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Methodology of Exchange and Maintenance of Isolation Devices for a Seismically Isolated Nuclear Power Plant

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ABSTRACT

The application of a base isolation to nuclear systems have been limited due to some important reasons. Those includes the deprivation of sufficient data for the long-term operation of such isolation devices, and the lack of specific standards.

The methodology suggested in this paper provides an isolator in which an isolated structure part is easily replaced and confined pressure can be easily controlled with a height-adjustable part. The height-adjustable part being adjusted by suppling or discharging fluid therein or therefrom. The design consideration of the height-adjustable part is introduced in this paper.

INTRODUCTION

Given the high risks to public safety that may arise from earthquakes, main facilities like nuclear power structures are expected to have a seismic isolation system with better safety performance compared to general structures.

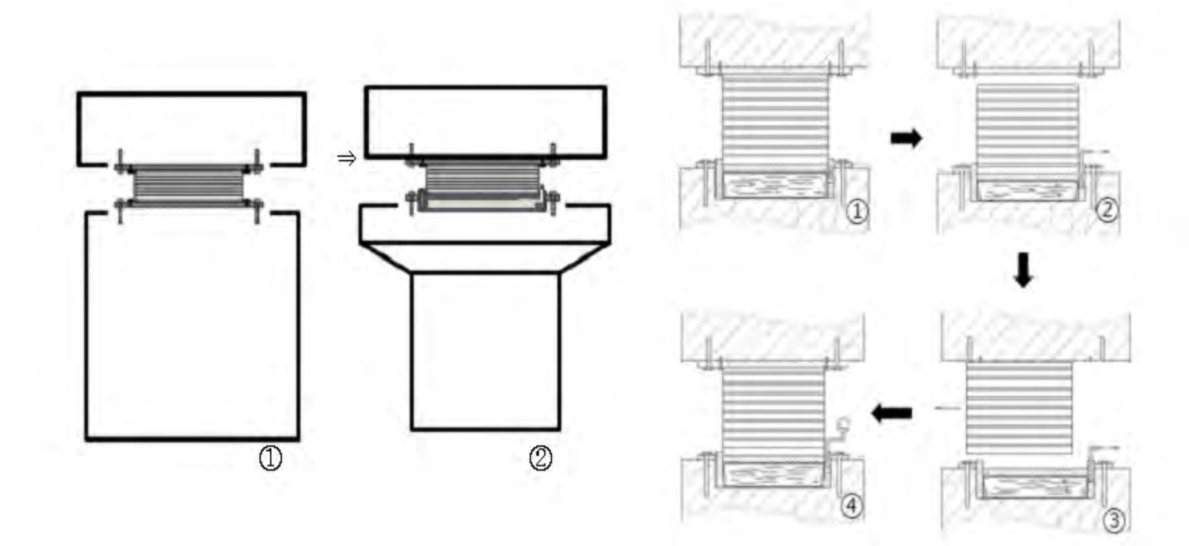
In consideration of the 60-year design life and decommissioning period, recent nuclear power structures must maintain structural soundness for at least 80 years. While changes in the dynamic characteristics caused by aging of isolation devices should be reflected in the design phase, there is no evidence showing how soundness can be maintained for 80 years. Against this backdrop, regulatory organizations of France have requested a replacement of isolation devices in seismically isolated nuclear power plants that have been recently built for research.

The properties and behavior of isolation devices are significantly influenced by pressure, which continuously changes depending on creep and other long-term behavior of the upper structure. As such, this paper presents a method that facilitates maintenance through replacement of the isolation device and pressure measurements. We also examined the effects of the new method on the buckling load of multi-layered natural rubber bearing (NRB).

DESIGN METHODOLOGY FOR REPLACEMENT AND MAINTENANCE OF ISOLATION DEVICES

The isolation device in the left of Fig. 1(a) is placed directly above the lower R.C. structure, while that on the right is above the fluid-containing height adjusting section. As shown in Fig. 1(b), this height adjusting section facilitates replacement of the isolation device and allows constant measurements of pressure. A step-by-step procedure is described below.

(1) During ordinary times, the upper adjustable section supports the isolation device and upper structure.
(2) When experienced by an earthquake, the fluid in the upper adjustable section is removed to carry out replacement or inspection.
(3) When the height is sufficiently low, the isolation device is removed. A new isolation device is inserted after inspecting the surrounding areas. (while other devices support the upper structure)
(4) The height is re-adjusted, and pressure measurements are taken based on monitoring.



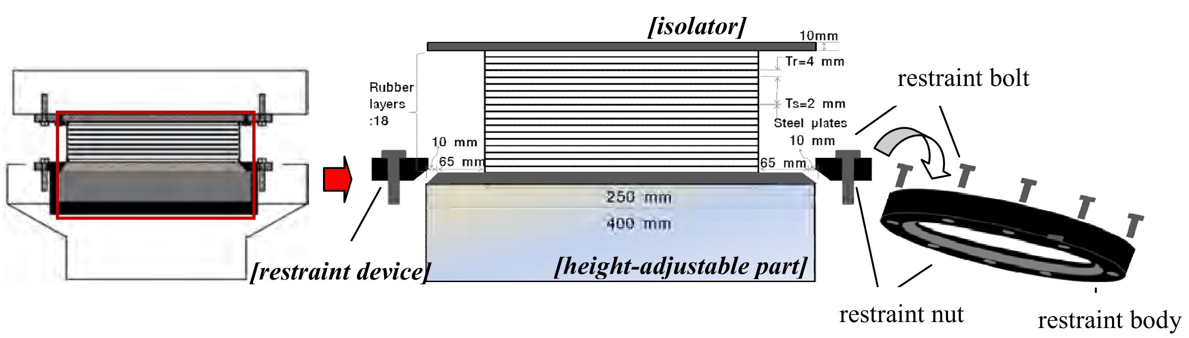
(a) Before and after inserting the height adjusting section (b) Isolation device replacement and pressure measurement

Fig. 1 Methodology and procedure of replacing the isolation device

DESIGN CONSIDERATION OF THE HEIGHT-ADJUSTABLE PART

Two main design consideration of the height-adjustable part :

• Stability of the height-adjustable part with restraint devices
• Effects of flexibility of bearing plates in isolation devices on the buckling load



(a) Isolator, height-adjustable part and restraint device (b) restraint assembly

Fig. 2 Isolator height-adjustable part and restraint device

For purposes of a verification test example, the following quantities were set up as shown in Fig. 2 and demonstrated in Table 1.

Table 1: Quantities for a verification test example

		value	unit
Load of upper structure (W)		25	ton
Isolator	Diameter (D_i)	250	mm
	No. of rubber layer	18	EA
	Sectional Area (A_i)	49087	mm2
	Total rubber thickness(T_i)	72	mm
	First shape factor (S_1)	15	-
	Secondary shape factor (S_2)	3.47	-
Plate	Plate thickness [top & bot.] (t_p)	10	mm
	Bottom plate edge slop	45	o
	Diameter (D_p)	400	mm
	Elastic Modulus	$0.21*10^6$	MPa
Restraint devices	Inner top diameter (D_{trt})	380	mm
	Inner bot. diameter (D_{rbi})	400	mm
	Outer diameter (D_{ro})	460	mm

Stability of the height-adjustable part with restraint devices

As shown in Fig. 3(a), the bottom plate of an isolator is under compressive pressure (2~3 Mpa) almost uniformly all over the section during ordinary times. When experienced by an earthquake, sectional stress distribution of the bottom plates varies due to the moment caused by relative horizontal displacement between top and bottom plates of the isolator as shown in Fig. 3(b).

The restraint assembly, which shaped donut ring as shown in Fig 2(b), prevent the bottom plate of the isolator from uplift which might caused by tensile stress due to moment.

The stability of the height-adjustable part of an example with the quantities demonstrated in Table. 1 were checked as the following procedures.

(1) Main assumption : the height-adjustable part containing fluid is supposed to be stable, if the uplift of the bottom plates of the isolator is prevented.

(2) Calculation of stress distribution of the bottom plate :

- During ordinary time (no shear displacement)

$$\sigma = \sigma(compression) = \frac{4W}{\pi D_p^{\ 2}} = \frac{-4 * 25ton}{\pi * (400mm)^2} = -1.95Mpa$$

- When shear displacement = 144mm (γ=200%), at edges of Fig.3 (b)

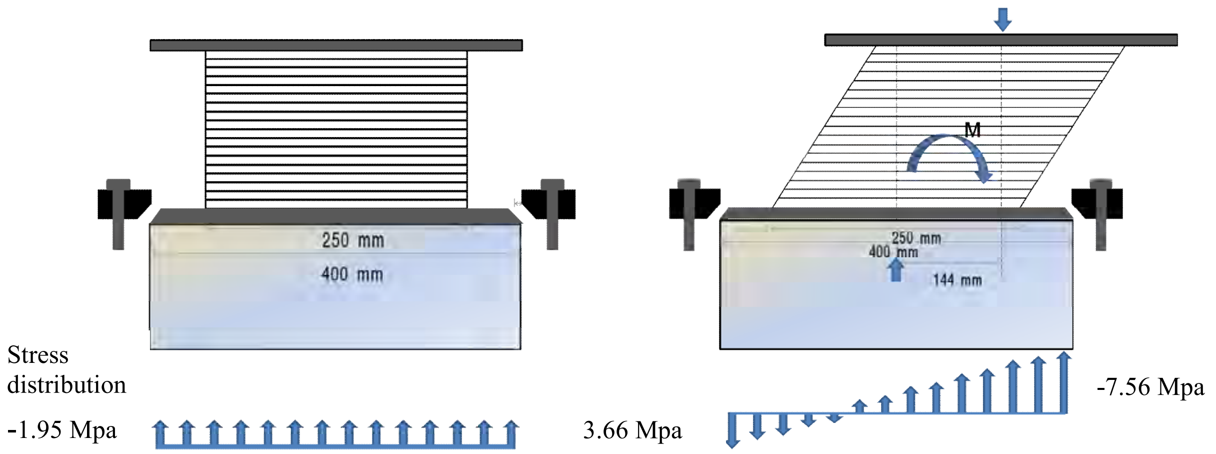
$$\sigma = \sigma(compression) + \sigma(moment)$$

$$\sigma(moment) = \frac{32W * 144mm}{\pi D_p^{\ 3}} = \pm 5.615(Mpa)$$

The stress distributions of the plate for each case are demonstrated in Fig. 3.

(3) Minimum thickness of the plates, required quantities of restraint assembly (including dimensions and material properties of the restraint assembly, number of bolts and nuts, etc.):

The demonstration of detailed procedure of the design is skipped in this paper. But lots of various designs were found to be possible and applicable for restraint roles to secure stability of the height-adjustable part.



(a) during ordinary time (no shear displ.) (b) when shear displacement : 144mm [γ= 200%]

Fig. 3 Stress distributions of bottom plate shear

Effects of flexibility of bearing plates in isolation devices on the buckling load

When a steel bearing plate connects the lower R.C. structure to the isolation device as shown in ① of Fig. 1(a), there is no need to consider the warping of isolation devices. However, if a fluid-containing adjustable section is inserted between the bearing plate and lower R.C. structure as given in ② of Fig. 1(a), the effects of bearing plate flexibility on the rubber and steel shim plate must be assessed. In other words, the warping of isolation devices has to be taken into account. Kelly et al. proposed the following equations for the flexibility of bearing plates in isolation devices based on the continuum theory.

$$EI = \frac{8Gh^5}{15t^2} \qquad (1)$$

$$EJ = \frac{2Gh^3}{1225t^2} \qquad (2)$$

Here, 2h is the width of an infinite strip, and t is the thickness of a single rubber layer. EI represents the bending stiffness of the isolation device, EJ the warping stiffness, and G the shear modulus of rubber.

The normalized buckling load (p) that can be resisted by the isolation device is given by Eq. 3. Here, P is the normal load, G is the shear modulus, and A is the section area.

$$p = \frac{P}{GA} \qquad (3)$$

Assuming that the isolation device is a column, the normalized column property (λ) is derived from Eq. 4. Here, 2l is the height of the isolation device including the bearing plate.

$$\lambda = \frac{\pi h}{2l} \qquad (4)$$

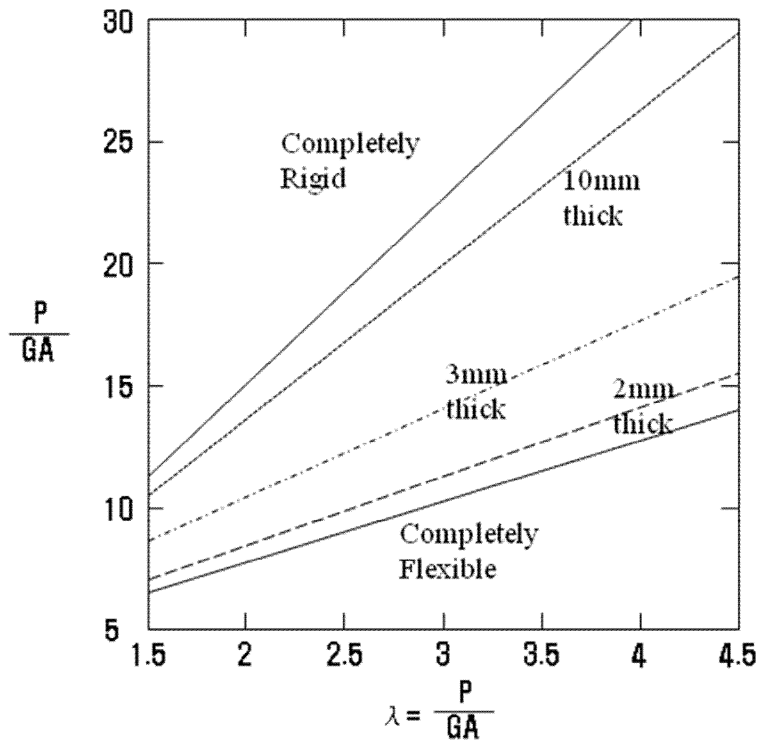


Fig. 4 Change in buckling load according to height of the isolation device and bearing plate flexibility

Fig. 4 was drawn based on the quantities for a verification test example from Table. 1.

The buckling load of the isolation device, as can be seen from Fig. 4, is almost doubled depending on whether the bearing plate is completely rigid or flexible. While it is evident that buckling load is significantly affected by bearing plate flexibility, the fact that quantitative results can be derived should be reflected in the design phase if we assume the bearing plate to be flexible.

CONCLUSIONS

In this paper, we presented a method that facilitates replacing the isolation device and taking pressure measurements by making use of the fluid-containing adjustable section. This method is useful as long-term aging characteristics of isolation devices are difficult to predict, and allows a more flexible response to earthquakes. Based on the continuum theory, we examined the effects on buckling load from the insertion of a fluid-containing adjustable section. The changes in flexibility of the lower structure lowered the resistance of the isolation device towards buckling up to 50%. Since the design of structures is not necessarily affected by a reduction in buckling resistance, more analysis is required on the compressible stiffness and restoring characteristics of isolation devices, as well as the economic effects of bearing plate thickness.

ACKNOWLEDGEMENTS

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