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Construction of Civil Building Using Three Dimensional Seismic Isolation System (Part 1, Design of Building Using Three Dimensional Seismic Isolation System)

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ABSTRACT :

Recently, buildings using seismic isolation system (SIS) become general to improve seismic safety in Japan. However, the SIS general is chiefly effective only to the horizontal motion, not effective for the vertical motion, by occasion of the following.

#1: The maximum acceleration of the vertical motion is 1/2-1/3 smaller of the horizontal motion.
#2: Even if the vertical motion is input to the building, the structure is not strongly damaged generally and does not harm the human life.
#3: An effective three dimensional (3D) seismic device has not be developed.

It is necessary in the future to achievine the following performance for the vertical motion for improvement of the seismic safety and the habitability.
#1: The accommodations in the computer facilities, the museums, and medical facilities receive neither fall nor damage, etc. in an earthquake.
#2: Comparatively small turbulence vibration should be prevented for BCP of precision equipments in such as power plants and the semiconductor factories.
#3: For a residence use, the severer specification of the structure and protection of property are needed.

The demand performance is the following items in a controlled device.
#1: Device which is easy to maintain, and is not necessary to substitute basically
#2: Device not greatly influenced at temperature
#3: Device whose performance is reproducible and whose modeling for design analysis is easy
#4: Device effective against the vibration from very small amplitude to large amplitude
#5: Device that can be controlled against rocking motion of building

We propose 3D seismic base isolation system for applying to a general building. The proposed 3D seismic isolation device consists of laminated rubber bearings as horizontal isolation device and air spring as vertical isolation device. A rocking suppression device with an oil damper is used to control a rocking vibration. In this paper, building concept of applied 3DSIS to a general building would be introduced.

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

1. DESCRIPTION OF THE BUILDING

The building, to which the 3D seismic base isolation system is applied, is a 9 meters high 3-storied apartment house. The typical floor plan is as below. It has 3 spans (2.7-7.2 meters) in the X-direction and 3 spans (4.5 meters) in Y-direction.

Figure 1 apparent of building

Use: Apartment house
Total floor space: 506.42 meters squares
Number of stories: 3
Height: 9.00 meters
Structure: Reinforced Concrete
Seismic devices: 3DSIS (high-damping laminated rubber bearing, air spring, slider (shear-force transmitting steel bar))
oil damper system with rocking suppression
oil damper for horizontal direction

2. STRUCTURAL PLAN OVERVIEW

2.1. Structural plan

This building is the base-isolated structure, which has the 3D seismic devices between the first-floor beam and the substruction, to improve the earthquake safety.

Seismic devices for the horizontal direction are high-damping laminated rubber isolators and oil dampers, and those for the vertical direction are air spring, sliders, and oil damper with rocking suppression (See Figure 2 & 3).

For the coseismic relative displacement between the substruction and the upper building, the horizontal clearance is set to 60.0 centimeters and the vertical clearance is set to 10.0 centimeters. Facilities pipes between the substruction and the upper building are also suitable to the relative displacement.

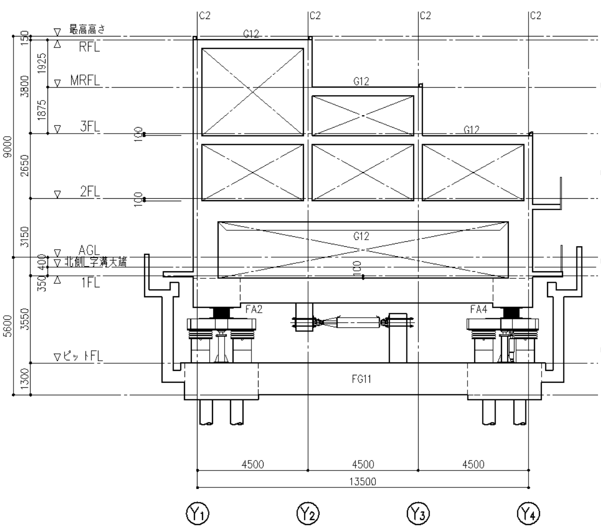

Figure 2 framing elevation

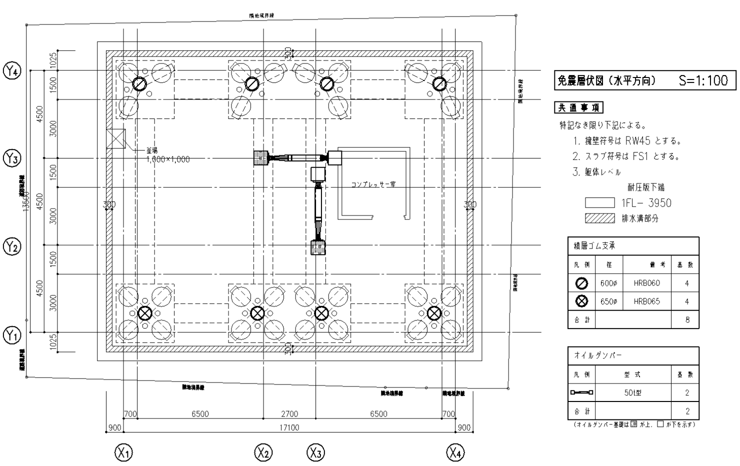

Figure 3 arrangement plan of seismic isolator's layer

2.2. Design criteria

Table 1 & 2 show the horizontal and vertical design criteria.

Table 1 Horizontal design criteria

			Level1	Level2
building		stress	within short-term allowable stress	within short-term allowable stress
		story drift angle (wituout rocking angle)	within 1/400	within 1/200
seismic isolator		relative story displacement	within 15 ㎝	within 30 ㎝
		shear deformation	100%	150%
		puressure(compression)	within stable deformation	within performance assurance deformation
		puressure(tension)	the pull force is not caused	the pull force is not caused
substruction	pile	bearing capacity	within short-term allowable bearing capacity	within short-term allowable bearing capacity
		stress	within short-term allowable stress	within finally capacity
	substruction beam	stress	within short-term allowable stress	within short-term allowable stress

Table 2 Vertical design criteria

			Level1	Level2
building	floor response	maximum absolute acceleration(Gal)	—	300
	—	building angle	—	within 1/100
vertical seismic isolators	air spring	vertical displacement(mm)	—	±85
		internal pressure (MPa)	—	2.0
	slider	stress	—	within short-term allowable stress
		stroke (mm)	—	±85
	supporting steel frame	angle	—	within 1/100
oil damper system with rocking control	oil damper	maximum damping force (kN)	—	500
		maximum velocity (cm/s)	—	30
		stroke (mm)	—	±85

3. SEISMIC BASE ISOLATOR OVERVIEW

3.1. 3D seismic base isolator

This device consists of a high-damping laminated rubber bearing which is used in general SIS, a supporting steel frame supported by air springs. It also has sliders (shear force transmitting steel bars) moving up and down and transmitting shear force from the upper building to the substruction, not to overburden air springs.

Thus the device can divide the horizontal transmitting system and the vertical transmitting system, and this make the seismic base isolator easy to analyze.

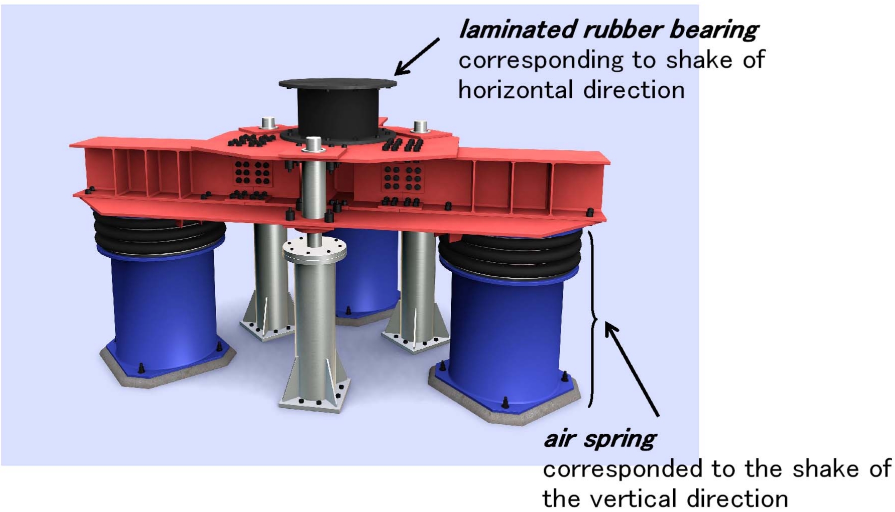

Figure 4 apparent of 3D seismic base isolation system

3.2. Oil damper system with rocking suppression

As each supporting point of this building move up and down separately, the building cannot resist against the rocking moves like earthquakes. Therefore, in the damper system as shown in Figure 5 & 6, two oil dampers are connected by cross-coupled pipes so that oil can move between dampers. Vertical energy will be absorbed by appropriate damping of pipe resistance, and rocking move will be controlled by the excessive damping of damper valve control.

This system is a passive device using oil pressure mechanism without the electric malfunction .

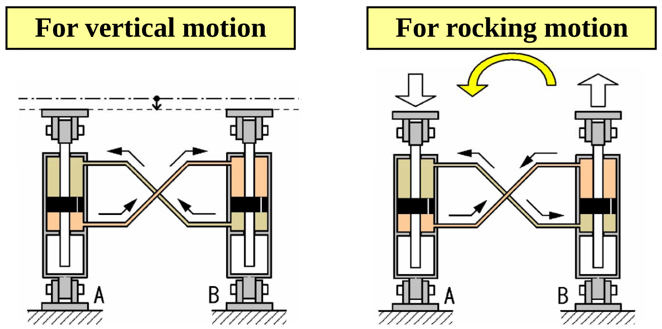

Figure 5 Mechanism of rocking suppression

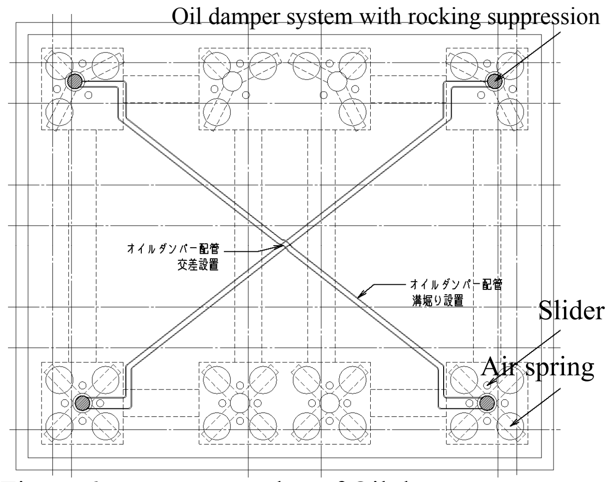

Figure 6 arrangement plan of Oil damper system with rocking suppression

4. ANALYTICAL MODEL OVERVIEW

The analytical model is shown in Figure 7, and parameters of each seismic base isolator is shown in Table 3.

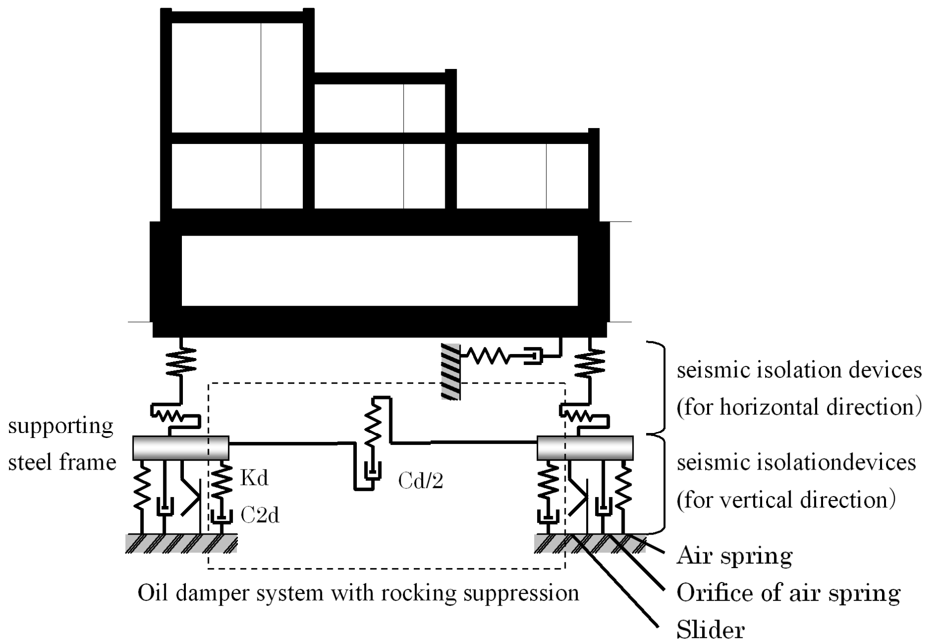

Figure 7 Analytical model

The building is modeled as the 3D frame. 3D seismic base isolators are set under each supporting point, and oil dampers with rocking suppression connect supporting points of opposing corners.

Table 3 Seismic isolation data

device	item	value	recital
high-damping laminated rubber bearing φ600 () is φ650	initial stiffness(kN/cm)	17.5（20.6）	bi-linear model
	secondary stiffness(kN/cm)	3.5（4.1）	
	intercept load(kN)	30（35）	
	vertical stiffness(kN/cm)	17190 (21430)	
sliders(3P)	initial stiffness(kN/cm)	60	4P is 80
	frictional force(kN)	50	4P is 55
air springs(3P)	stiffness(kN/cm)	28.3	4P is multiply 4/3
	orifice damping(kNs^2/cm^2)	0.0118	
oil damper (for rocking suppression)	stiffness(kN/cm)	575.5	Actually , input Kd/2
	damping(kNs/cm)	125	Actually, input Cd/2
oil damper (for vertical direction)	stiffness(kN/cm)	575.5	
	stiffness(kNs^2/cm^2)	0.190	
oil damper (for horizontal direction)	stiffness(kN/cm)	375	
	damping(kNs^2/cm^2)	12.5	

5. ANALYSIS

5.1. Eigenvalue

Table 4 & 5 show the result of eigenvalue analysis in each vertical and horizontal directions.
Weight is allocated to each supporting points, and the vertical amplitude of the second floor long span beams is taken into account in the analysis.

In the eigenvalue analysis considering the seismic base isolator's layer vertically, the value of sliders' friction force, which is dependent on horizontal force, is obtained by the equivalent stiffness of the estimated displacement value.

Table 4 Eigenvalue(horizontal directions)

case of analysis	order	Eigenvalue(sec)		shear deformation
		X-dir	Y-dir	
fixed base model	1 2 3	0.204 0.108 0.074	0.260 0.135 0.097	-
seismic isolation model (15cm deformation)	1 2 3	3.122 0.155 0.093	3.123 0.210 0.120	Level1
seismic isolation model (30cm deformation)	1 2 3	3.687 0.155 0.093	3.688 0.210 0.120	Level2

Table 5 Eigenvalue(vertical directions)

case of analysis	Eigenvalue(sec)
fixed base model	0.17
seismic isolation model (no fliction of slider)	1.27
seismic isolation model (equivalent stiffness in 5.0cm vertical deformation)	1.10

5.2. Eigenvalue mode

Figure 8 shows the vertical first order eigenvalue mode when the seismic isolator's layer is fixed.

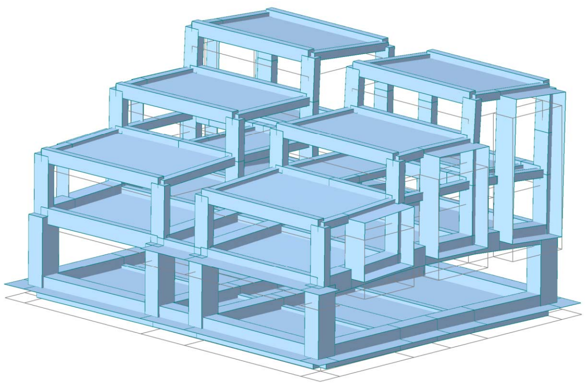

Figure 8 the vertical first order eigenvalue mode

5.3. Input earthquake motions

Table 6 & 7 show the horizontal and vertical input earthquake motions.

Table 6 Input earthquake motions(horizontal direction)

earthquake	duration (sec)	input maximum acceleration (cm/s^2)^{*1} Level1	Level2
EL CENTRO 1940 NS	50	255 (25)	510 (50)
TAFT 1952 EW	50	248 (25)	496 (50)
HACHINOHE 1968 NS	35	168 (25)	330 (50)
simulated earthquake motion (Kobe phase)	120	146 (13.0)	693 (71.1)
simulated earthquake motion (Hachinohe phase)	120	135 (11.8)	703 (82.2)
simulated earthquake motion (El Centro phase)	54	149 (12.1)	686 (76.7)
simulated earthquake motion (assumed Kanto phase)	119	-	557 (72.1)

Table 7 Input earthquake motions(vertical direction)

earthquake	duration (sec)	input maximum acceleration (cm/s^2)^{*1} Level1	Level2
EL CENTRO 1940 UD	50	—	307 (15.8)
TAFT 1952 UD	50	—	290 (19.1)
HACHINOHE 1968 UD	35	—	166 (15.1)
simulated earthquake motion (Kobe phase)	120	—	238 (32.4)
simulated earthquake motion (Hachinohe phase)	120	—	282 (30.8)
simulated earthquake motion (El Centro phase)	54	—	292 (36.3)
simulated earthquake motion (assumed Kanto phase)	119	—	228 (25.1)

5.4. Analysis result

5.4.1 Effects of 3D seismic base isolator

The vertical components in the response analysis, in which vertical and horizontal earthquake motions are input simultaneously, are shown in Figure 9 & 10, and the horizontal components are shown in Figure 11 to 14. For reference, Figure 9 also shows the analysis results of the vertical maximum absolute acceleration in case of only horizontal seismic base isolator and in the case of the fixed base.

Comparing these graphs shows that, in the simulated earthquake motion (Kobe phase), the absolute acceleration of the first floor decreases drastically from 238-261 gal with horizontal seismic base isolator only or with no isolator to 155 gal with the 3D seismic base isolator. It also shows that, in the other earthquake motions, response values reduce to 1/2 - 1/3.

In the graph of vertical maximum absolute acceleration with horizontal seismic base isolator only or with no isolator, the absolute acceleration is amplified widely at the top of the building. The reason of this seems that the vertical amplitude of long span beams has effect on the building response. In these cases, vertical seismic isolators also can equalize absolute acceleration of each floor.

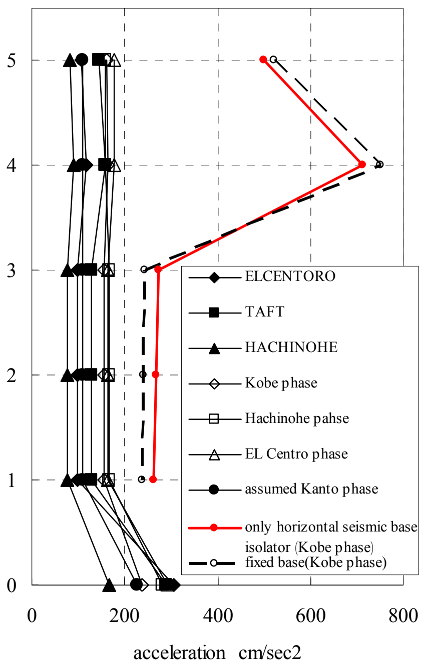

Figure 9 maximum absolute vertical acceleration

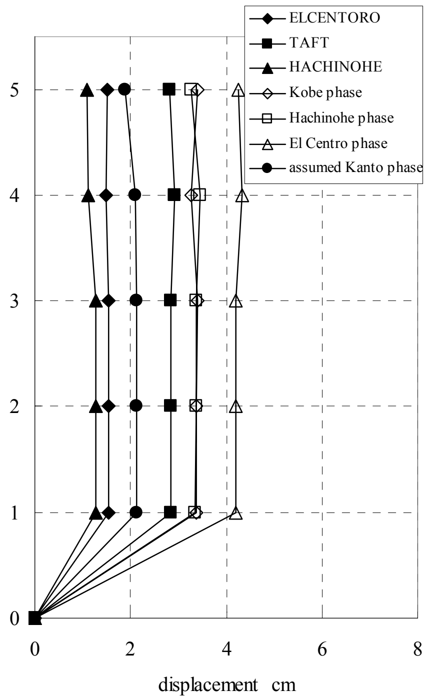

Figure10 maximum vertical displacement

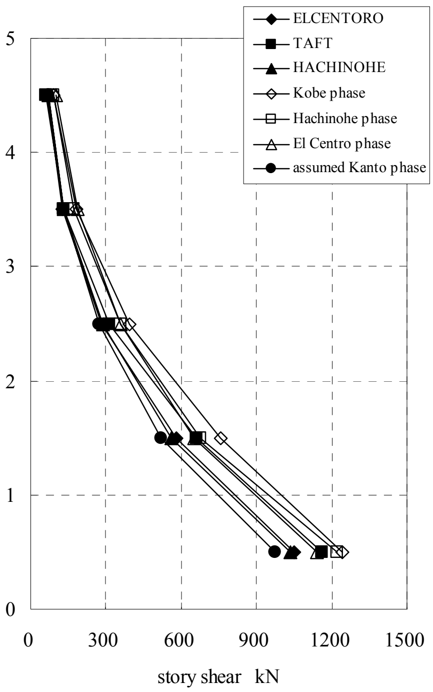

Figure11 maximum horizontal story shear

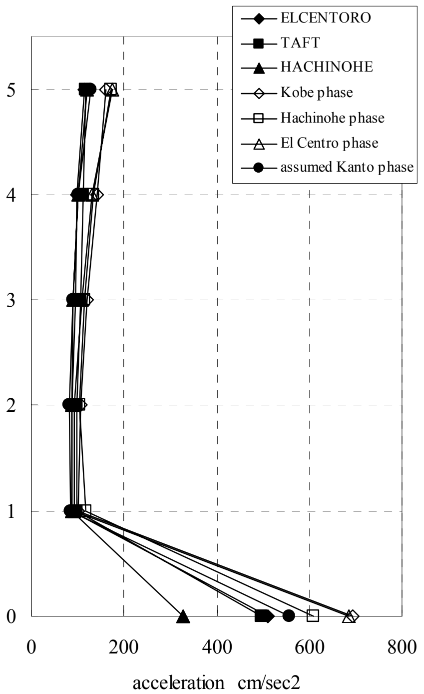

Figure 12 maximum absolute horizontal acceleration

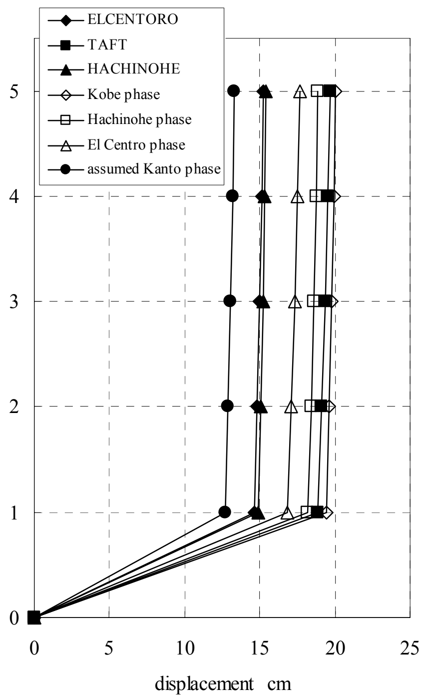

Figure13 maximum horizontal displacement

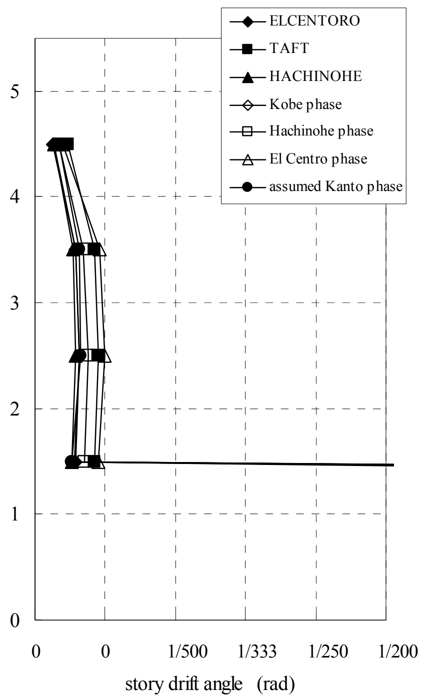

Figure14 maximum horizontal story drift angle

5.4.2 Effects of oil damper system with rocking control

Table 6 shows how the oil damper system with rocking suppression have effect on the rocking angle (building angle) in the response analysis in which vertical and horizontal earthquake motions are input simultaneously.

It shows that the oil damper system with rocking control cannot only decrease the rocking angle but also decrease the maximum absolute acceleration at the supporting points.

The reason of this seems that the supporting points move subserviently each other by the oil dampers system so that vertical moves of each point are smoothed.

Table 8 How the oil damper system with rocking control have effect on the rocking angle

	rocking suppression	no rocking suppression
building angle	1/4716	1/1133
maximum absolute vertical acceleration at the supporting points(gal)	188	239
maximum absolute vertical seismic coefficient at the supporting points	0.19	0.24

6. SUMMARY

In this paper, an actual building with 3D seismic base isolators was designed and their effects were verified. In coming papers, the establishment of measurement system in the base isolation layer and in a building, actual seismic effects, and actual motions of the building will be reported.