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BEHAVIOR OF A BASE-ISOLATED BUILDING AT FUKUSHIMA DAI-ICHI NUCLEAR POWER PLANT DURING THE GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: Based on the experience of the Niigataken Chuetsu-oki Earthquake in 2007 at Kashiwazaki-Kariwa Nuclear Power Plant (NPP), TEPCO constructed the buildings equipped with seismic base-isolation system, which houses emergency response centers for each Nuclear Power Plant, including Fukushima Dai-Ichi NPP. Although strong ground motion was observed at Fukushima Dai-Ichi NPP in the Great East Japan Earthquake in 2011, the base-isolated building was not damaged. This paper shows behavior of the building during the earthquake using observation records.

Key Words: Great East Japan Earthquake, Fukushima Dai-Ichi NPP, Base-isolated building, Observation records, Simulation analysis

INTRODUCTION

The Niigataken Chuetsu-oki Earthquake (M6.8) occurred on July 16, 2007. Though the strong ground motion that was 6+ by JMA intensity measure was observed at TEPCO Kashiwazaki-Kariwa NPP site, reactors were shut down safely and no damage to the safety of NPP facilities occurred.

According to the requirement to provide “Emergency Headquarter” in NPP site, there is one located at Kashiwazaki-Kariwa NPP site on the first floor of the office building. The main shock of the Niigataken Chuetsu-oki Earthquake gave little structural damage so that the “Emergency Headquarter” remained safe. However, some damage such as the falling down of ceilings, failure of locks of doors, turning over of racks, trouble of sanitary system and so on, brought the loss of the functions to carry out the emergency response (TEPCO,2007).

Following the fact above, TEPCO has planned to provide “Base-isolated Important Building” that possesses the function as “Emergency Headquarter” to every NPP site, so one of the buildings was constructed at Fukushima Dai-Ichi NPP site in March, 2010.

OUTLINE OF THE BASE-ISOLATED IMPORTANT BUILDING

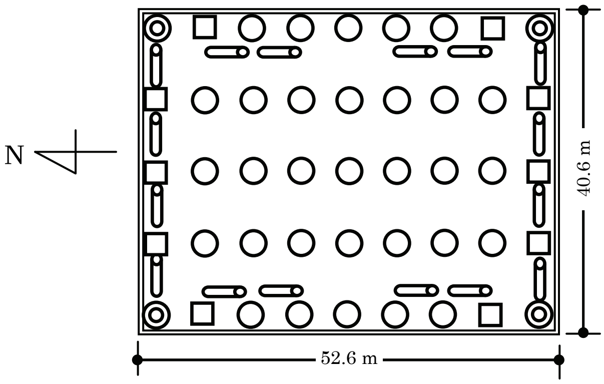
The exterior and the outline of the building are shown in Picture 1 and in Table 1, respectively. Base-isolation system consists of 4 Laminated rubber bearings (LRBs) at corners, 10 Natural rubber bearings (NRBs) at perimeter, 31 sliding bearings and 16 oil dampers. Sliding bearings are employed to obtain longer natural period since the 2 story building brings relatively small axial force on each bearing. Oil dampers are provided to avoid excessive displacement. Figure 1 shows the arrangement of base-isolation devices.

For the Base-isolated Important Building at Fukushima Dai-Ichi NPP, 7 input motions are employed as design ground motion, 3 spectrum compatible artificial ground motions (1.5 times specified by Building Law), 3 standard observation records, 1 Design Basis Ground Motion (780 Gal at base) used for the seismic design of reactor facilities.

Picture 1 Exterior of the Base-isolated Important Building

Table 1 Outline of the Base-isolated Important Building

Place	Okuma-machi, Futaba-gun, Fukushima Prefecture
Completion	March, 2010
Use	Emergency Headquarter
Building Area	1,815 m^2
Total Floor Area	3,600 m^2
Number of Floor	2 Floors
Building height	11.95 m
Structure Type	SRC with S



Mark	Device	Numbers
◎	Laminated rubber bearing (LRB) (Diameter : ϕ 1200mm (rubber); Thickness : H=240mm; Diameter : ϕ 240mm (lead plug))	4
□	Natural rubber bearing (NRB) (Diameter : ϕ 1200mm; Thickness : H=240mm)	10
○	Sliding bearing	31
⊂⊃	Oil damper	16

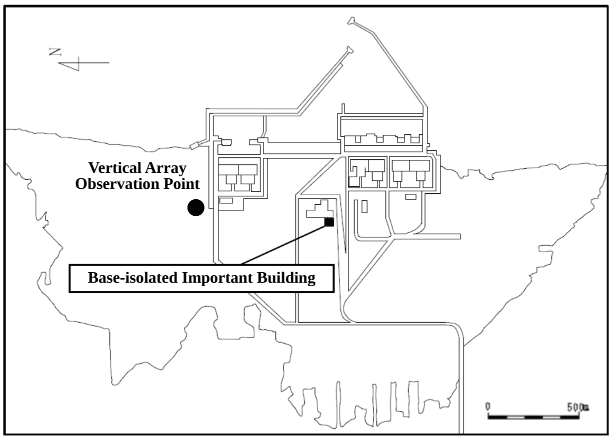
Fig. 1 Arrangement of base-isolation devices

EARTHQUAKE OBSERVATION

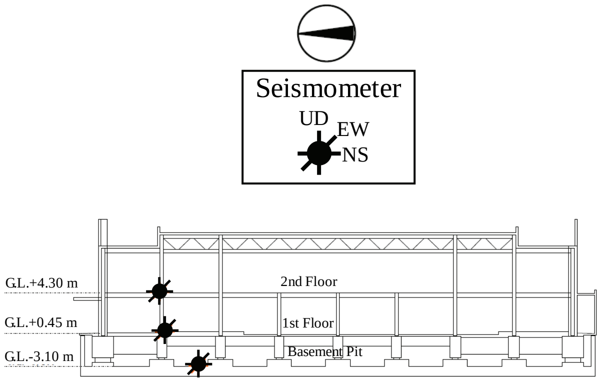
In order to examine the performance of base-isolation, seismic motions are recorded by seismometer installed at the basement pit, the first floor and the second floor of Base-isolated Important Building in Fukushima Dai-Ichi NPP site. Observation in the ground is also carried out in northern part of the site. Figure 2 shows the arrangement of the observation points.

20 days after start of observation on February 21, 2011, the Great East Japan Earthquake (Mj9.0) occurred on March 11, 2011. Though the main shock and after shocks were recorded on that day, data collection was completed about 2 months after since data collection was disturbed by some accident such as hydrogen explosion.

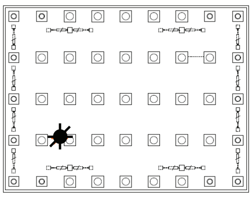
Figures 3 to 5 show the time histories of accelerations. Figure 6 shows the pseudo velocity response spectra. From these figures it can be seen that horizontal responses at the first floor and the second floor are remarkably reduced comparing with that at the basement pit, especially in the period range of 2 second and shorter. On the other hand, the vertical responses at the first floor and the second floor are slightly larger than that at the basement pit.



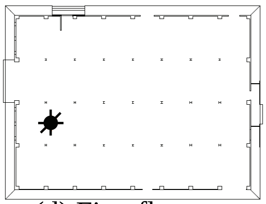
(a) Vertical array observation point



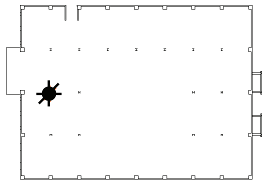
(b) Building section



(c) Basement pit

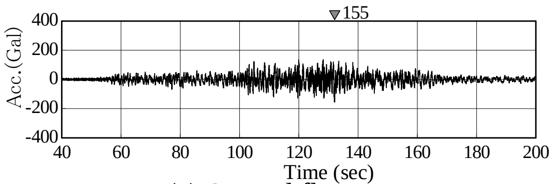


(d) First floor

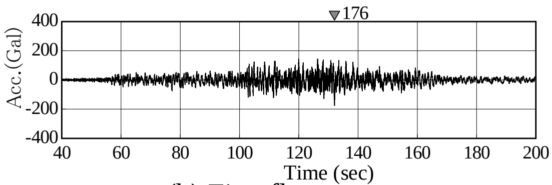


(e) Second floor

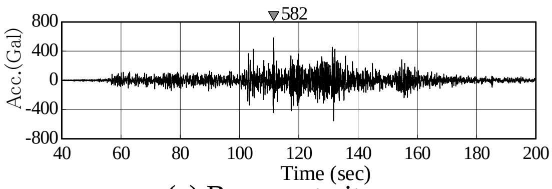
Fig. 2 Observation points



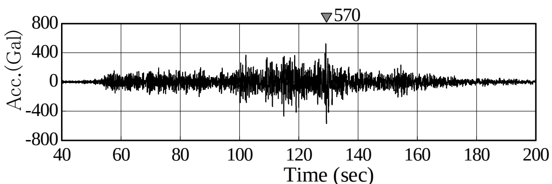
(a) Second floor



(b) First floor

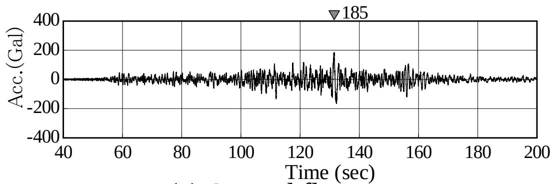


(c) Basement pit

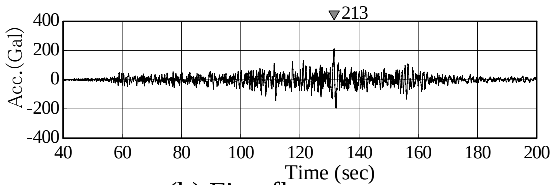


(d) Ground surface

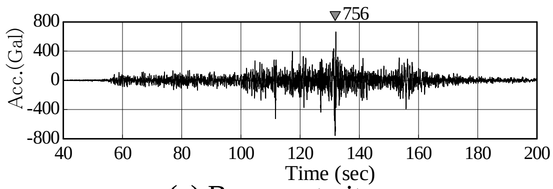
Fig. 3 Time histories of acceleration (NS)



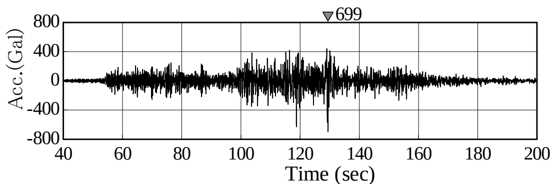
(a) Second floor



(b) First floor

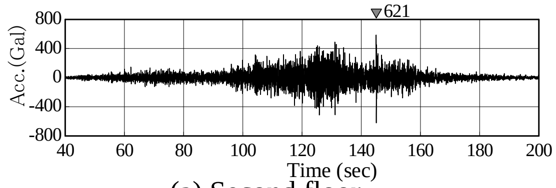


(c) Basement pit

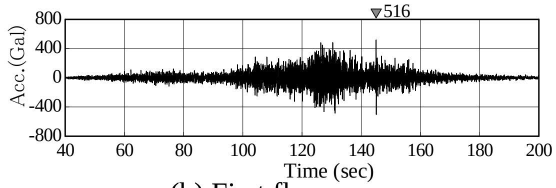


(d) Ground surface

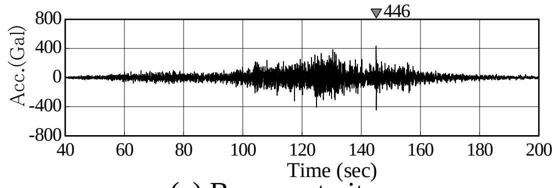
Fig. 4 Time histories of acceleration (EW)



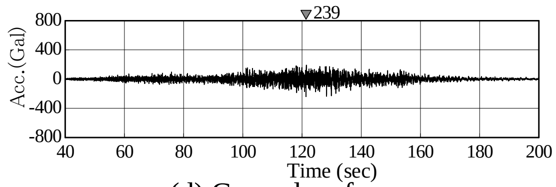
(a) Second floor



(b) First floor

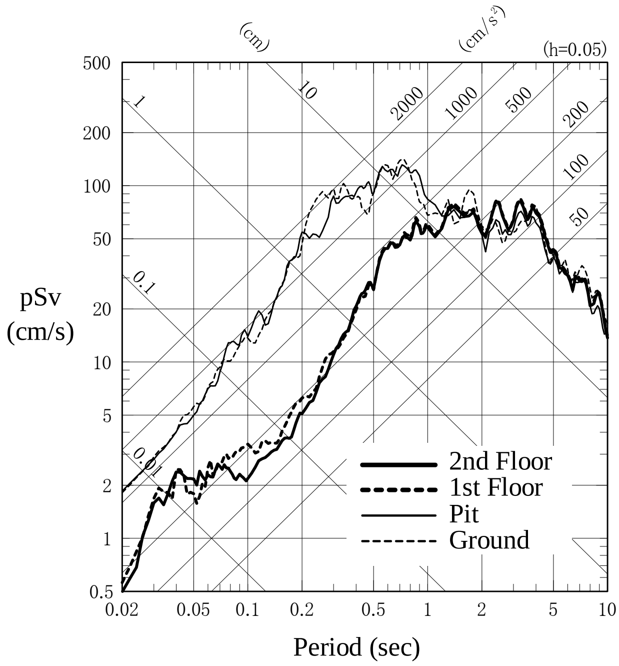


(c) Basement pit

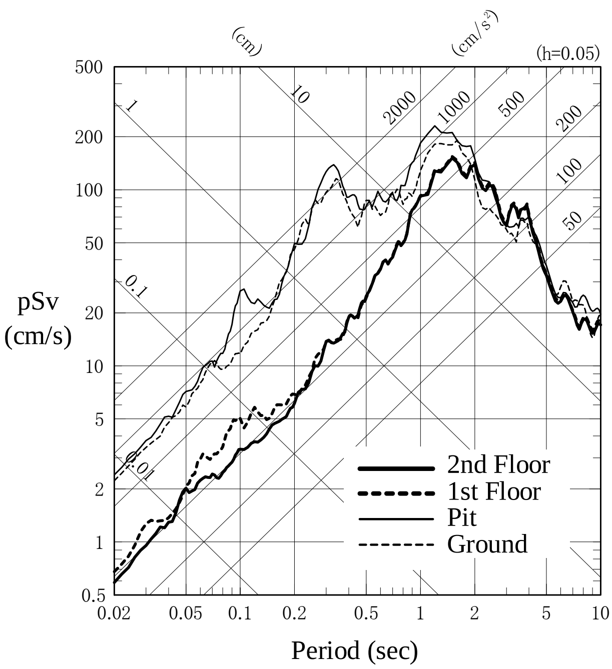


(d) Ground surface

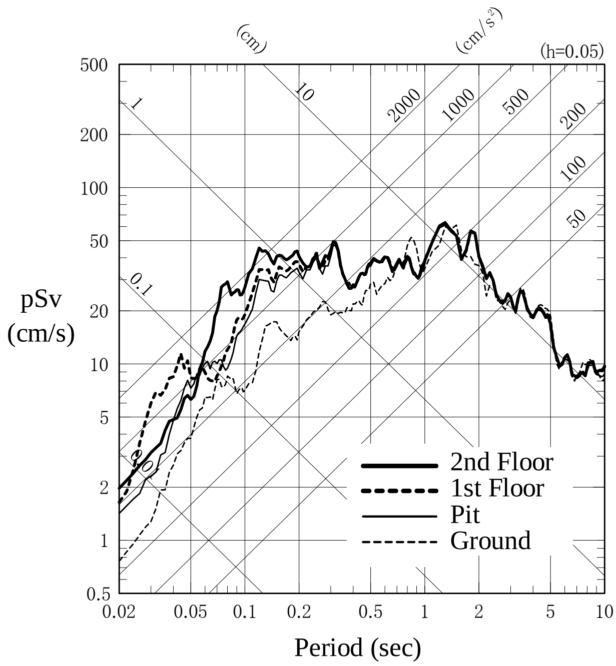
Fig. 5 Time histories of acceleration (UD)



(a) NS



(b) EW



(c) UD

Fig. 6 Pseudo velocity response spectra

From Fig. 7 showing the ratios of responses to that at basement pit, it can be seen that horizontal responses are reduced by 30% in the shorter period range and the vertical responses increase at 0.03 sec. for first floor and at 0.08 sec. for second floor, respectively.

In order to examine oscillation characteristics, band-passed motions corresponding to the 0.3 sec. which is the natural period showing very small spectral ratio for horizontal motion, and 0.03 sec. and 0.08 sec. which are the natural periods showing very large spectral ratio for vertical motion are calculated followed by acceleration distributions shown in Fig. 8. In this figure, acceleration distributions from 0 to 250 sec. are drawn for each time step of 0.01 sec.

Figure 8 shows that base-isolation can decrease the horizontal responses of the upper structure, and that 0.03 sec. corresponds to the vertical first mode of base-isolation and upper structure system and 0.08 sec. corresponds to the vertical first mode of the upper structure itself.

Figure 9 shows the orbit of relative displacement between the first floor ant the basement pit obtained by integrating the acceleration records. In the horizontal plane, large displacement of about 20cm is obtained in E-W direction, and a very small displacement of 1 cm is obtained in the vertical plane.

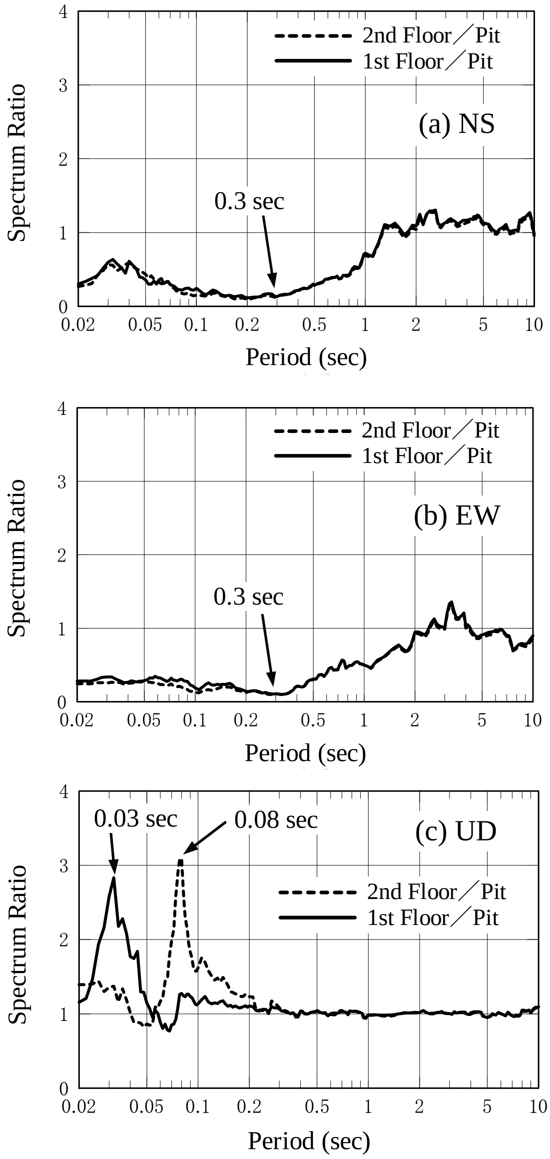
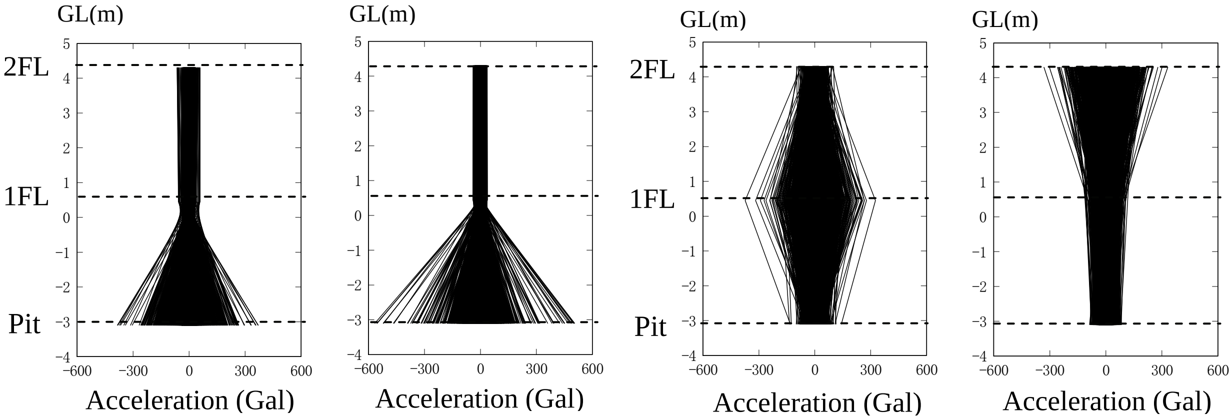


Fig. 7 Response spectrum ratio of the floor vs basement pit



(a) NS
around 0.3 sec.(2～4Hz)

(b) EW
around 0.3 sec.(2～4Hz)

(c) UD
around 0.03 sec.(20～50Hz)

(d) UD
around 0.08 sec.(10～15Hz)

Fig. 8 Acceleration distribution of band-passed wave

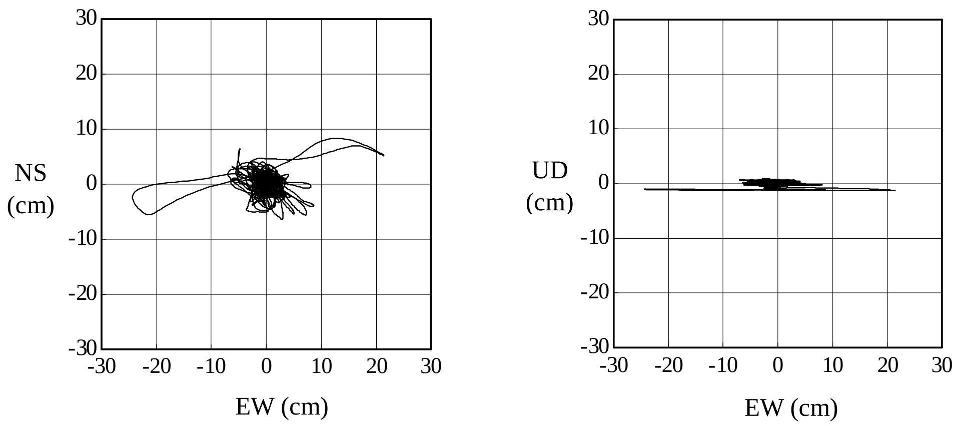


Fig. 9 Orbit of relative displacement between first floor ant basement pit

SIMULATION ANALYSIS

Simulation of observed record was carried out with the oscillation model employed in the design of Base-isolated Important Building. The upper structure was modeled as lumped-mass model with 3 masses as shown in Fig. 10. Specifications of the model are summarized in Table 2. Specifications of NRB, LRB, sliding bearing and oil damper in the base-isolation system are summarized in Table 3. NRB is a linear spring, but other devices are modeled by non-linear spring as shown in Fig. 11.

Observation record at basement pit was employed as input motion, and input revel was set as shown in Fig. 10. Comparisons of simulated peak acceleration and observed peak acceleration at each floor are shown in Fig. 12. Figures 13 and 14 show the comparison of the simulated time histories and observed ones.

Though simulated peak accelerations are slightly smaller than observed ones, there is a good agreement between time histories. Also there is a good agreement between the acceleration response spectra as shown in Figs. 15 and 16. Figure 17 shows the comparison of orbit of relative displacement, which are obtained by integrating acceleration time history. It can be seen that simulated relative displacement agree with observed one.

From the above comparison, it is concluded that oscillation model used in the seismic design can simulate the real phenomena very well and that the design of the Base-isolated Important Building was conducted properly.

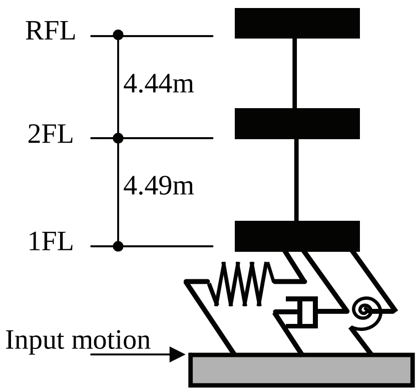


Fig. 10 Oscillation model

Table 2 Specifications of oscillation model

Floor	Height (m)	Weight (kN)	Horizontal stiffness (kN/m)	
			NS direction	EW direction
RFL	-	23,700	-	-
2FL	4.44	18,600	1.660 x10^7	1.191 x10^7
1FL	4.49	42,600	1.827 x10^7	2.136 x10^7
Total	-	84,900	-	-

Table 3(a) Specifications of NRB

Shear modulus Gr (N/mm^2)	Total section area Ar (cm^2)	Total thickness d (cm)
0.294	113,048	24

Table 3(b) Specifications of LRB

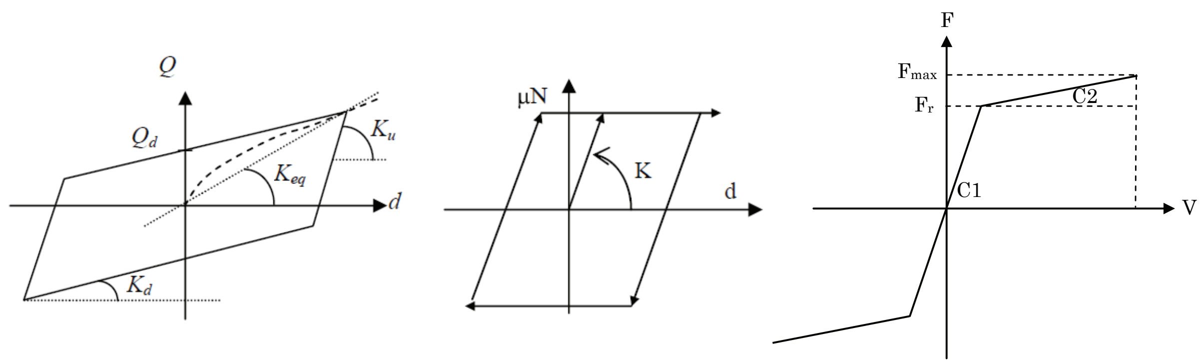
Shear modulus Gr (N/mm^2)	Total section area of rubber Ar (cm^2)	Total section area of lead plug Ap(cm^2)	Total thickness d (cm)
0.392	43,429	1,810	24

Table 3(c) Specifications of sliding bearing

Total vertical force N(kN)	Friction coefficient μ	Friction force μN(kN)	Horizontal stiffness K(kN/m)
60,417	0.013	785.4	3.93×10^5

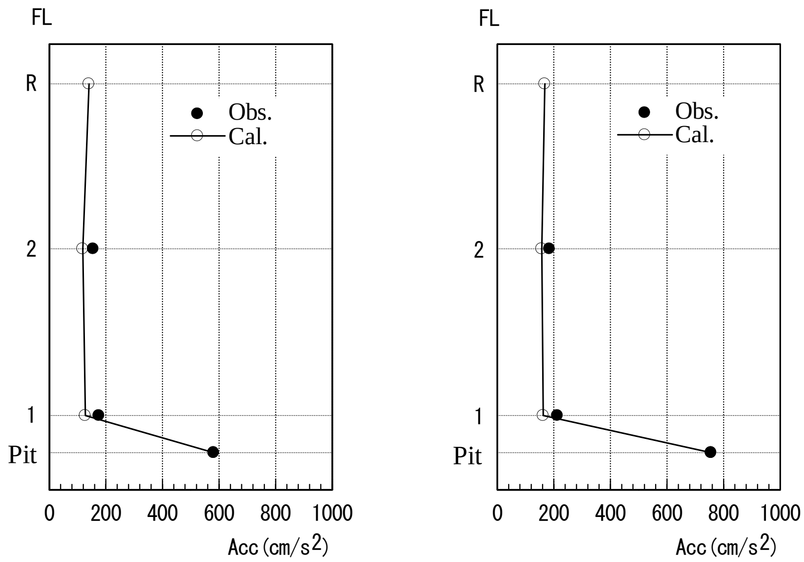
Table 3(d) Specifications of oil damper

Damping coefficient C1 (kN/kine)	Damping coefficient C2 (kN/kine)	Relief force Fr(kN)	Relief load velocity Vr(m/s)	Max. load Fmax (kN)	Max. velocity Vmax (m/s)
25.0	1.70	800	0.32	1,000	1.50



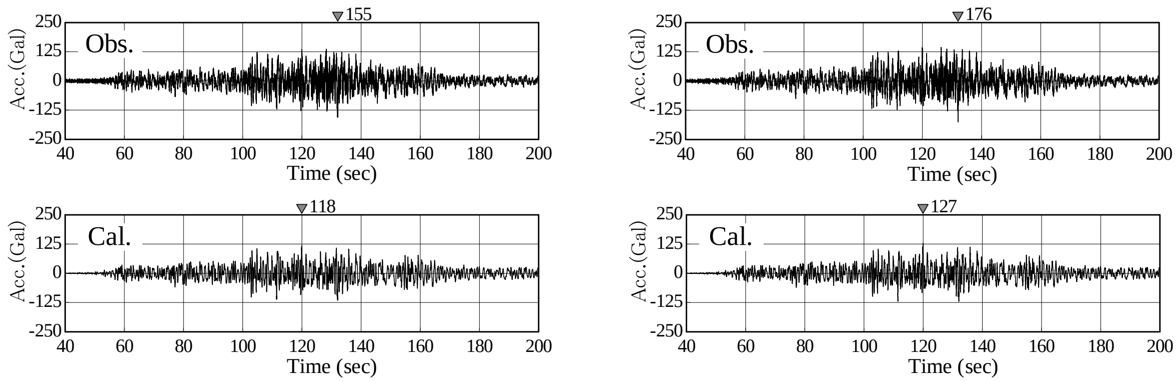
(a) LRB (b) sliding bearing (c) oil damper

Fig. 11 Nonlinear hysteresis characteristics of devices



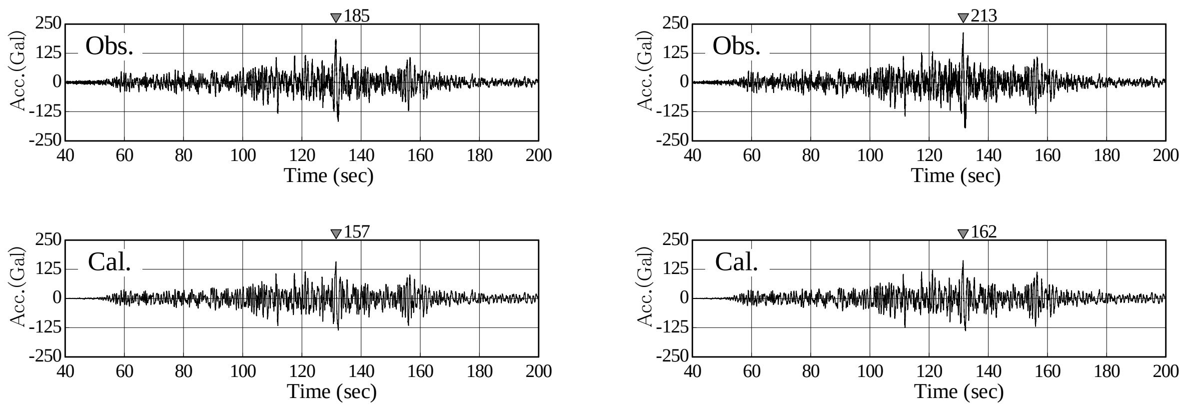
(a) NS (b) EW

Fig. 12 Comparison of simulated peak acceleration and observed one



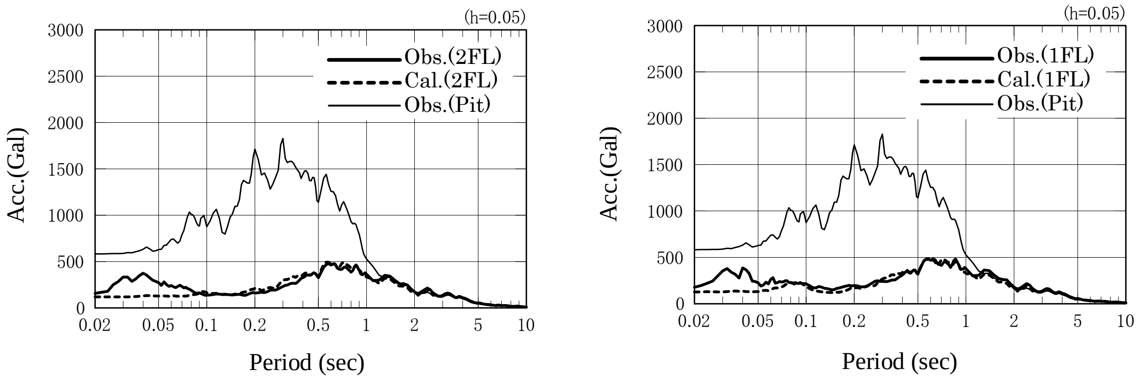
(a) Second floor (b) First floor

Fig. 13 Comparison of simulated time histories and observed one (NS)



(a) Second floor (b) First floor

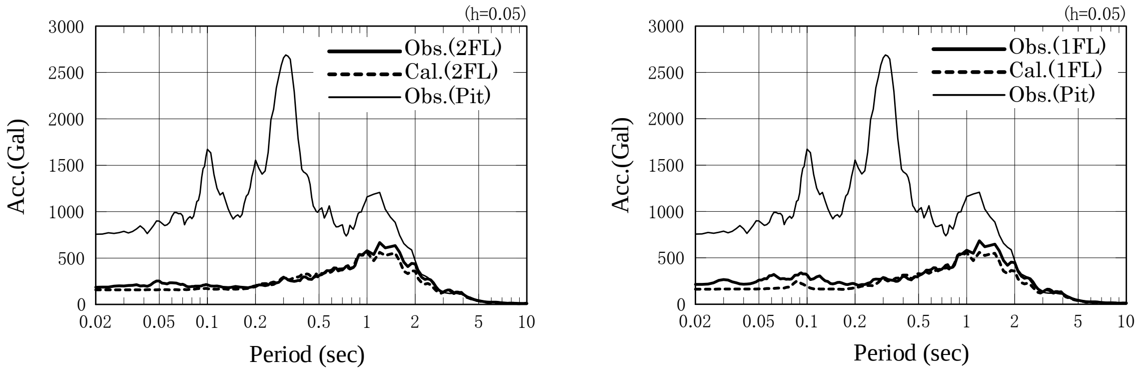
Fig. 14 Comparison of simulated time histories and observed one (EW)



(a) Second floor

(b) First floor

Fig. 15 Comparison of acceleration response spectra (NS)



(a) Second floor

(b) First floor

Fig. 16 Comparison of acceleration response spectra (EW)

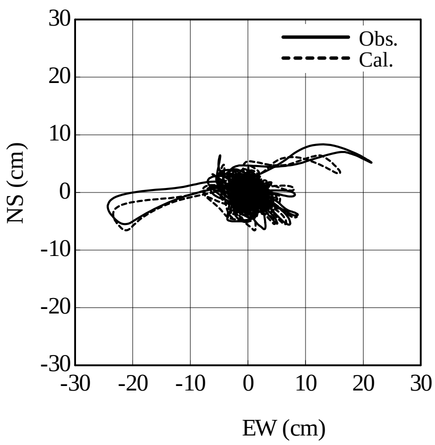


Fig. 17 Comparison of orbit of relative displacement

CONCLUSION

Based on the experience of the Niigataken Chuetsu-oki Earthquake in 2007 at Kashiwazaki-Kariwa NPP site, the Base-isolated Important Building for emergency response was constructed in Fukushima Dai-Ichi NPP site in March, 2010. As the earthquake observation at the Base-isolated Important Building of Fukushima Dai-Ichi NPP had only begun from February 21, 2011 to examine the performance of base-isolation, valuable data by the Great East Japan Earthquake could only be collected for 20 days after starting observation.

By examining the observation records and conducting simulation analysis, it was confirmed that the Base-isolated Important Building possessed sufficient base-isolation performance for the horizontal motion and that the seismic design of the building was adequate. For these reasons, the building suffered no damage from the Great East Japan Earthquake and demonstrated satisfactory performance as an “Emergency Headquarter.”.

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