CONSTRUCTION OF CIVIL BUILDING USING THREE DIMENSIONAL SEISMIC ISOLATION SYSTEM
(Part 2, Tests for Three Dimensional Seismic Isolation System)

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ABSTRACT :

The three dimensional(3D) seismic base isolation system for applying to the civil building have been proposed in Part 1. In this paper, test results for confirming mechanical property of the device are reported. The proposed 3D seismic isolation system consists of the 3D seismic isolation device and the rocking suppression device. The 3D seismic isolation device consists of laminated rubber bearings as horizontal isolation devices and air springs as vertical isolation devices. The rocking suppression device consist of oil dampers connected by oil pressure piping in order to control a rocking vibration which becomes easy to be excited because the vertical rigidity of seismic device lowers. To confirm the applicability to a real building to each device, the tests with actual size devices were executed. As the results, the seismic isolation performance of 3D isolation device was confirmed, and the rocking control performance of the rocking suppression device was confirmed.

KEYWORDS: three dimension seismic isolation, air spring, laminated rubber bearing, oil damper, rocking suppression device, piping resistance

1. TEST AND ANALYSIS OF THREE DIMENSIONAL SEISMIC ISOLATION DEVICE

1.1 Outline of the tests

The proposed 3D seismic isolation device consists of laminated rubber bearings as horizontal isolation devices and air springs as vertical isolation devices. The air springs are connected with a rigid frame to move together. The slider which moves only vertically is installed so that horizontal load does not act on the air spring.

The tests shown in Table 1.1 are executed in order to confirm the target performance of the devices.

Table 1.1 Outline of Tests

	Dynamic characteristic tests of air springs	Resisting pressure test of an air spring	Characteristic test of 3D seismic isolation device
Purpose	Confirmation of amplitude and velocity dependency	Confirmation of ultimate pressure	Grasp of mechanical characteristic
Performance target	#Vertical Natural period is 1.3(s) in supporting 38ton mass. #Vertical damping is 5% or more.	The ultimate pressure is 2MPa or more.	#A total characteristic must become the summation of an individual characteristic of element. #Friction must be few.

1.2 Dynamic characteristic tests of air springs

The air spring is composed of the air room of about 950mm in the diameter by the rubber bellows and the auxiliary steel tank. The plate that has orifice is set up between the air room and the auxiliary tank. The vertical damping is caused by the air that flows through orifice.

Figure 1.1 shows the situation of a dynamic test of the air spring. Figure 1.2 shows the example of the relation between the vertical displacement and the axis force.

It is understood to obtain the hysteresis damping by orifice.

Figure 1.3 shows the velocity dependency of the stiffness and the damping coefficient of the air spring. Figure shows the calculation result by Kunieda (1958). It is understood that the correspondence of the calculation result and the test results is good.

When the air spring supported 38ton in mass, it was confirmed that the vertical natural period was about 1.25 seconds and that the damping ratio was 6.8% in the amplitude 50mm.

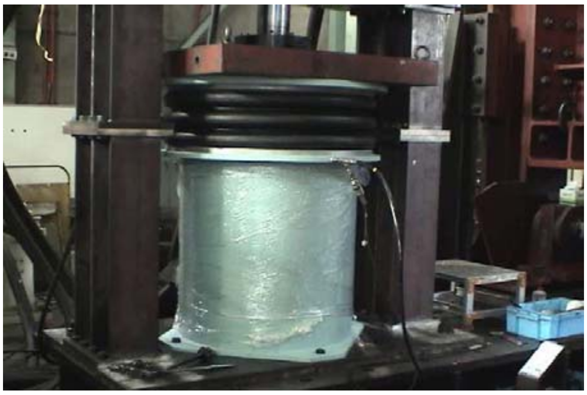


Figure 1.1 Photograph of Dynamic test of air spring

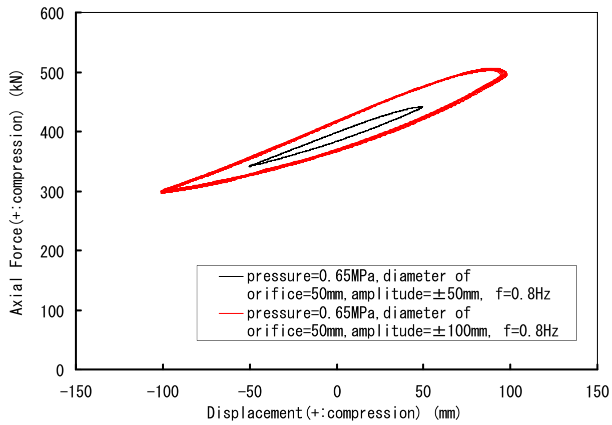
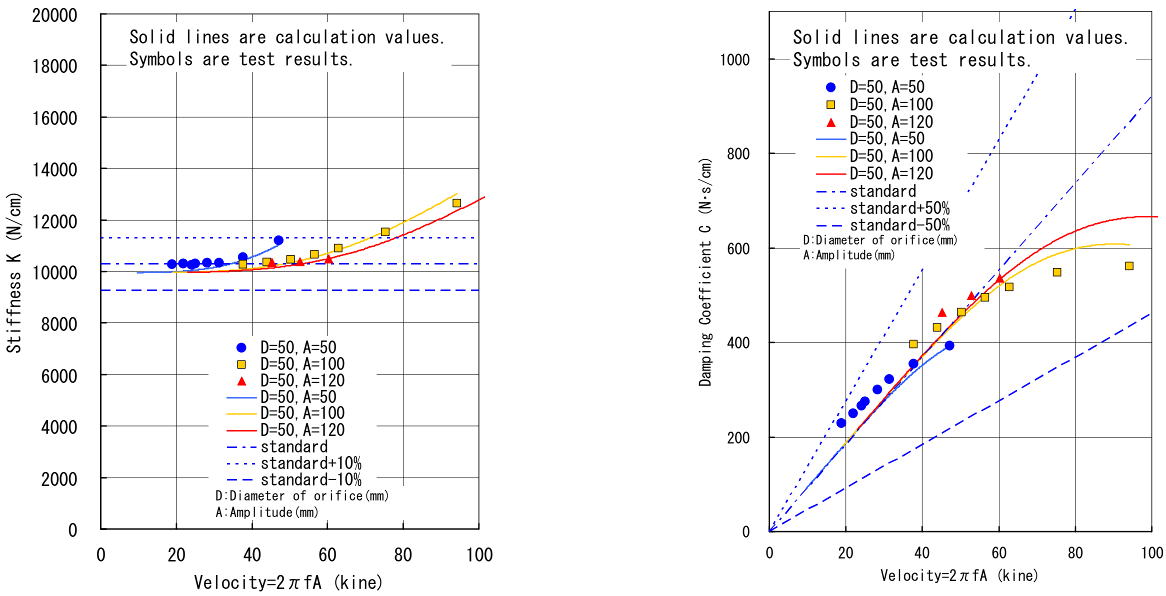


Figure 1.2 Example of hysteresis loop of air spring (pressure=0.65MPa, amplitude=50,100mm,frequency=0.8Hz)



a. Stiffness b. Damping coefficient

Figure 1.3 Dependency of velocity on stiffness and damping coefficient (Diameter of orifice =50mm)

1.3 Resisting pressure test of air spring

The air spring is placed between the restraint devices that compose of upper and lower steel plates and 6 PC steel bars. The air spring is pressurized by injecting water. The pressurizing pattern was assumed to be monotonous. Figure 1.4 shows the situation of the resisting pressure test.

Figure 1.4 Photograph of the resisting pressure test

Table 1.2 shows the resisting pressure test results. Figure 1.5 shows the example of the ultimate mode of the air spring. The mean value of the ultimate pressure became 4.6MPa. This value is about seven times pressure assumed by the ordinary design(0.65MPa).

Table 1.2 Ultimate pressure of air springs

	Ultimate pressure(MPa)	Ultimate mode
Device 1	4.7	Breaking of coating rubber of bead wire
Device 2	3.8	Breaking of the girdle hoop
Device 3	5.3	Water leak between mounting plate and bead ring
Mean	4.6	-
Standard deviation	0.75	Coefficient of variation=0.16

Figure 1.5 Breaking situation of rubber bellows (Device 1)

1.4 Characteristic test of 3D seismic isolation device

The test device consists of actual size devices that combined three air springs, three sliders, and a laminated rubber bearing.

The variable compulsion displacement was vertically added to the laminated rubber bearing with the constant horizontal displacement.

Figure 1.6 shows the situation of the test.

Figure 1.7 shows the example of the vertical hysteresis of the device. When the vertical displacement reverses, the stiffness changes because of friction of slider.

Friction increases when the air spring is compressed. Hysteresis becomes asymmetry a little.

The moment by the horizontal force and the P-Δ moment caused by horizontal displacement of the rubber bearing acted on the device. It is thought that a large moment acted on the device in the test because the rotation restraint in the top of rubber bearing is small. In the state to restrain the rotation of the top of rubber bearing like an actual building, it is thought that the moment that acts on the device is decreased and the frictional force is decreased.

Figure 1.6 Photograph of 3D seismic isolation device

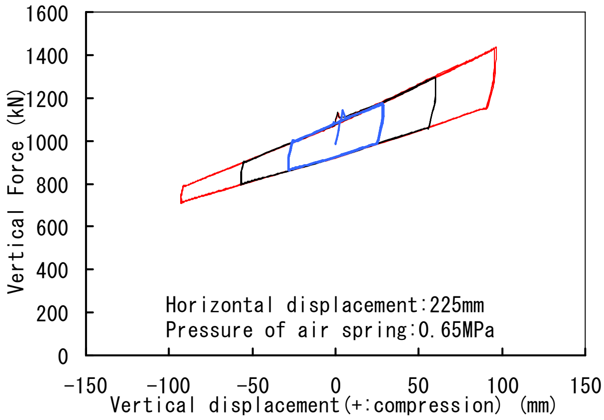


Figure 1.7 Example of vertical hysterisis loop of the device

2. CHARACTERISTIC TEST OF ROCKING SUPPRESSION SYSTEM WITH OIL DAMPER

2.1. Outline

In this section, we report the feature of the rocking suppression system with oil dampers by the analysis and the experimental result. It experimented by vibration test using oil dampers which imitated this equipment and hydraulic circuit to confirm rocking suppression performance, and it confirmed following performance, and compared with the analysis. Then, it corrected the parameter of the hydraulic circuit model for the building design model, and it compared and verified the validity of the analogy of the spring-mass system model and the hydraulic circuit model.

2.2. Modeling

Concept of the analogy and the verification by the test of the spring-mass model and the hydraulic circuit model is shown in Figure 2.1.

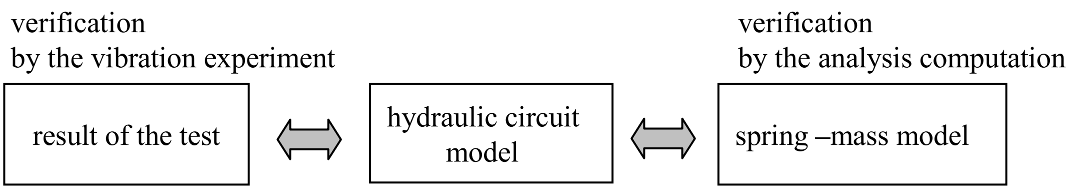
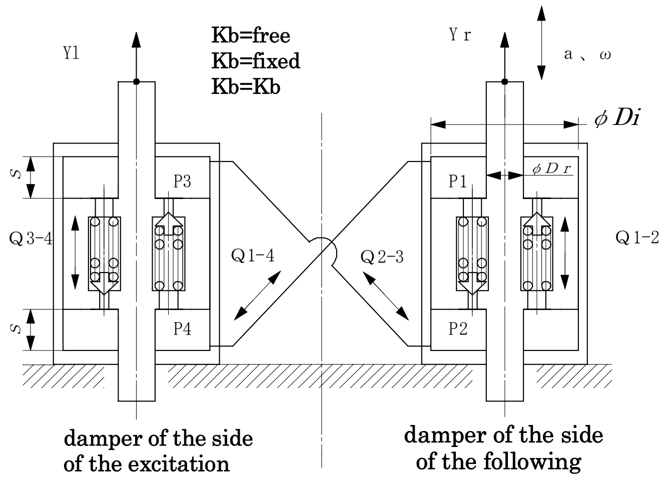


Figure 2.1 Analogy of the hydraulic circuit model and the building analysis model

The rocking suppression system makes possible to move in the same phase with the mechanism which connects the hydraulic pressure rooms on both sides of the piston in the mutual difference by the plumbing.



Y_r, Y_l ; axis displacement of each damper
F_r, F_l ; axis damping-force of each damper
$Q_{1\text{-}2}$, $Q_{3\text{-}4}$; flow rate of each piston valve
$Q_{2\text{-}3}$, $Q_{1\text{-}4}$; flow rate of each connecting-pipe
P_1-P_4 ; pressure at each pressure room
C_d ; damping coefficient of valve (proportional with the velocity)
C_{2d} ; damping coefficient of connecting pipe (proportional with the square of the velocity)

Figure 2.2 Hydraulic circuit model of rocking suppression system

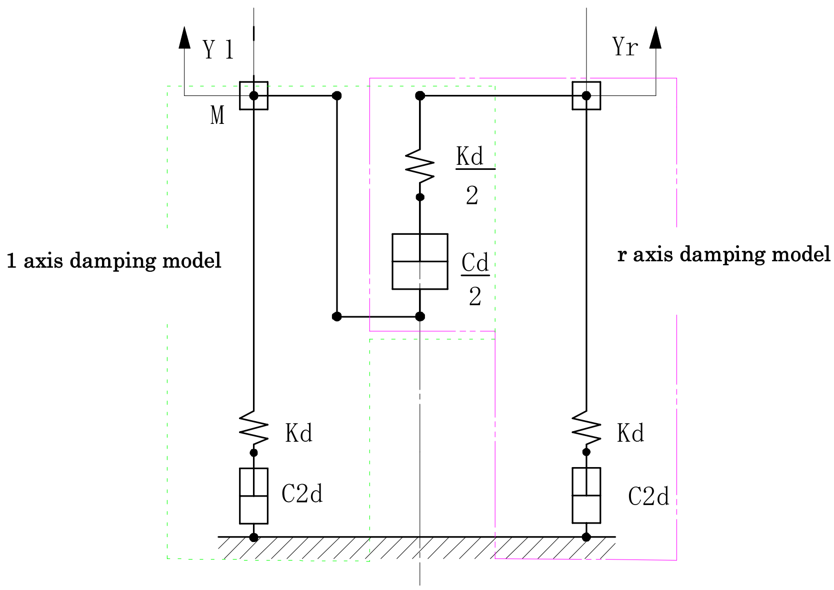


Figure 2.3 Spring –mass model

2.3. Analysis specification

The specification of the rocking suppression system is shown in Table 2.1.

Table 2.1 Specification of rocking suppression system

Repartition	Item	Specification
Oil damper	Damping coefficient C_d(kN-s/m)	1.25×10^4
	Area of piston A(m^2)	0.014
	Stroke ±S(m)	0.1
	boost pressure P_0(Pa)	3
Piping	Size (inch)	1/2
	Length of piping L(m)	10
	damping coefficient C_{2d}(kN-s^2/m^2)	6.5×10^3

2.4. Experiment design

It was experimented about the model of Figure 2.2.
There was plumbing which connects two oil dampers each other by cross. One of the dampers was set at the testing machine and it excited, and measured pressure and load. The other was following one of three kinds of modes. They are #1 free model, #2 elastic load model, #3 fixed model.
The picture of the elastic load type test supply is shown in Figure 2.4.
Figure 2.5 shows the test circuit of elastic load mode.
The test purpose of the test model is shown in Table 2.2 and the condition of vibration is shown in Table 2.3.

Figure 2.4 Elasticity load type test supply

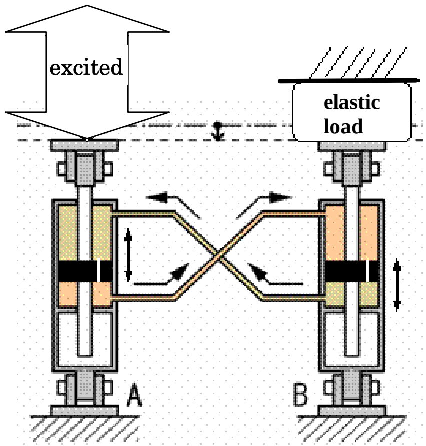


Figure 2.5 Test circuit of elastic load mode

Table 2.2 Test model and test purpose

Test model	Test purpose
A) Damper free model	# It confirms that it operates synchronously by small power. # It checks the influence of the plumbing resistance, too. # It compares with the analysis.
B) Elastic load model	# It confirms that it synchronizes even if the resistance of the following side damper is big.
C) Damper fixed model	# Assuming the condition of the biggest rocking power, it adds vibration by the condition to fix the following damper , and it confirms rocking effect. # It reviews the compressibility influence of oil, too.
D) Simulation confirmation	# It compares the measured value and the analysis value of the pressure and the displacement and it confirms the effect of the simulation analysis.

Table 2.3 Vibration condition

Test item	Amplitude (mm)	Period (sec)	Spring stiffness(kN/m)
Damper free	±30.0	1.27	—
Elastic load	±20.0	1.27	2520
Damper fixed	±10.0	3.00	—

2.5. The comparison between the analysis result and the experimental result

Analysis result and experimental result are shown in Figure 2.6 - Figure 2.8.
As for the following side damper, both displacement and load are flattering well.
Also, it was possible to confirm that it becomes identical about the hydraulic model and spring-mass model analysis result and experiment measuring result on the practical use level.

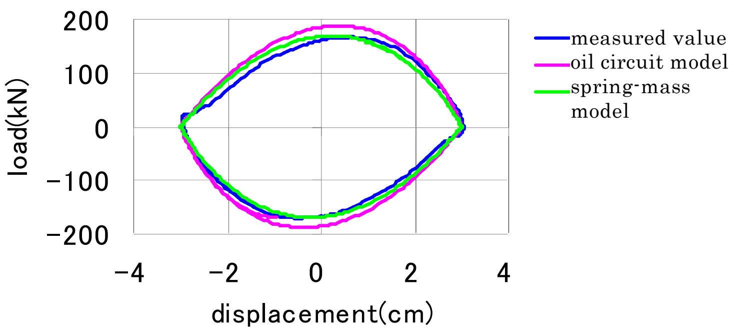


Figure 2.6 Load-displacement relation of following side damper (damper free model)

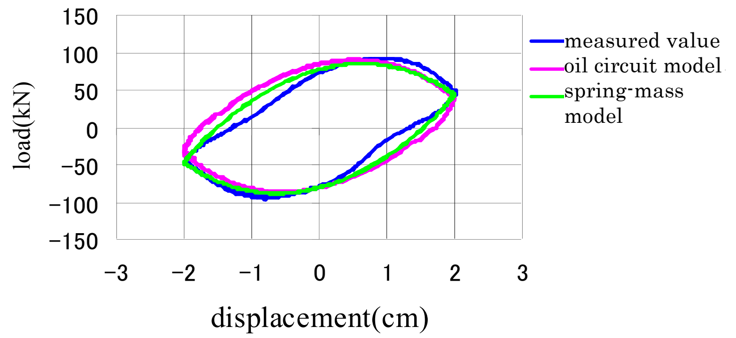


Figure 2.7 Load-displacement relation of following side damper (elastic load model)

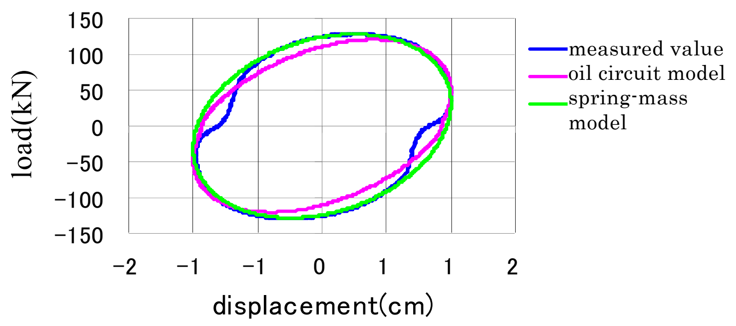


Figure 2.8 Load-displacement relation of following side damper (damper fixed model)

3. CONCLUSION

The characteristic test and analysis of the 3D seismic isolation device was executed. The conclusions of the investigation are as follows.

#1 The stiffness and the damping of the air spring confirmed the explanation by the evaluation formula in the past. The dynamic characteristics of the air spring confirmed that vertical natural period was 1.25 seconds in supporting 38 ton mass and damping ratio was about 6% as assumed by the design.

#2 The ultimate pressure of the air spring was examined to confirm the margin of the pressure in ordinary use. The ultimate pressure of the air spring reached 4.6 MPa on the average of three specimens.

#3 The operation of the device when a horizontal load and a vertical load acted was confirmed from the mechanics characteristic test of 3D seismic isolation device.

The characteristic test and analysis of the rocking suppression system was executed. The conclusions of the investigation are as follows.

#1 It was possible to confirm the following ability of the oil damper in the rocking suppression system by the experiment and the analysis.

#2 It was possible to analogize the spring-mass analysis system which is used in the building design and the compression stiffness of oil and the flow of the circuit analysis system which is used in the hydraulic circuit design, and it was confirmed that the experimental result and the measuring result were very approximate.

As the results, the seismic isolation performance of 3D isolation device and the rocking control performance of the rocking suppression device were confirmed.

REFFERENCE

Kunieda, M.(1958). Theory and Experiment on Vertical Vibration of Rolling Stock Equipped with Air Spring, Railway Technical Research Report No.6, Japanese National Railways (in Japanese)