*Transactions of the 17th International Conference on Structural Mechanics in Reactor Technology (*SMiRT 17)
Prague, Czech Republic, August 17 –22, 2003
Paper # K10-1

Structure of 3-Dimensional Seismic Isolated FBR Plant with Vertical Component Isolation System

Masaki Morishita[1)], Seiji Kitamura[1)], Yoshio Kamishima[2)]
Tetsundo Nakatogawa[3)], Akinori Miyamoto[3)] and Takahiro Somaki[3)]

1) Japan Nuclear Cycle Development Institute, Japan
2) Advanced Reactor Technology Co. Ltd., Japan
3) Obayashi Corporation, Japan

ABSTRACT

A structural concept of a vertical component isolation system for FBR plants, assuming a building adopting a horizontal base isolation system, has been studied. In this concept, a reactor vessel and major primary components are suspended from a large common deck supported by isolation devices consisting of large coned disk springs. The device which realized isolation frequency 1Hz was designed, and the suitability of the device to an FBR plant was examined. By the response analysis, it was confirmed that the appropriate isolation effect was obtained. There is a prospect in which the vertical component isolation system can be realized.

KEY WORDS: vertical component isolation system, coned disk spring, common deck, plant layout

1. INTRODUCTION

Although the horizontal component of earthquake motion is sufficiently reduced by the base isolation system using laminated rubber bearings, the vertical component is transmitted directly. If a three-dimensional isolation were achieved, it would substantially enhance plant economy and safety. Two types of systems can be considered to realize the three-dimensional isolation. One is a three-dimensional base isolation system, and the other is a combination of horizontal base isolation and vertical component isolation. In FBR plants, structural problems in which the consideration for vertical motion is required are jump of fuel assemblies, reactivity change and buckling of reactor vessel. Since vertical isolation coverage can be limited to the area in which a reactor vessel and primary coolant system are installed, we have constructed a structural concept of vertical component isolation system called “common deck isolation system” [1].

When the isolation system is adopted in individual component separately, the relative displacement will be dynamically taken in the primary coolant system piping, because each response characteristic is different. In order to avoid this problem, a reactor vessel and major primary components are suspended from a large slab structure called “common deck”, and vertical isolation devices are installed between the deck and substructure. From next two features of this system, it seems to be advantageous from the three-dimensional base isolation system. Excessive rocking responses do not take place in native, because the offset between the center of gravity and the isolation support position of the support structure can be made small. Each isolation system becomes simple by separating the isolation direction. On the other hand, the component layout has to be changed a little with the common deck installation.

The required performance for the isolation device in applying to the FBR plant has been evaluated [2]. As the result, the appropriate isolation effect is obtained by making to be isolation frequency about 1.0Hz and damping ratio 20 to 40%. In this report, design technique of the vertical isolation device which realizes isolation frequency 1Hz is described. And, the plant layout planning in applying the vertical isolation system is examined. In addition, the earthquake response analysis of isolation system is carried out, and it is confirmed that the appropriate isolation effect is obtained.

2. VERTICAL ISOLATION DEVICE

2.1 Coned disk spring

It is necessary to select spring elements for the isolation device considering configuration, maintenance and environment, because they are installed near the primary coolant system. The followings are considered as functional requirements for the device. 1) The heavy weight of the installation structure should be supported, and simultaneously, a longer period in vertical direction should be attained. 2) It has high rigidity for degrees of freedom except for vertical direction. 3) Throughout the plant life, the function should be maintained. 4) And, assumed failure modes are not catastrophic. A coned disk spring with metallic material was chosen as vertical isolation device as it satisfies these requirements. The disk spring can be stacked in various configurations. By stacking the coned disk spring of the same shape in parallel, it is possible to obtain support load per one element. By piling up this set more and more in several series, large stroke can be achieved. The structure of the isolation system is composed of some isolation devices under the common deck, while the allocation of rigidity and weight is considered.

The coned disk spring for seismic isolator has following features. 1) The ratio of all deflection to plate thickness is set in about 1.3 in order to obtain large stroke. Therefore, the restoring force characteristics show nonlinearity. 2) The effect of the ground end cannot be disregarded. 3) The effect of the friction becomes remarkable, because large number of coned disk springs is stacked. Considering these features, a single coned disk is designed using the equation by Curti-Orland [3]. And, the equation of Niepage [4] which can appropriately consider the effect of the friction is also used in the design of the isolation device.

2.2 Design example of isolation device

"The three-dimensional isolation development project" set the input earthquake motion, named "Case Study S2 wave", for the isolation device development, and evaluated the required performance for the isolation device which could be applied to the FBR plant [2]. In this examination, the required performance has been evaluated from the viewpoint of prevention of jump of fuel assembly, prevention of reactivity change, prevention of the buckling of reactor vessel, and control of relative displacement. As a result of the examination, the development target of the vertical isolation frequency is around 1.0Hz, and damping ratio shall have 20 to 40%.

In order to examine applicability of the vertical isolation element with the target characteristics to fast reactor plants, a design of the isolation element was attempted under following conditions: isolation frequency of 1.0Hz, amplitude of response displacement of ±100mm (both sides stroke becomes 300mm including margin), supported structure weight of 2.7MN.

As material of the coned disk, ordinary high tensile spring steels Japanese Industrial Standard (JIS) SUP10, which is almost the same as SAE 6150 in USA, can be used. This material is generally used as a coned disk spring material and is easy to be obtained. Outside diameter of the coned disk was set to be 1m and thickness was set to be 27mm, considering current productivity from the viewpoint of machining and heat treatment.

According to the following procedures, the isolation element was designed. 1) Considering the plant configuration, number of isolator and support load per one isolator are decided. 2) Referring to existing standards for the coned disk spring [5-6], the other geometries, such as inside diameter and disk free height, are determined. 3) Using the equation of Curti-Orland, relation between load and deflection of the coned disk spring is calculated. The stress restriction is confirmed here. 4) The load in the position of a half deflection is read, and number of disks in parallel is decided from the support load per one isolator. 5) From the difference in a half deflection and effective deflection, the number of disks in series which satisfies the maximum stroke is determined. 6) Using the equation of Niepage, the restoring force characteristics of whole seismic isolator are calculated. The friction coefficient gave the experimental value [7]. From secant stiffness in the equilibrium position, it is confirmed that the equivalent natural frequency of the system is around 1Hz.

A design example of the structure of the isolation device is shown in Fig.3. By stacking 5 disks in parallel and 14 sets in series, the isolation device is made up 70 disks in total. The unloaded height of a stack becomes about 2,2m. Support load per one unit is 2.7MN. The guide of the double cylindrical structure is installed in the stacks. The sliding mechanism of vertical direction using many steel balls is established between cylinders. It also supports the horizontal seismic load taken in the deck. The details of the sliding mechanism will be examined in future.

2.3 Design example of damper

Requirements of a damper suitable for the vertical component isolation system are that it is small, simple, and cheep while the stability is good. If the damper can be combined with the isolation device, it becomes easy to be placed in the plant. A steel beam damper with the hysteretic behavior has satisfied these requirements. In order to increase the low cycle fatigue strength, a tapering beam damper (Fig.4) was designed. The restoring force characteristics of the damper are shown in Fig.5. It is possible to produce the necessary damping force, when the device was combined with 3 dampers per one unit. The characteristics could be replaced in the Ramberg-Oswood model.

The earthquake response analysis was carried out in order to confirm the effect of the isolation device with dampers. The response analysis of FBR building (Fig.7) for input seismic wave (Fig.6) was carried out, and response acceleration in the isolation device installation position was obtained. Next, the response acceleration at the common deck was calculated by using a single-degree-of-freedom model. Fig.8 shows results of the analysis. Since it together satisfies 100mm tolerance of the response displacement and 1G tolerance around 10Hz in the floor response spectrum, it can be judged that this combination has the appropriate isolation effect.

3. PLANT LAYOUT

3.1 Common deck

The common deck is mounted on reactor vessel and primary system components, and it becomes large steel- concrete structure supported by the vertical isolation devices. It is designed in following policies. 1) Considering quantity of out-of-plane deformation by dead weight and earthquake response, the rigidity of the deck is designed. 2) It is made to be the structure in which maintenance of isolation device and damping device is possible. 3) For the entrance to the common deck upper part, it has the radiation shielding performance. 4) The deck has heat shielding performance necessary for the protection of the electricity equipment. In order to suppress temperature rise and thermal deformation of the deck, heat insulating material is installed in the deck underside and cooling unit is established in the concrete.

3.2 Plant layout

The applicability of the common deck isolation system to a 1,500MWe sodium cooled loop type FBR plant [8] was examined. In this plant, the common deck supports reactor vessel and two integrated components which combined the intermediate heat exchanger with the pump. The deck becomes a rectangle of 35m×16m size. The thickness of the deck is made to be about 2m in order to ensure the necessary rigidity. Total installation weight is about 80MN, and it is supported in the isolation device in 28 units. Considering weight distribution and rigidity allocation, the isolation device was mainly placed at circumference of reactor vessel and peripheral part of the deck (Fig.9). The layout planning example is shown in Fig.10. Since the elevation which supports reactor vessel and integrated component is different, the component is supported by the steel cylinder hung from the deck.

In case of this layout planning, it is necessary to reinforce ceiling slabs of a reactor vessel upper room, because vertical walls on the common deck is not installed. From the viewpoint of the protection of radiation, additional shields are installed in the circumference of primary piping and equipments on the common deck. By controlling the relative displacement at 100mm or less, the secondary system piping can be designed as well as the non-isolation plant. From them, the common deck system judges that it can be applied to the FBR plant. However, the area of the reactor building increases at about 10%, and amount of material increases by the reinforcement of slabs and the addition of shields.

3.3 Seismic response analysis

The eigenvalue analysis for the common deck and installation components was carried out. The common deck was modeled in the shell element. Reactor vessel and components were modeled in the rigid beam, and it gave the lumped mass to the center of gravity position. In this analysis, equivalent linear stiffness of the coned disk spring and the damping elements in the equilibrium position was given. The first four modes are shown in Fig.11. The first mode is the rocking of the long side direction, and the secondary mode is the rocking of the short side direction, and the third mode is a response of the vertical direction. Participation factor of the rocking mode is several percent of that of vertical response. The mode in which the deck causes out-of-plane deformation appears after the fourth mode. Participation factors of these modes are small.

In order to know the rocking response, the earthquake response analysis was carried out by modeling the common deck in the beam element (Fig.12). In this analysis, the nonlinear restoring force characteristics of coned disk spring and damper were given. Fig.13 shows the rocking displacement. Difference between both decks edges is about 4mm, and the gradient of the deck becomes about 0.01 degrees. It can be confirmed that the effect of the rocking is small in case of this structure.

4. CONCLUSION

The concept of vertical component isolation system applied to the FBR plant was constructed. Technical realization prospect of this structure was obtained. In the future, the research is advanced for following problem solutions. 1) The applicability of the design equation of coned disk spring of the full scale is examined [7]. 2) The long term stability of the isolation device is examined from the viewpoint of friction coefficient, fatigue strength, low temperature creep characteristics. 3) The damping system is tested, and the restoring force characteristics are confirmed. 4) The structure which supports the horizontal load is developed.

REFERENCE

1. Morishita M., “A conceptual study on vertical seismic isolation for fast reactor components”, Proc. of SMiRT-13, KB09, 1995
2. Kato A. et al, “A Development Program of Three-Dimensional Seismic Isolation for Advanced Reactor Systems in Japan”, SMiRT-17, K258, 2003
3. Curti G. and Orland M., “Ein neues Berechnungsverfahren fur Tellerfedern”, DRAHT 30-1, pp.17-22, 1979
4. Niepage P., “Uber den Einfluß der Reidung und kreiskegelformiger Last einleitungselement auf die Kennlinie von Einzeltellerfedrn und Tellerfederpaketen”, Konstruktion, pp.379-384, 1984
5. JIS B2706, “Coned disk spring”, (in Japanese), 2001
6. SAE HS 1582, “Manual on design and manufacture of coned disk springs and spring washers”, 1988
7. Kitamura S. et al, “Experimental study on coned disk springs for vertical seismic isolation system”, SMiRT-17, K143, 2003
8. Nibe N. et al, “Feasibility studies on commercialized fast breeder reactor (1) –sodium cooled fast breeder reactor-”, SMiRT-16, S1257, 2001

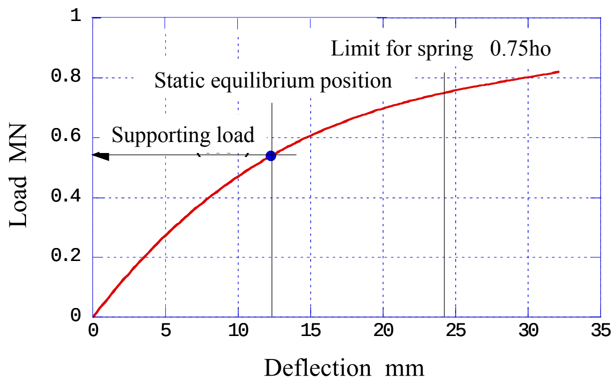


Fig.1 •Characteristics of single disk spring

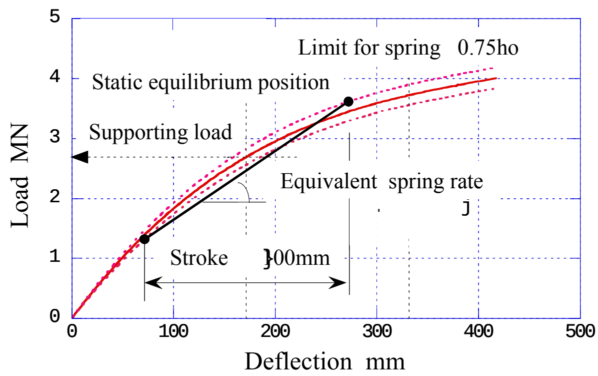


Fig.2 •Characteristics of vertical isolation

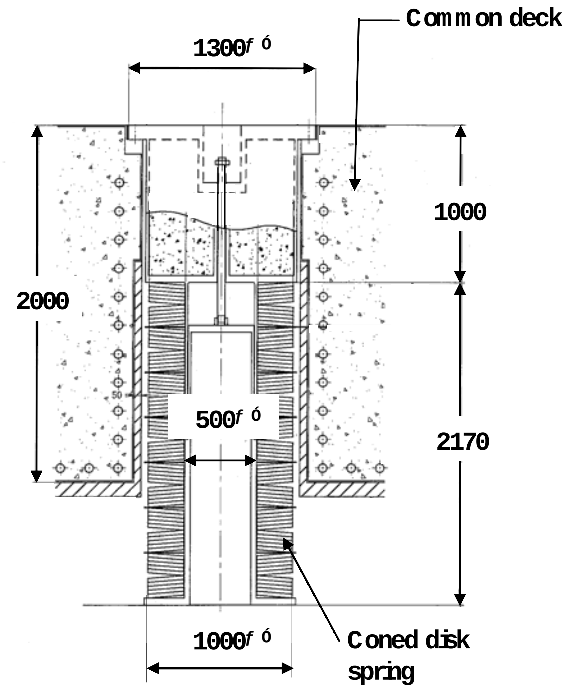


Fig.3 •Vertical isolation device

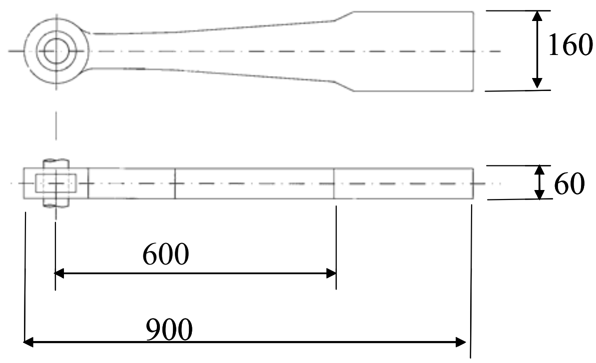


Fig.4 •Damping device

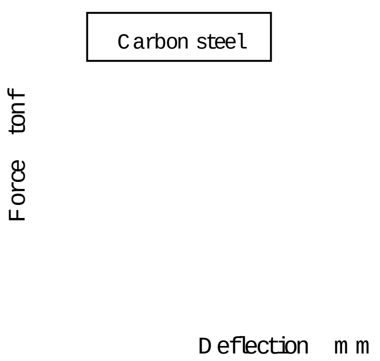


Fig.5 •Restoring force of damper

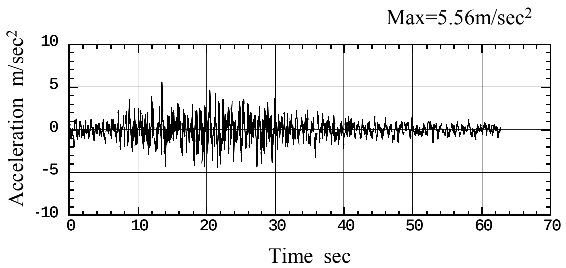


Fig.6 • Input earthquake motion

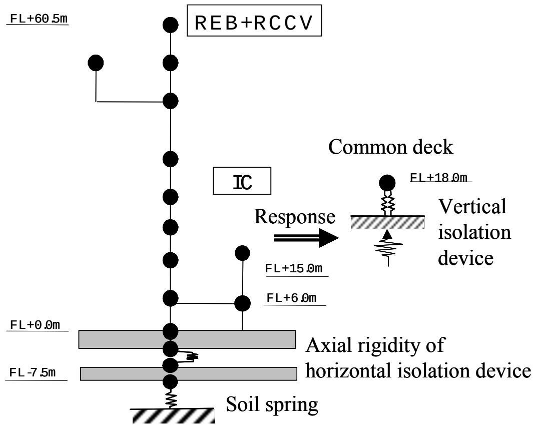
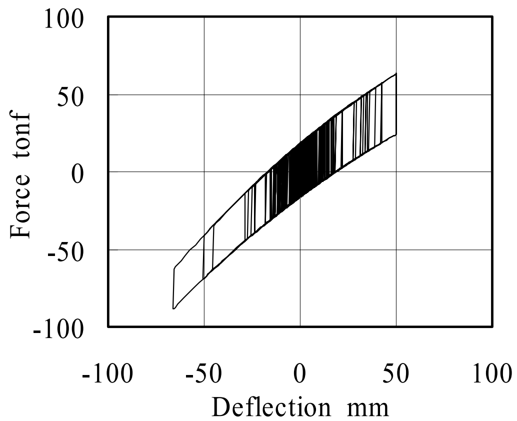
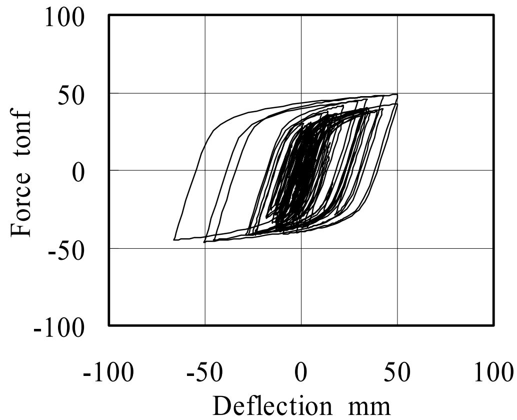


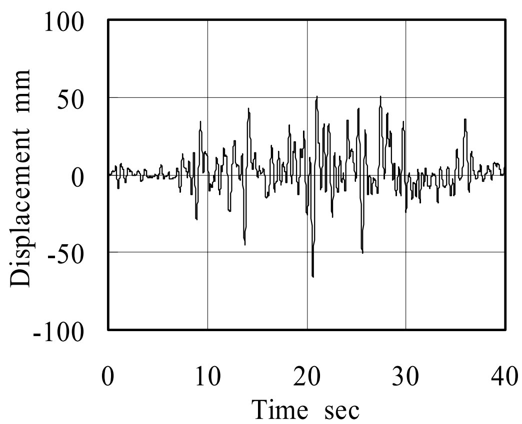
Fig.7 • Analysis model



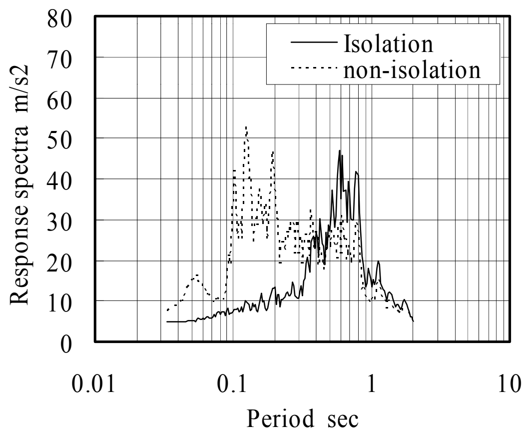
(a) Response of disk spring



(b) Response of damper



(c) Displacement



(d) Response spectra

Fig.8 • Results of response analysis

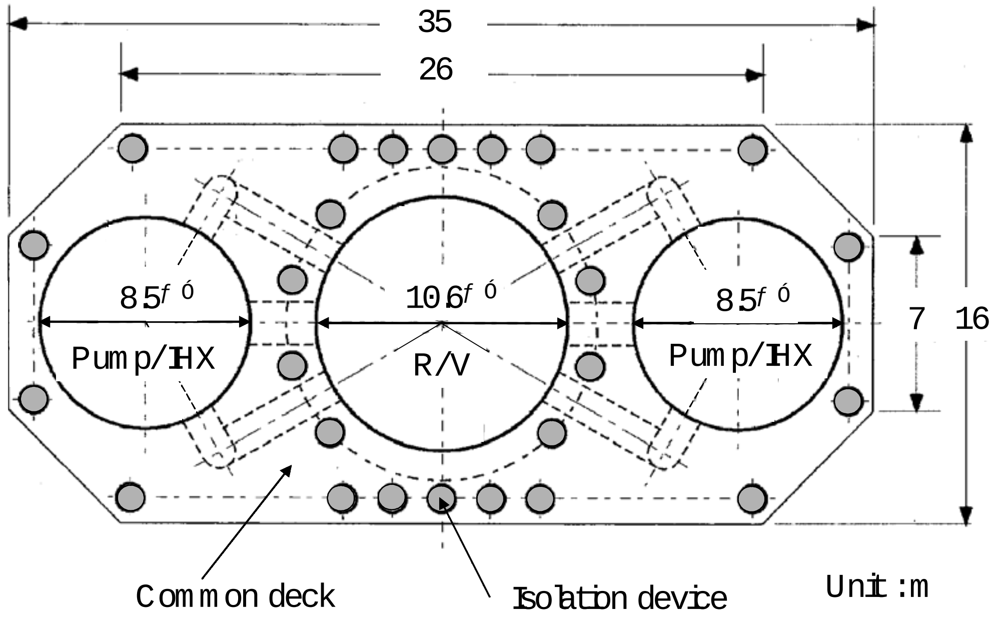


Fig.9 • Arrangement plan of isolation devices

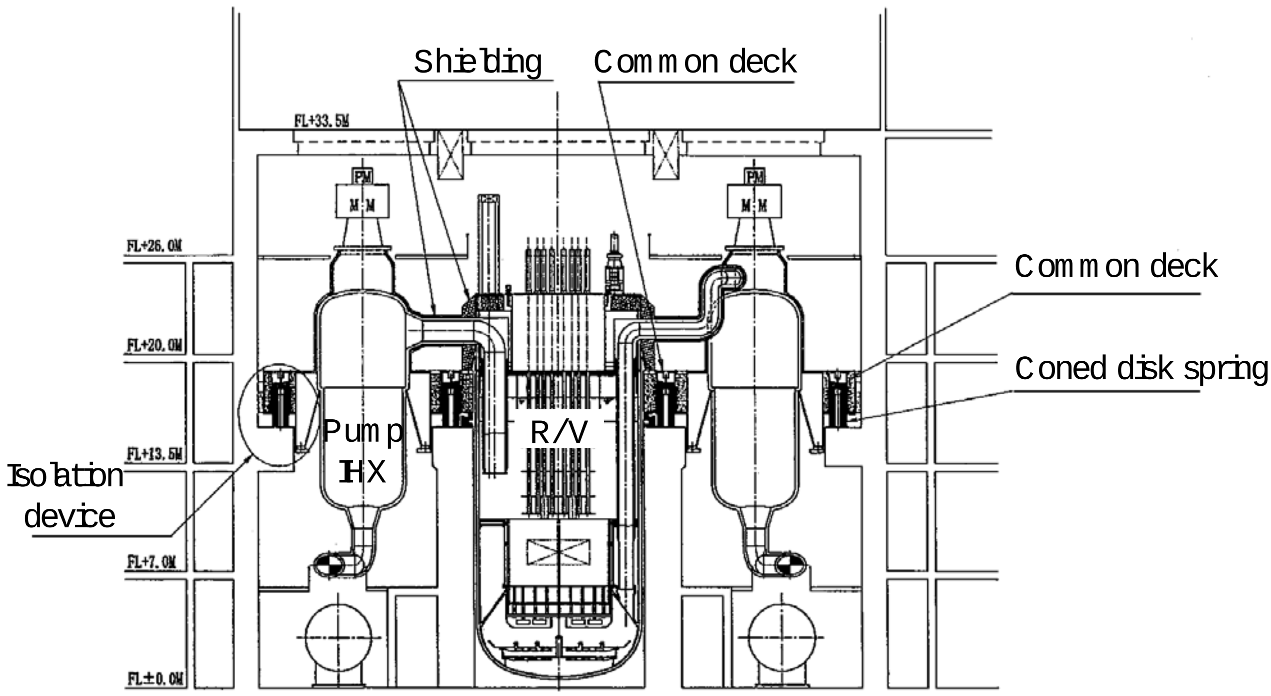


Fig.10 • Examination case of plant layout

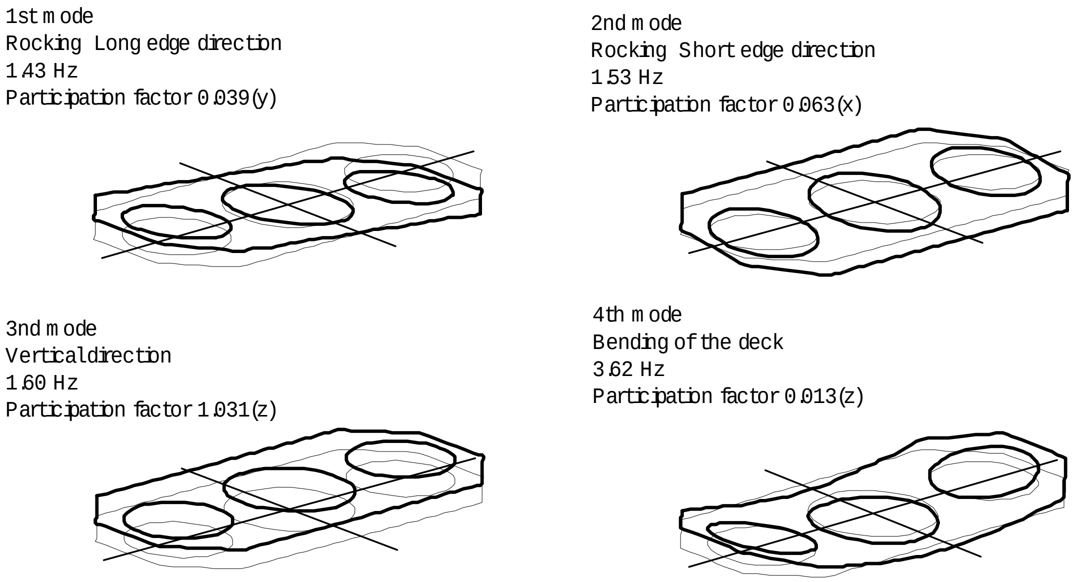
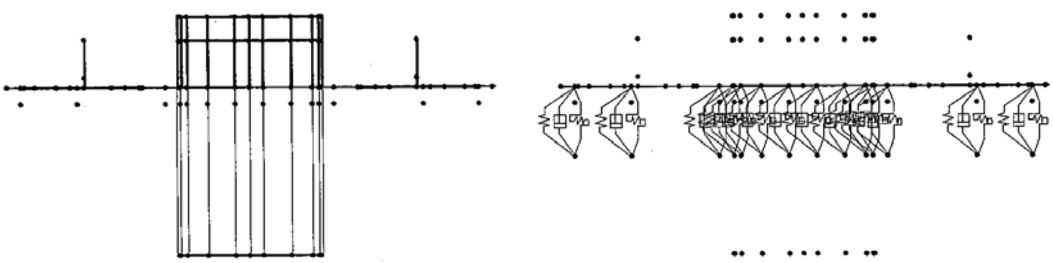


Fig.11 • Mode shape of common deck



(a) • Beam model (b) • Isolation device model

Fig.12 • Analysis model for rocking

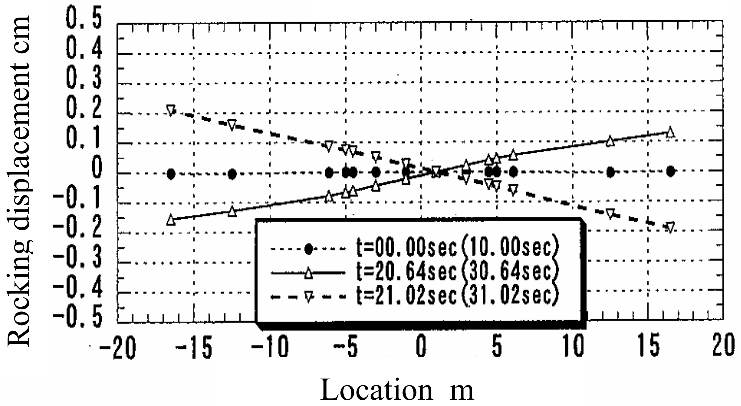


Fig.13 • Rocking response