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Research on 3-D Base Isolation System Applied to New Power Reactor 3-D Seismic Isolation Device with Rolling Seal Type Air Spring : Part 1

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ABSTRACT

Three dimensional (3D) seismic isolation device has been developed to use for the base isolation system of the heavy building like a nuclear reactor building. The developed device is the 3D seismic isolation device that consists of the laminated rubber bearing as a horizontal isolation device and the rolling seal type air spring as the vertical isolation device in series.

In this research, the 3D seismic isolation device reduction model whose scale is 1/10 is made and the workability of the device by the horizontal and vertical dynamic load is examined. Two experiment parameters are considered. One is the case that the structure of the part that the horizontal load and the vertical load contact is pin condition and the other is the case of the roller condition. As a result of the examination, the workability of the vertical direction is confirmed when the horizontal load acts.

The pressure resistant ability test for the air spring is performed by the monotonic pressurization. As the result, it is confirmed that pressure resistant ability improved by restricting the side deformation of the air spring and that the material of the existing air spring can withstand high pressure use sufficiently.

As the result, it is confirmed that the developed 3D seismic isolation device is applicable to the actual plant.

KEY WORDS: seismic isolation, 3-dimensional, air spring, rolling seal, rubber bearing, FBR.

INTRODUCTION

The 3D seismic isolation device has been developed to use for the base isolation system of the heavy building like a nuclear reactor building. The 3D seismic isolation device consists of the laminated rubber bearing as a horizontal isolation device and the rolling seal type air spring as the vertical isolation device in series.

As the laminated rubber bearing and air spring are practically and widely used in ordinary buildings and industrial structures, reliability of these devices is demonstrated.

Each device has no problem in using separately, but in case of connecting two devices in series, there are two problems. One is workability of the vertical direction when the horizontal load acts. The other is high supporting ability for the economical efficiency and simplicity of arrangement.

In this study, feasibility test is carried out to verify the applicability of the proposed 3D isolation device to the actual structure.

ACTUAL 3D SEISMIC ISOLATION DEVICE

Outline of proposed 3D seismic isolation device is shown in Fig. 1 and dynamic properties and specifications of device are shown in Table 1. The dynamic properties are determined by considering the results of horizontal and vertical earthquake response analysis [1].

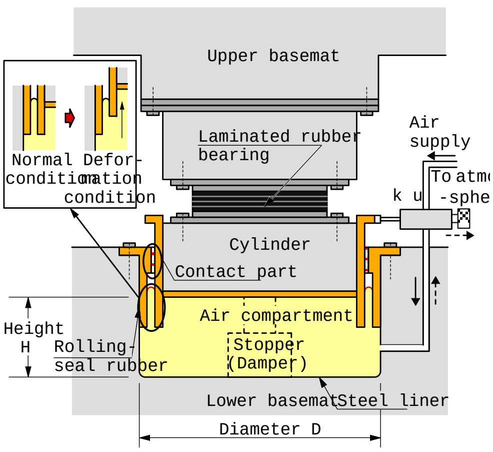


Fig. 1 3Dimensional isolation device

Table 1 Outline of 3D Device

Dynamic Properties	Horizontal Initial Period	1.0 s
	Horizontal Isolation Period	2.8 s
	Horizontal Yield Coefficient	0.1
	Vertical Isolation Period	2.0 s
	Vertical Damping Factor	0.2
Specifications	Supporting Load	9800 kN
	Diameter of RB (m)	1.6 m
	Total rubber thickness of RB	0.225 m
	Diameter of Air Compartment	3.0 m
	Height of Air Compartment	1.4 m
	Pressure of Air Compartment	1.6 MPa

The device realizes the 3D isolation property by the laminated rubber bearing as the horizontal isolation system and the air spring as the vertical isolation system independently. The specifications of laminated rubber bearing are decided by the past horizontal isolation study on FBR plant [2].

The air compartment is set up in lower basemat. The vertical working part consists of the rolling seal type air spring that can work in large deformation. The surrounding air spring system consists of air supply, air tanks and leveling devices that keep the height of structure constant automatically.

The product of the pressure by the effective contact area decides the supporting capacity of the air spring. The maximum static pressure of ordinary air springs is about 0.9MPa. The pressure of the proposed device is supposed about 1.6MPa at normal condition and about 2.0MPa at earthquake. So the supporting Load of a device is 9800 kN, the arrangement of the devices is expected to become simple. The example of the arrangement to the FBR plant is shown in Fig. 2.

It is necessary for the contact part that transmit the horizontal force to have almost no friction because of smooth move in vertical direction.

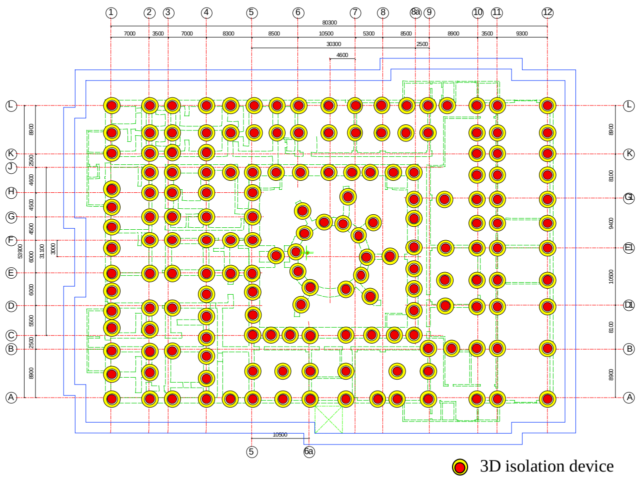


Fig. 2 Arrangement of device

FEASIBILITY TEST

1) Objectives of test

The objectives of this test are shown below.

a) Confirmation of workability of vertical direction under horizontal load

b) Grasp of ultimate pressure of ordinary air spring

2) Similarity Law

The scale ratio of the model to a prototype is 1/10 and both acceleration and stress are equal to those of a prototype. The similarity law is shown in Table 2.

Table 2 Similarity Law

Parameter	Similitude	$\lambda = 10$
Length	$1/\lambda$	1/10
Velocity	$1/\sqrt{\lambda}$	1/3.16
Acceleration	1	1
Time	$1/\sqrt{\lambda}$	1/3.16
Mass	$1/\lambda^2$	1/100
Stress	1	1

3) Test Model

The pressure of test model is lower than the specification of the actual device because the existing air spring is used in test model. The dimension of the test model is calculated by the modified prototype whose pressure of the air compartment is 0.8MPa. The dimension of the test model is shown in Table 3 comparing with the prototype. The outline of test model is shown in Fig. 3.

The air spring part of the test model is made of existing sleeve type air spring. The rolling seal type is realized by constraining the side bellow of the sleeve type air spring.

The laminated rubber bearing is manufactured of the natural rubber according as the dimension of Table 3.

Two kinds of mechanism are considered in the contact part of the horizontal load and vertical load. One is a pin condition that represents free rotation. The other is the roller condition that represents constrained rotation

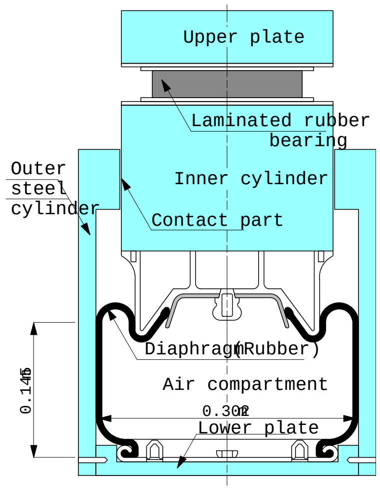


Fig. 3 3D isolation device for experiment (scale : 1/10)

Table 3 Dimension of Modified Prototype and Test Model

Parameter	Prototype	Model
Support Load (kN)	4900	49
Horizontal Isolation Period (s)	2.8	0.886
Vertical Isolation Period (s)	2.0	0.633
Pressure of Air Compartment (MPa)	0.8	0.8
Diameter of Air Compartment (m)	3.02	0.302
Height of Air Compartment (m)	1.45	0.145
Diameter of RB (m)	1.6	0.16
Total rubber thickness of RB (m)	0.45	0.045

4) Test Case

Test cases are shown in Fig. 4.

a) Case 1: Ultimate static test

To grasp the ultimate pressure value and failure mode of existing air spring, the monotonic pressurization test are performed under constant height of air spring. In this test, water is used instead of air.

The dynamic vertical tests are performed for reference to grasp the vertical dynamic property of this test model.

Outline of this test is shown in Photo 1.

b) Case 2: Dynamic vertical test

The dynamic vertical tests under sinusoidal wave force are performed to grasp the vertical dynamic properties and to grasp the effect of contact conditions, that is effect to the vertical properties by the difference of pin and roller condition.

c) Case 3: Dynamic vertical test with constant horizontal force

The vertical dynamic tests with constant horizontal force are performed to grasp the vertical dynamic properties and to grasp the effect of contact conditions.

d) Case 4: Dynamic vertical and horizontal test

The dynamic tests acting the vertical and horizontal force simultaneously are performed to grasp the vertical dynamic properties and to grasp the effect of contact conditions.

Outline of test 2-4 is shown in Photo 2.

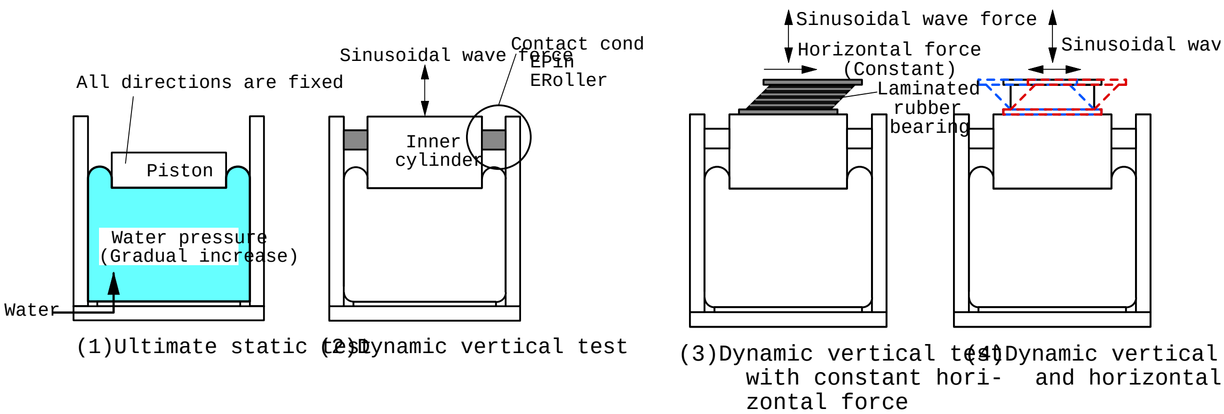


Fig. 4 Test case

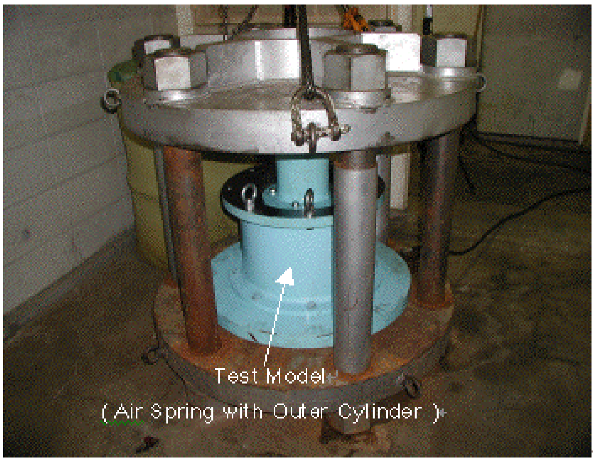


Photo 1 View of Test Case 1

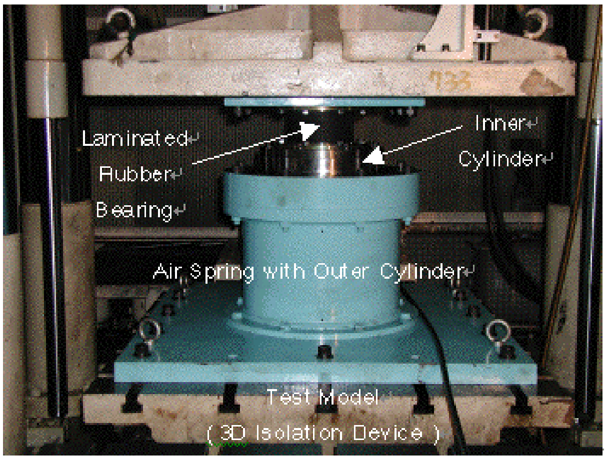


Photo 2 View of Test Case 2-4

5) Test Results

a) Case 1: Ultimate static test

As the results of ultimate pressurization test, the maximum pressure was more than 7.5MPa. The ultimate static pressure of ordinary air springs is about 2.0MPa, but the pressure resistant ability improved by restricting the side deformation of the air spring

The failure is occurred at the piston made of aluminum as shown in Photo 3. After broken pieces of the piston penetrated the rubber seal, a leakage of water is occurred.

b) Case 2: Dynamic vertical test

The relations between the vertical force and the vertical displacement under the sinusoidal vertical force (amplitude: 20mm, frequency: 1Hz, 1.5Hz, 2Hz) are shown in Fig. 5.

It is recognized from these figures that the effect of the force frequency is almost small and the restoring property shows nonlinear property without hysteresis.

c) Case 3: Dynamic vertical test with constant horizontal force

The relations between the vertical force and the vertical displacement under the sinusoidal vertical force (amplitude: 20mm, frequency: 1.5Hz) and constant horizontal force (horizontal displacement: 20mm) are shown in Fig. 6,7, comparing the effect of contact conditions. Fig.6 shows the result of pin condition and Fig.7 shows the result of roller condition.

It is recognized from these figures that the effect of the contact condition is almost small and the restoring property shows nonlinear property with slight hysteresis. It seems that there was a little friction on the contact part, but the device worked smoothly at the test.

d) Case 4: Dynamic vertical and horizontal test

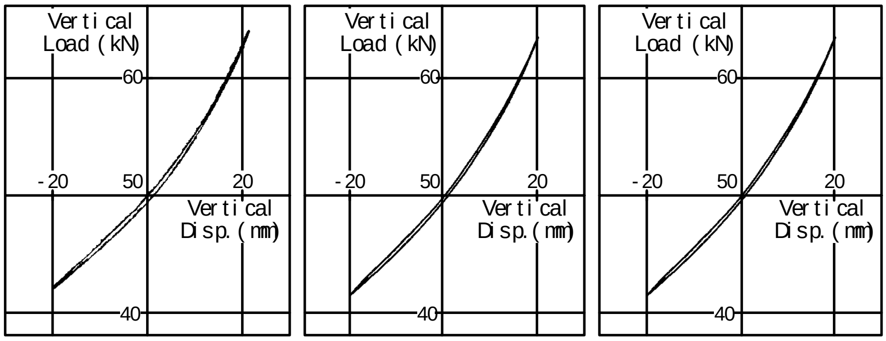
The vertical and horizontal property under the sinusoidal vertical force (amplitude: 20mm, frequency: 1.0Hz, 1.5Hz) and the sinusoidal horizontal force (amplitude: 20mm, frequency: 1.0Hz, load: 5.9kN) are shown in Fig. 8. These figures show the results of pin condition on the contact part.

It is recognized from these figures that the effect of the forcing frequency is almost small and the vertical restoring property is almost the same as the results of the dynamic vertical test shown in Fig.5.

As the horizontal restoring property is almost the same as the device test results of the laminated rubber bearing, it is recognized that the effect of the contact part is almost small.

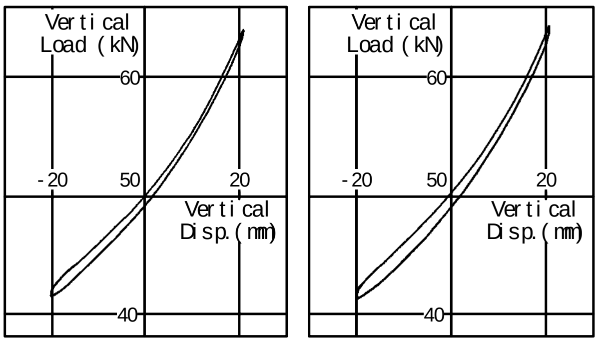
The vertical and horizontal property under the sinusoidal vertical force (amplitude: 20mm, frequency: 1.5Hz) and the sinusoidal horizontal force (amplitude: 20mm, 40mm, frequency: 1.0Hz, load: 5.9kN, 12kN) are shown in Fig. 9. These figures show the results of roller condition on the contact part.

The hysteresys area of the vertical restoring property becomes larger in accordance with the increase of horizontal displacement from 20mm to 40mm. It seems that friction on the contact part increases with horizontal displacement, but the device worked smoothly at the test.



Vertical frequency: 1Hz | Vertical frequency: 1.5Hz | Vertical frequency: 2Hz

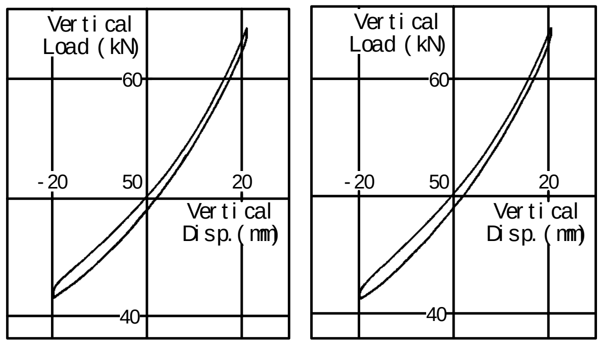
Fig.5 Dynamic vertical property under cyclic load (Vertical amplitude : 2cm, Pin type)



Vertical amplitude : 2cm
Vertical frequency: 1Hz

Vertical amplitude : 2cm
Vertical frequency: 1.5Hz

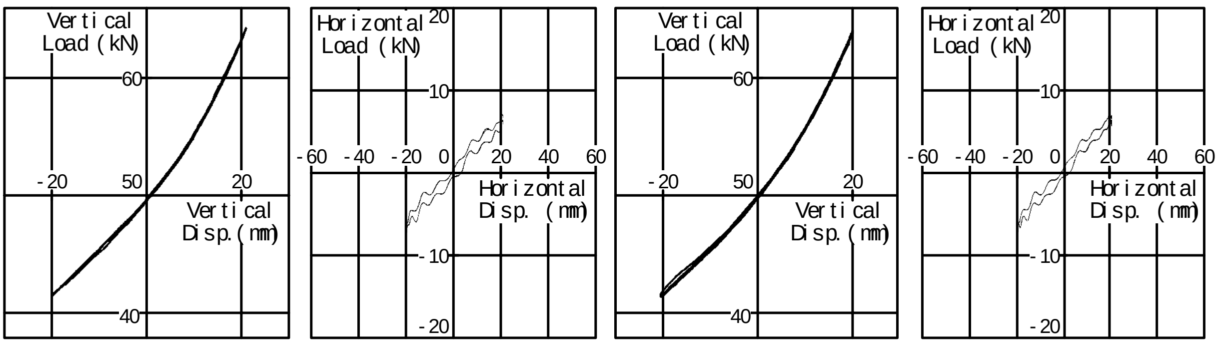
Fig. 6 Dynamic vertical property with constant horizontal displacement (Constant Horizontal Disp. : 2cm,Pin type)



Vertical amplitude : 2cm
Vertical frequency: 1Hz

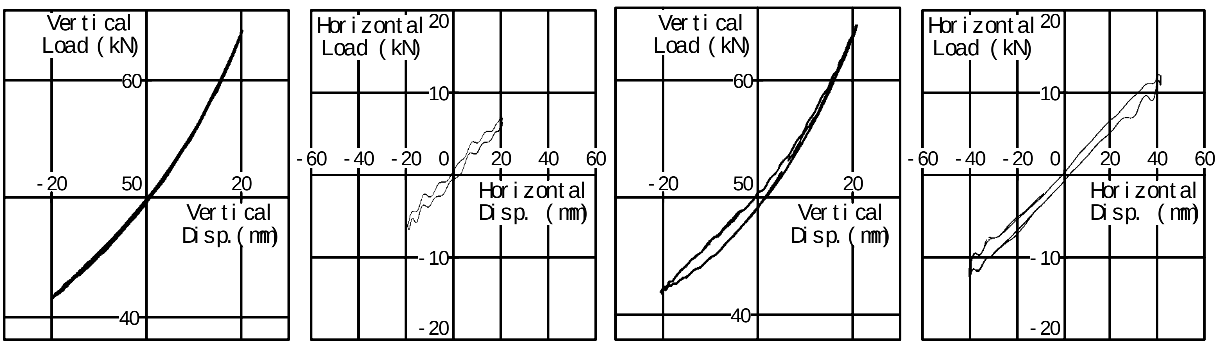
Vertical amplitude : 2cm
Vertical frequency: 1.5Hz

Fig. 7 Dynamic vertical property with constant horizontal displacement (Constant Horizontal Disp. : 2cm,Roller type)



Vertical amplitude : 2cm,Vertical frequency : 1Hz | Vertical amplitude : 2cm,Vertical frequency : 1.5Hz

Fig. 8 Dynamic vertical and horizontal property (Horizontal amplitude:2cm,Horizontal frequency:1Hz, Pin type)



Horizontal amplitude : 2cm,Horizontal frequency : 1Hz | Horizontal amplitude : 4cm,Horizontal frequency : 1Hz

Fig. 9 Dynamic vertical and horizontal property (Vertical amplitude:2cm, Vertical frequency:1.5Hz,Roller type)

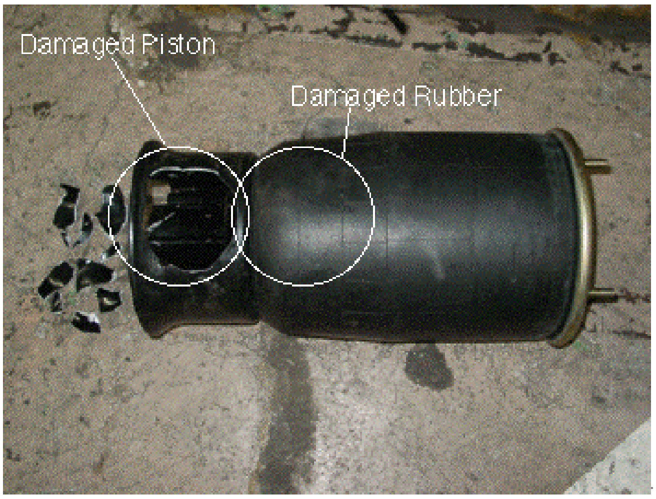


Photo 3 Damage of Air Spring Piston

CONCLUSION

The 3D seismic isolation device reduction model whose scale is 1/10 is made and the workability of the device by the horizontal and vertical dynamic load is confirmed.

The pressure resistant ability test for the air spring is performed by the monotonic pressurization. As the result, it is confirmed that pressure resistant ability improved by restricting the side deformation of the air spring and that the material of the existing air spring can withstand high pressure use sufficiently.

As the result, it is confirmed that the developed 3D seismic isolation device is applicable to the actual plant.

In the future, it is necessary for the practical use of this device to confirm the workability and pressure resistant ability by lager models than this study and to concretize the attachment of rubber seal, the damping device, countermeasure against rocking and the concept of the isolation system.

ACKNOWLEDGEMENT

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