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DEVELOPMENT OF THREE-DIMENSIONAL SEISMIC ISOLATION SYSTEMS FOR FAST REACTOR APPLICATION

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ABSTRACT: A project has been undertaken in Japan to develop three-dimensional (3D) seismic isolation systems for advanced fast reactors application, under the sponsorship of the Japanese government. Within this program, 3D base isolation systems with pneumatic and/or hydraulic devices are developed. A vertical isolation system with coned dish springs is also developed for reactor components with combined use of horizontal base isolation. This paper depicts a whole picture of the project and describes the current status of the development efforts.

Key Words: Three-dimensional seismic isolation, fast reactor, pneumatic spring, hydraulic system, coned dish spring

INTRODUCTION

A significantly increased benefit of mitigated earthquake loads can be expected by 3D seismic isolation, since the earthquake loads are inherently three-dimensional and their vertical components sometimes play a crucial role in the structural design of the reactor components. A true earthquake-load-free design can be achieved by the 3D seismic isolation. The 3D seismic isolation is especially effective for the fast reactors, where economic competitiveness is strongly required and the components are designed to be rather flexible to accommodate to relatively large thermal loads.

From these points of view, a research project has been undertaken to develop 3D seismic isolation systems for the next generation reactors application (Morishita, 2001). The program is sponsored by the Ministry of Economy, Trade and Industry of the Japanese government, with a purpose of providing support to the advanced reactor development efforts in Japan. Within this program, 3D base isolation systems with pneumatic and/or hydraulic devices are developed. A vertical isolation system with coned dish springs is also developed for reactor components in combined with horizontal base isolation of the nuclear island.

TARGET PERFORMANCE OF 3D ISOLATION SYSTEMS

At the starting stage of the program, it was necessary to define the target performance, especially the vertical isolation frequency and damping, of the 3D seismic isolation systems to be developed. For this purpose, a design ground motion was defined, and an extensive series of parametric dynamic analyses was made with respect to the vertical frequency and damping.

Design ground motion

The basic idea in defining the design ground motion was that it should be sufficiently large so that no further increase was required in the future. With this in mind, the horizontal ground motion spectrum used in a past design study of a base isolated fast reactor (Kato, 1995) was selected; see Fig. 1. This spectrum was created so that it enveloped all the S2 design ground motions of the Japanese light water reactors in the short period acceleration range and, the spectral velocity was extended up to 2.0 m/s in the period ranging from 0.62 s to 10.0 s, since the long period range was very important for the seismic isolation systems. The vertical ground motion spectrum was then defined in the present study applying a spectral ratio of 0.6 through the entire period, resulting in the maximum spectral velocity of 1.2 m/s, which is also shown in Fig. 1.

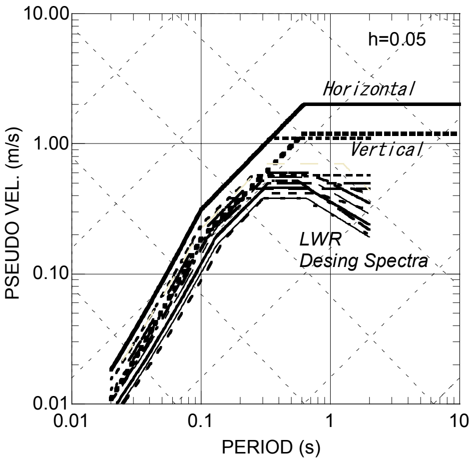


Fig. 1 Design ground motion

Isolation Frequency and Damping

In order to identify an appropriate range of vertical frequency and damping for 3D seismic isolation purposes, an extensive series of dynamic analysis of a 3D isolated structure was made. Here, the vertical frequency and damping were the analysis parameters and ranged from 0.5 Hz to 20 Hz and 2% to 60%, respectively, while the horizontal isolation frequency and damping were fixed to be 1.0/0.5 Hz (1st/2nd stiffness) and 20%, respectively. The procedure and results of the analysis are described in detail in the reference (Kato, 2003).

The target performance was then identified based on the response results and the criteria in view of component design aspect and structure design aspect. The component design aspect includes sufficient reduction of vertical acceleration while avoiding excessive relative displacements on piping. The structure design aspect includes suppression of vertical acceleration amplification, avoidance of uplift of isolation devices, and sufficient reduction of horizontal acceleration.

As a result, ranges of appropriate frequency and damping both for 3D base isolation and component vertical isolation systems were identified as shown by the shaded area in Table 1. Note that sufficiently low frequency and high damping are required especially in case of 3D seismic isolation.

Table 1 Identified target frequency and damping

(a) For 3D base isolation system

Frequency (Hz)	Damping (%)			
	2	10	20	40
20				
3.0				
1.5				
1.0				
0.67				
0.5				

(b) For Component vertical isolation

Frequency (Hz)	Damping (%)			
	2	10	20	40
20				
3.0				
1.5				
1.0				
0.67				
0.5				

DEVICES FOR 3D BASE ISOLATION

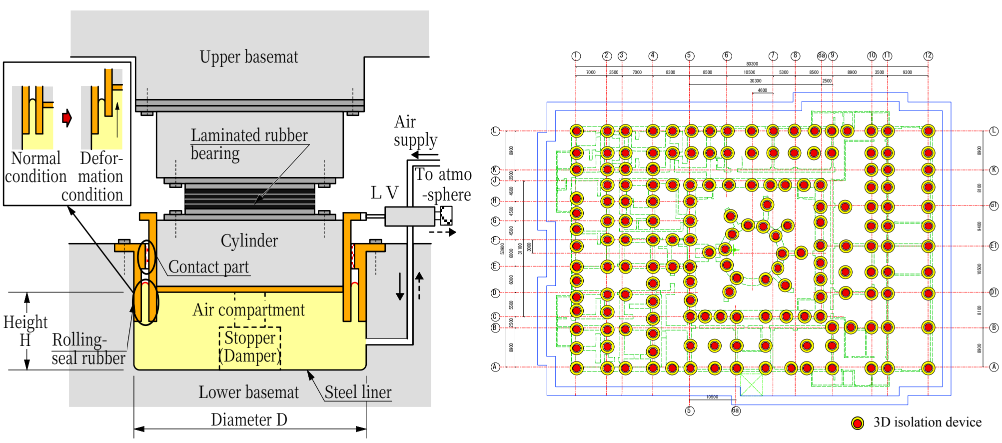
At the starting time of the program, a number of conceptual ideas for a 3D base isolation device were proposed. Selections were made on three steps, comparing advantages and disadvantages the candidates had. Finally it was decided to adopt a hybrid use of pneumatic and hydraulic systems that are described below.

Air spring with rolling seal

This concept uses a series connection of a laminated rubber bearing and an air spring with rolling seal type rubber (Suhara, 2003), as is shown in Fig. 2. A cylindrical cavity is prepared in the lower basemat of the nuclear island and used as an air compartment. A steel/concrete cylinder is inserted to the cavity with a rolling seal type rubber to form an air spring. The cylinder is then connected to the rubber bearing which is connected to the upper basemat. A large stroke in the vertical direction is enabled by using the rolling seal. As a supporting system, air supply system and leveling devices are provided.

The diameter and the height of the compartment are 1.4 m and 3 m, respectively. The design air pressure is 1.6 MPa for normal condition and 2.0 MPa for design earthquake condition, resulting in the design vertical frequency is 0.5 Hz and the loading capacity of 9800 kN.

Some experimental tests using small scale models of the device have been carried out to see whether the critical issues of this system can be resolved, and some successful results are being obtained, see also Suhara, 2003.

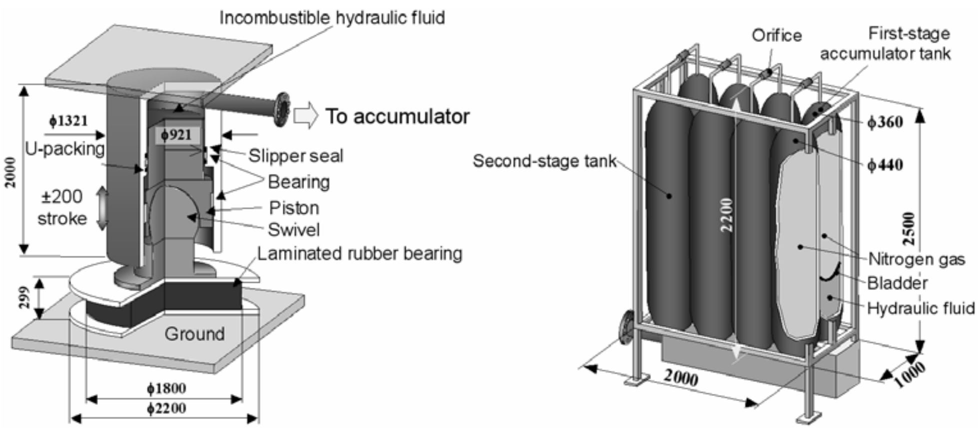


(a) Schematic drawing of 3D isolator (b) Layout plan of 3D isolators

Fig. 2 3D base isolation device with air spring and rubber bearing

Hydraulic system

In this system an isolator is consisted of a rubber bearing and a load carrying hydraulic cylinder which is connected to an accumulator unit (Kashiwazaki, 2003), as shown in Fig. 3. The units are laid out in a similar way as shown in Fig. 2.(b).



(a) Schematic drawing of 3D isolator (b) Accumulator unit

Fig. 3 3D base isolation device with hydraulic system and rubber bearing

In an event of seismic excitation, the vertical seismic force is converted by the load-carrying cylinders into pressure fluctuations of the hydraulic fluid, each cylinder being connected through piping to the first-stage tank of the accumulator unit. In this tank, the hydraulic fluid space is bounded by a flexible bladder containing nitrogen gas, to which the fluctuating pressure is transmitted. The vertical restoring force is generated by the bulk modulus of the gas contained in this first stage tank and in the second stage tank of constant volume. An orifice installed in the pipe connecting the first to the second stage tanks generates required vertical damping force.

The load carrying capacity of a unit is designed to be 9800 kN with fluid pressure being 15 MPa for normal condition and 20 MPa for design earthquake condition. The height and the outer diameter of the cylinder are 2 m and 1.3 m, respectively. For safety purposes, noninflammable hydraulic fluid is used.

Some experimental tests using small scale models of the device have been carried out to see whether the critical issues can be resolved, and some successful results are being obtained, see also Kashiwazaki, 2003.

Rocking suppression device

When a structure is 3D isolated, rocking motions are inevitably excited by horizontal inputs. Excessive rocking motions are undesired and should be suppressed, since they amplify the vertical displacements of the isolators that are placed on the periphery of the structure. In fact, the vertical displacements are in some cases doubled from the pure vertical translation motion.

As a promising solution to this problem, “rocking-suppression cylinder” is proposed in conjunction with the hydraulic system (Kashiwazaki, 2003), which is schematically illustrated in Fig. 4. The load carrying cylinders placed on the periphery of the structure are inter-connected by the rocking suppression cylinders. The rocking suppression cylinder has two hydraulic chambers and ports, one of which is connected to four load-carrying cylinders, and the other to one of the four accumulator units. Thus, out-of phase motion of the load carrying cylinders at the both sides of the structure is suppressed, while in-phase motion is freely allowed.

Basic functions of this rocking suppression system have been confirmed by a small scale vibration test.

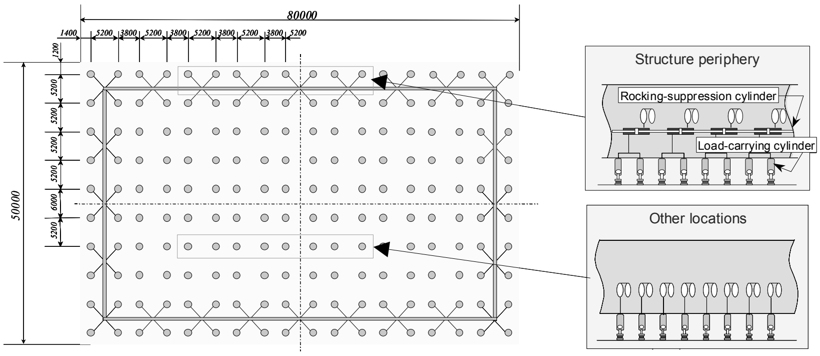
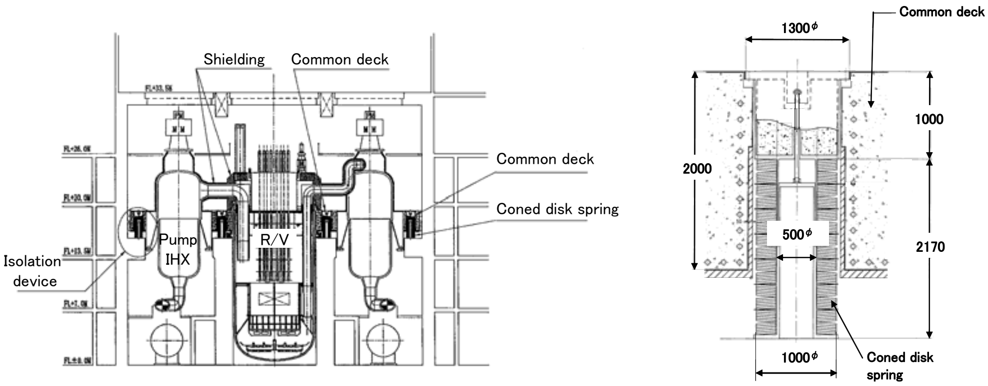


Fig. 4 Rocking suppression system

VERTICAL ISOLATION SYSTEM FOR COMPONENTS

In parallel with the 3D base isolation development effort, a concept of vertical isolation system for components, which we call "common deck isolation system", is also pursued (Morishita, 2003). Here, the idea is that the reactor vessel and the major primary components are suspended from a flat slab structure (common deck) inside the reactor containment. This common deck is then supported by a couple of vertical isolation devices installed around each component (Fig. 5(a)). Horizontal base isolation of the nuclear island is assumed.



(a) View of vertical isolation system (b) vertical isolator with coned dish springs

Fig. 5 Common deck isolation system

The vertical isolation device adopted is a set of large bore coned dish springs; see Fig. 5(b). They are piled up in parallel and/or in series to obtain required stiffness and stroke. In the present study, the vertical isolation frequency is designed to be 1.0 Hz, which is a bit higher than that of the 3D base isolation. This is due to a rather strict displacement limit of the secondary coolant piping systems.
The dimensions of a unit dish springs are: 1.0 m and 0.5 m in outer/inner diameters, and 27 mm in thickness. Seventy dishes (five in parallel and then 14 in series) are used to compose one unit isolator, with a stroke of ±100 mm and load capacity of 2.7 MN, to achieve 1.0 Hz. The total height of a unit is about 2.2 m. Twenty-eight units are used to support the common deck and the primary components. Necessary damping is provided by steel hysteretic dampers.

A key feature of this system is that the rocking motion is inherently not a concern, because it is possible to adjust the system so that the height of the center of gravity and the supporting level to be identical.

Some experimental tests on the mechanical and dynamic characteristics of the isolator are carried out.

CONCLUSIONS

A large-scale R&D project on 3D seismic isolation systems is underway for next generation nuclear reactor application. It is expected by 3D isolation application, a significantly enhanced safety and economy is achieved in the design of these plants.

In the project, a very large design ground motion is assumed and sufficiently low isolation frequency in the vertical direction, such as 2 s, is pursued to attain sufficient isolation benefit.

As for the 3D base isolation, combined use of a rolling seal type air spring and a hydraulic system was finally selected and developed. A rocking suppression device with hydraulic system is also proposed.

A concept of vertical component isolation in combination with horizontal base isolation is also pursued and developed. Here, coned dish springs are used as the isolator.

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