertical response of base isolated reactor building

In order to provide with a set of input conditions for the survey of vertical isolation characteristics, a series of dynamic soil-structure interaction analyses on a base isolated reactor building was first made. The vertical ground motion used, which is shown in Fig. 3, was generated from a target spectrum which was made by modifying the horizontal design spectra of an existing plant (Watabe, 1990). A lumped mass analysis model was constructed based on a design of a loop type FBR plant, see Fig. 4. The soil condition considered ranges from a soft rock site with the shear wave velocity (*Vs*) of 700 m/sec to a hard rock with *Vs* = 2000 m/sec. The axial rigidity of the isolation layer (rubber bearing) assumed, in terms of natural frequency, *fv*, ranges from 10 to 20 Hz.

Some typical results of the analyses are shown in Fig. 5 in the form of floor response spectra (FRS) at the reactor support level. There are basically three peaks in these FRS's, the first of which is rather a wide peak ranging from about 0.1 sec to 0.3 sec. The other peaks correspond to the higher order modes and lie in shorter period ranges. The FRS is more dependent on the rubber bearing stiffness in the hard rock case than in the soft rock case. Especially in the hard rock case, the first peak of the FRS becomes very large when the rubber bearings are not stiff enough.

2.2 Survey for optimal isolation characteristics

Using the structure response obtained from the above analyses, a series of parametric survey was made with a single d.o.f. model to identify an appropriate range of isolation frequency and damping values.

Some typical results are shown in Fig. 6. Here, the normalized acceleration is the ratio of maximum response to input. Naturally, the response acceleration decreases as the isolation frequency is lowered, while the response displacement increases. It is noted from the figure the response acceleration is dependent more on the soil condition than on the rubber bearing stiffness, and that the isolation is more effective in the hard rock case. Higher damping is effective for the reduction of both acceleration and displacement. If one can expect at least 10% damping or more, (this value seems to be realistic for the friction damping of dish springs) it may be allowed to set the isolation frequency up to around 3 Hz, except for the very soft rock cases. From the displacement point of view, the lowest frequency applicable seems to lie around 2 Hz, since a significant increase of displacement is seen below 2 Hz. Based on these observations, it is judged the frequency range of 2 to 3 Hz is appropriate and that at least 10% damping is required for vertical isolation.

2.3 Design of dish springs as isolation device

A trial design was made on large bore dish springs as isolation devices to see if the above identified isolation frequency is achievable in an actual scale. The assumed size and weight of the isolated structure/components are;

- ❑ Common deck: 40 m in diameter, 2 m in thickness, 6000 ton in weight
- ❑ Reactor-block: 8 m in diameter, 4700 ton in weight
- ❑ IHX's and Pumps: 1400 ton (sum of 4 loops)

The isolation frequency was chosen to be 2.5 Hz, and the load supporting capacity and the stroke were set to be 2 G's (1 G of static weight plus 1 G of dynamic response including safety margin) and 80 mm, respectively.

Using Almen/Laszlo formula (Almen, 1936) for the load-deflection relation, the dimension of the dish springs were determined, as listed in Table 1.

2.4 Dynamic characteristics of vertically isolated common deck

A preliminary analysis was made on the whole common deck system to see its fundamental dynamic characteristics and the effect of isolation. Here, the common deck was modeled by shell elements, reactor-block and components by lumped mass rod elements, and the isolation devices by linear spring elements. In Fig. 7 shown are the vibration modes, where only the common deck is depicted for simplicity. While the fundamental mode (2.4 Hz) is the rigid body motion of the common deck, in the second mode (3.8 HZ) some deformation of common deck into a conical shape is seen. However, the modal mass contributing to this mode is negligibly small. Fig. 8 compares the response acceleration of the core support plate in the reactor-block. The effect of isolation, i.e., the reduction in acceleration response, is clearly seen.

3. CONCLUSION

A concept of vertical isolation system which uses common deck structure and large-bore dish springs as isolation device was proposed. Appropriate and realistic ranges of isolation frequency and damping were identified to be 2 to 3 Hz and about 10%, respectively. A trial structural design was made of the actual scale dish spring and common deck to show possibility of realization of the system. From the preliminary analysis, it was shown that the present isolation system is effective in reducing the vertical response acceleration of the components.

ACKNOWLEDGMENT

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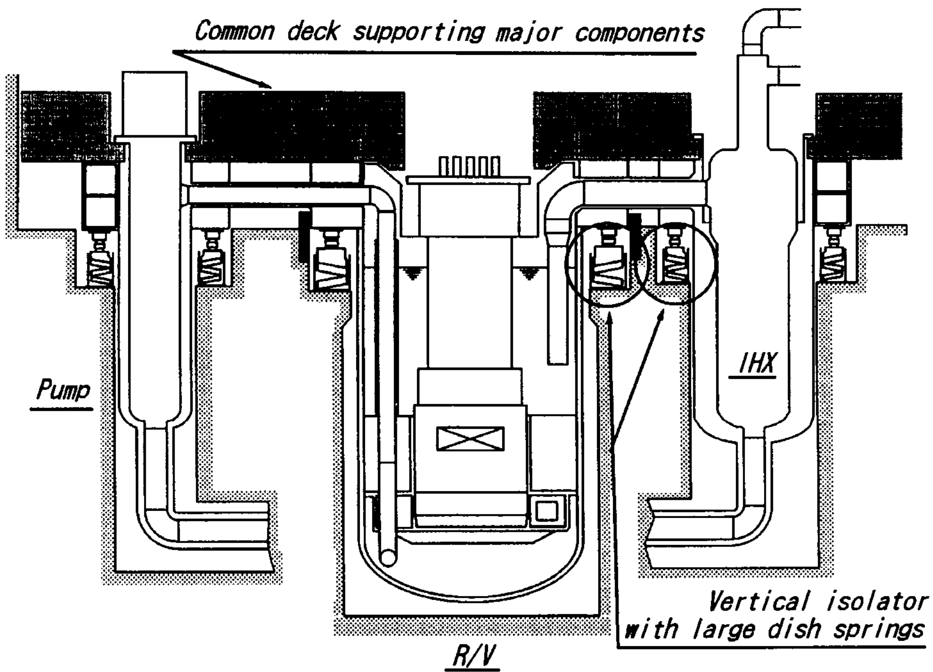


Fig. 1 Schematic drawing of common deck isolation system

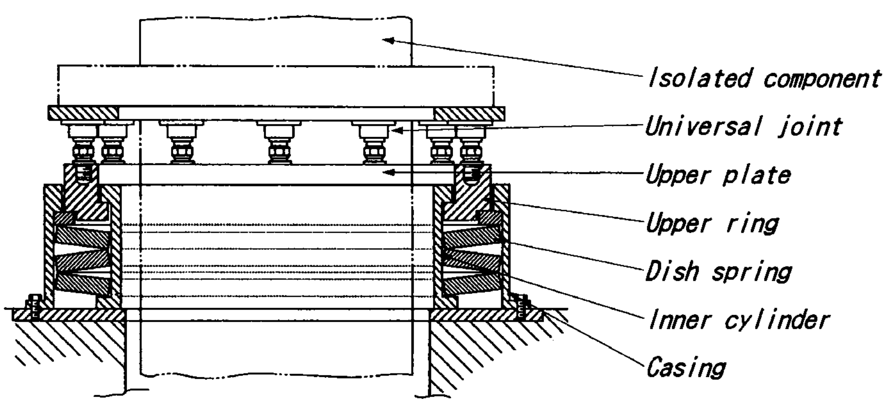
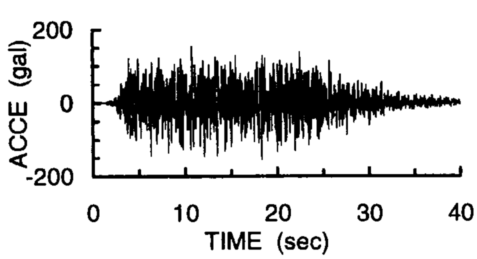


Fig. 2 Vertical isolation device with large dish springs



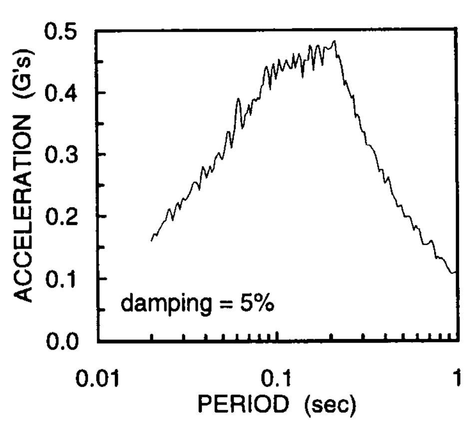


Fig. 3 Acceleration time history and Response spectra of input ground motion

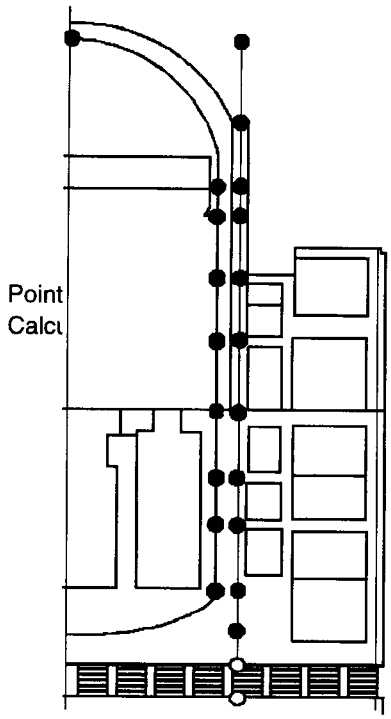


Fig. 4 Analysis model of base isolated reactor building

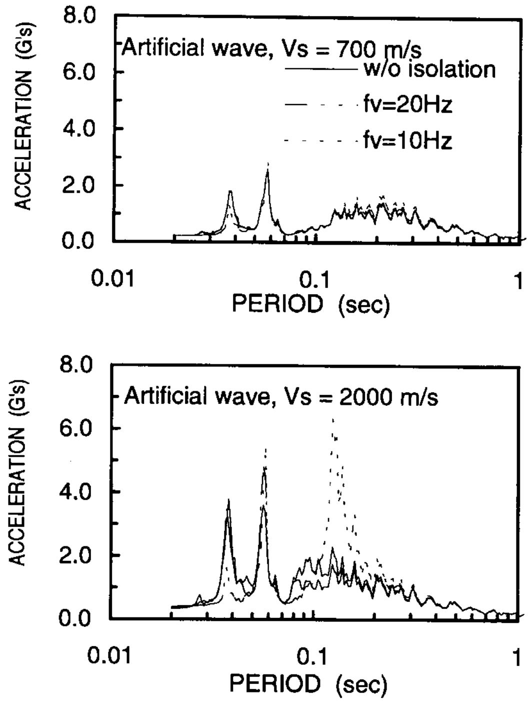


Fig. 5 Floor response spectra at reactor support level

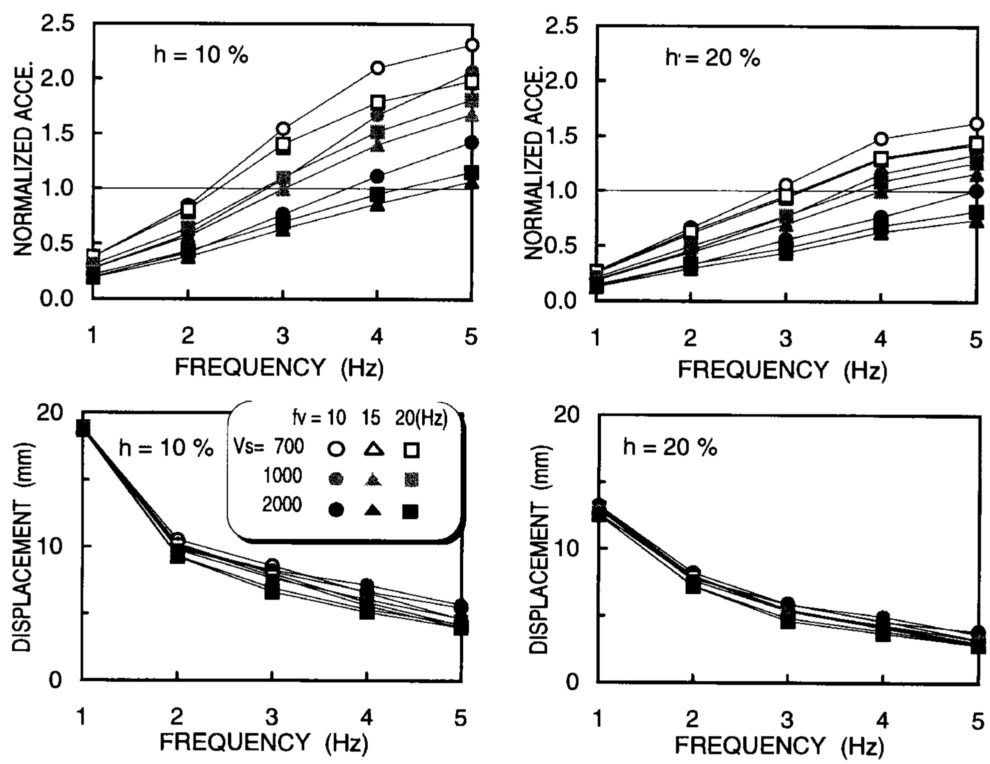


Fig. 6 Response of 1 d.o.f. system

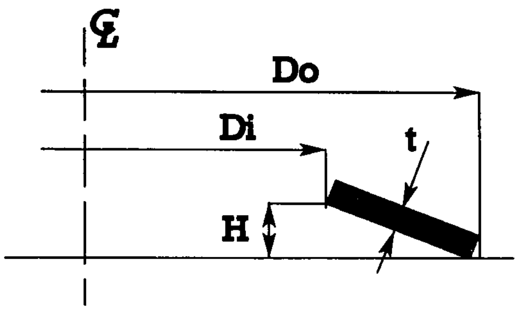
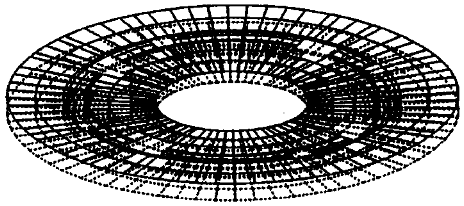


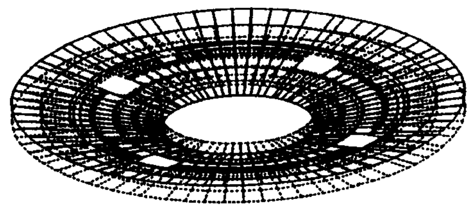
Table 1 Dimension of dish springs

	R/V	IHX	Pump
Do (m)	14.0	8.2	6.0
Di (m)	10.8	6.2	4.0
H (mm)	330	120	150
t (mm)	440	160	200
N	1	1	3 (series)

N: Number of springs



Mode 1 2.41 Hz



Mode 2 3.77 Hz

Fig. 7 Vibration modes of isolated common deck

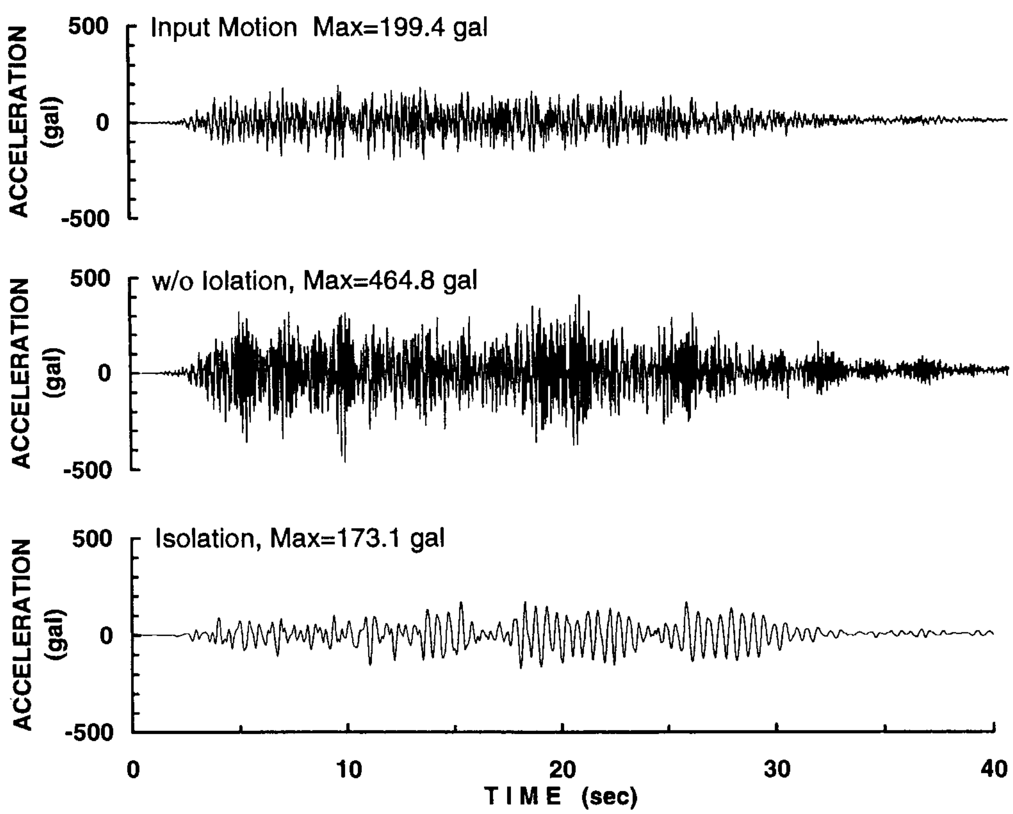


Fig. 8 Comparison of response acceleration at core support plate