Viscoelastic Rubber Dampers for Cable Racks

Takeshi NOMURA*, Yosuke KAWABATA, Tomokazu TAKADA, Takashi IKEDA, Eisaku ASATSUMA and Jun FUNAHASHI

Cable racks for electrical wiring in buildings and factories have received a lot of damage during earthquakes compared to those in seismic structures because they are non-structural materials. We investigated the vibration characteristics of the cable racks by shaking test tables in actual use conditions. We then optimized the damping structure of the racks to enable them to hold wires tightly and prevent damage effectively. We also examined the workability of the rack structure for existing buildings.

Keywords: cable rack, nonstructural component, damping, viscoelastic damper

1. Introduction

The Great East Japan Earthquake, which struck on March 11, 2011, caused serious damage to many nonstructural components. According to a report,(1) damage to the cable racks accounted for 68% of the total damage to electrical equipment (nonstructural components). Since fallen heavy cables, as shown in Photo 1, cause injury or death, it is important to improve the seismic resistance of cable racks. In the past, research was conducted by Sumi, Teramoto, et al.,(2) and verification efforts have been carried out by private companies, but the number of scientific papers, etc. is limited.

Photo 1. Fallen Cable Racks

We evaluated the characteristics of various anti-seismic measures for cable racks by means of a shaking table experiment to confirm their effectiveness. Based on this evaluation, Nsys (a damping system using our viscoelastic dampers) was put on the market by Negurosu Denko Co., Ltd., a cable rack manufacturer. This paper is intended to introduce the results of the experiment and provide an overview of the product. Regarding the experiment, we report the results of an evaluation of seismic resistance against input in an orthogonal direction to cable racks, which particularly causes cable racks to fall.

2. Cable Rack System

(1) Overview of the cable rack system

A cable rack is a component for organizing and supporting trunk power lines, trunk communication lines, and various cables. Compared with piping work, etc., cable rack systems offer high workability, and are suited to the laying of many cables. As shown in Fig. 1, the horizontal structural plane is configured by assembling master beams and slave beams like a ladder. Master beams and slave beams are connected by welding. Suspension bolts are provided downward from inserts embedded in slabs or from metal fittings set on steel frames, etc. The rack support member supports the dead weight of the suspension bolts. Braces, etc. must be arranged as aseismic elements at an interval of 12 m or less.(3) This research focuses on a large-scale cable rack system with a width of 1,000 mm.

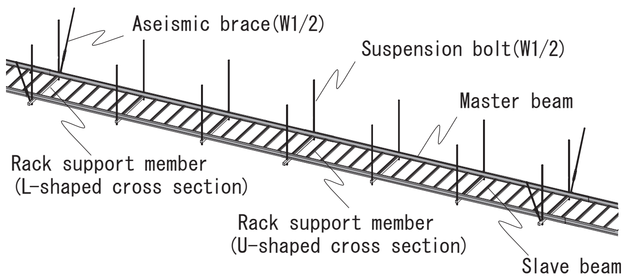


Fig. 1. Cable Rack System Subject to the Experiment

(2) Aseismic elements and damping components that we propose

In this research, we used three types of aseismic elements for the shaking table experiment, as shown in Fig. 2: aseismic elements using general aseismic braces (turnbuckles) (Fig. 2 (a)), aseismic elements with viscoelastic dampers arranged instead of aseismic braces (Fig. 2 (b)), and aseismic elements with viscoelastic dampers arranged between suspension bolts on the assumption of ensuring seismic reinforcement (Fig. 2 (c)). On the structural plane where a viscoelastic damper was arranged, buckling stiffening was provided for suspension bolts, as shown in Fig. 2 (d). A resin-based spacer was provided between a stiffener and a suspension bolt at locations indicated in Figs. 2 (b) and 2 (c). As a damper, a styrene-based high-damping viscoelastic material (thickness: 5 mm) was inserted and bonded between the outer cylinder and the inner cylinder, and was connected in series to achieve a thickness of 10 mm in substance. Table 1 shows the performance characteristics of the damper that was used for the experiment. Here, K'd is the equivalent shear rigidity, and Cd is the equivalent shear damping coefficient.(4) To connect dampers, the inner cylinder was secured using M6 drill screws, and the outer cylinder was connected to the frame using M12 semi-finished bolts.

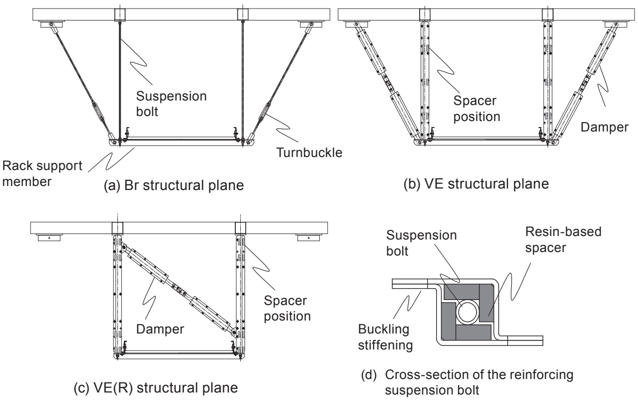


Fig. 2. Details of the Perpendicular Structural Plane

Table 1. Parameters of the Damper

Permissible shear strain		250%
Critical shear strain		500%
Dynamic performance ∗Standard conditions	K's	3.28 kN/cm
	Cd	0.446 kN • s/cm
	Damping force	3.24 kN

∗Temperature: 20°C Frequency: 1Hz Shear strain: 1.5

3. Shaking Table Experiment Plan

3-1 Overview of the specimens and parameters

For the specimens, we assumed a cable rack with aseismic elements provided at an interval of 10.8 m; a section of 5.4 m was taken out by taking symmetry into consideration. Figure 3 shows the basic frame of a specimen. The cable rack was supported in a perpendicular direction by suspension bolts and rack support members at an interval of 1.8 m. At both ends of a specimen (i.e. Y1 and Y4 structural planes), aseismic elements or viscoelastic dampers were arranged. The

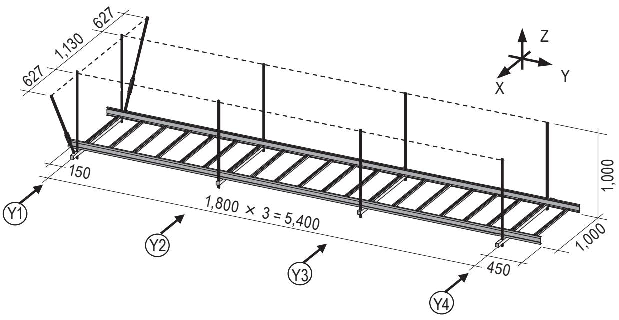


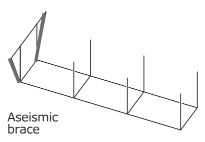
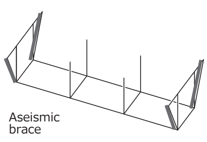
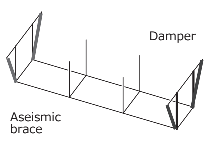
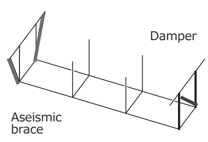
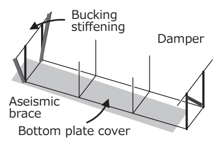
Fig. 3. Overview of the Specimen
(In the case of the Br-No specimen. Cables are not drawn)

arrangements determined the parameters of the specimens. The mass of the cables was 97.2 kg/m, and the mass of the cable rack was 8.9 kg/m. The movement of cables in a longitudinal direction was restrained using a steel sheet at both ends of a specimen, by taking the boundary conditions of cables into consideration. Assuming the same conditions as those for the actual construction, cables and slave beams were banded together using a nylon band at an interval of 2.7 m.

Table 2 shows the parameters of the specimens. Br-No was a specimen of a general design, with aseismic braces provided only on the Y1 structural plane. Br-Br was a specimen with additional aseismic braces provided on the Y4 structural plane. Br-VE and Br-VE(R) were specimens with dampers provided instead of aseismic braces. Br(R)-VE(R)+Co was a specimen with the horizontal structural plane of Br-VE(R) reinforced with a bottom plate cover (thickness: 1.6 mm). The suspension bolts for the Y1 structural plane in the Br(R)-VE(R)+Co specimen were also subject to buckling stiffening. The denominations of the specimens are as follows: Br for an aseismic brace (Brace), VE for a viscoelastic damper (ViscoElastic), R for seismic reinforcement (Retrofit), and Co for a bottom plate cover (Cover).

Figure 4 shows the configuration of a specimen. Suspension frames were set up on a ball screw-type shaking table, and a cable rack was attached to the suspension frames. The table was shaken in the X direction. The first natural frequency of the suspension frames was about 50 Hz based on the free oscillation derived from the impact force. To meet the boundary conditions, a jig was installed near the Y1 structural plane, as shown in Fig. 5, to restrain the rotation of the cable rack around the Z axis. A presser bar was attached to the master beam, and the L-shaped steel component under the master beam was sandwiched by ball casters, in order to create a mechanism that does not resist the movement in the X direction (shaking direction) but resists the force in the Y direction with high rigidity. The distance between the ball casters was adjusted using a thin sheet below them. The gap with the L-shaped steel component was adjusted to 0.7 mm or less. The rotation around the Z axis was restrained only by the Y1 structural plane as described above,

Table 2. Specimen Parameters

Specimen name	Br-No	Br-Br	Br-VE	Br-VE(R)	Br(R)-VE(R)+Co
Natural period	0.706 sec	0.319 sec	0.322 sec	0.324 sec	0.234 sec
Damping constant	2.5%	2.9%	4.1%	4.2%	5.1%
Viscoelasticity	-	-	100 cm^2 × 2	150 cm^2	150 cm^2
Cover	N/A	N/A	N/A	N/A	A
Shape					

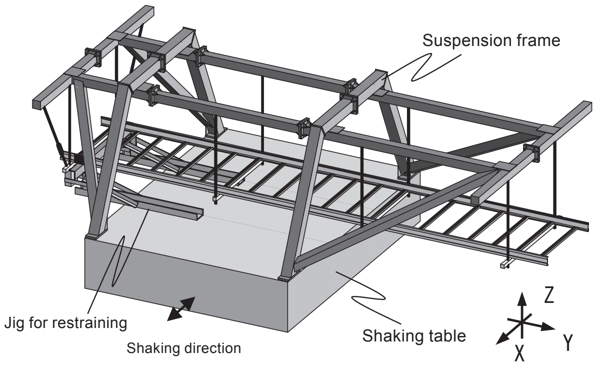


Fig. 4. Setup of the Shaking Table Experiment

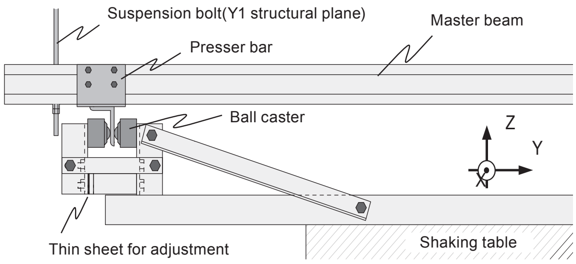


Fig. 5. Jig for Restraining Rotation around the Z Axis

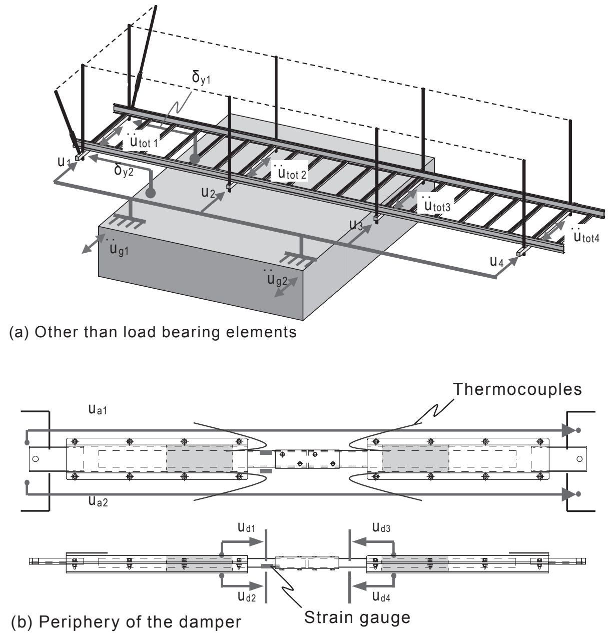


Fig. 6. Measurement Plan for the Shaking Table Experiment

because the cable rack deformation was considered to be caused mostly by shear deformation with little bending deformation.

3-2 Measurement plan

Figure 6 (a) shows the measurement plan. An accelerometer was arranged at both ends of the shaking direction ($\ddot{u}_{g1}$, $\ddot{u}_{g2}$). To measure the overall behavior, an accelerometer was attached to the rack support members of the Y1–Y4 structural planes ($\ddot{u}_{tot1}$~$\ddot{u}_{tot4}$). The relative horizontal displacement was measured using a wire displacement gauge from the jig secured to the shaking table (u1-u4). To confirm the rotation of the specimen around the Z axis, displacement in the Y direction on the Y1 structural plane was measured (δy1, δy2). Figure 6 (b) shows the measurement plan around the damper. The damper axial force (Fd) was calculated using the strain gauge attached to the inner cylinder. Two displacement gauges were attached to each of the two viscoelastic bodies. The damper displacement ud was calculated using Eq. (1a). The overall displacement ua was also measured to confirm the influence of factors other than the damper deformation (e.g. joints), and was calculated using Eq. (1b). Four thermocouples in total were inserted into the viscoelastic damper, and the temperature of the viscoelastic damper at the start of shaking was controlled to 20 ± 0.2°C.

$$u_d = (u_{d1}+u_{d2})/2 + (u_{d3}+u_{d4})/2, \quad u_a = (u_{a1}+u_{a2})/2 \;\cdots\cdots \text{(1a, b)}$$

Also, strain gauges were attached to the suspension bolts and aseismic braces to measure the axial force and moment distribution. The overall deformation of aseismic braces was also measured, as in the case of dampers.

3-3 Shaking plan and response spectrum

In general, nonstructural components, such as cable racks, are subject to input of the building response. Among waves that influence various periodic bands, BCJ-L2*[1] was employed as a general wave, without assuming a specific building. The BCJ-L2 wave was standardized for use, and was applied at 10%, 30%, 50%, 70%, 100%, and 170%, in this order. A 10% input was performed between each input, to monitor the changes in the dynamic characteristics of the specimens.

Figure 7 shows the acceleration response spectra of the input seismic motion measured at BCJ-L2_170% shaking. Although the tendency was different depending on the periodic band, the overall values were about 30 percent higher than the target values. It should be noted that the specimens' behavior is considered to have influenced the shaking table's control. At near the natural period of the specimen, the periodic band tended to be slightly lower than other periodic bands.

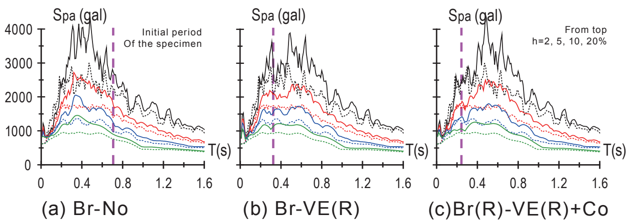


Fig. 7. Response Spectrum of the Input Wave
(Solid line: measurement, Dashed line: target)

4. Results of the Shaking Table Experiment

4-1 Maximum response

Figure 8 shows the maximum response displacement and acceleration. To remove the high-frequency noise, the period of 0.06 seconds or less for acceleration was cut using a low pass filter. When Br-No is compared with Br-Br (the two are different in the interval of the aseismic structural plane), Br-Br's displacement and deformation are small, but its acceleration is high. When Br-Br is compared with Br(R)-VE(R)+Co (the two are different in aseismic characteristics and damping), the maximum displacement and deformation of Br(R)-VE(R)+Co (with damping features) are small; acceleration is also suppressed. When Br(R)-VE(R)+Co is compared with Br-VE(R) (the two are different in the presence of a cover), the response of Br-VE(R) (without a cover) is high. The rigidity of the cable rack is low without a cover. The force transmission efficiency is considered to have been low. When Br-VE(R) is compared with Br-VE (the two are different in terms of damper installation method), Br-VE(R) with the damping and reinforcing construction demonstrates effectiveness equivalent to that of Br-VE. The seismic response was significantly reduced by installing a cover to increase the rack's rigidity and installing a damper as a damping element.

4-2 Hysteresis of dampers and aseismic braces

Figure 9 shows the correlation between the load and deformation of the dampers, and Table 3 shows the temperature increase and amount of absorbed energy of the dampers in each specimen. The hysteresis of the viscoelastic damper calculated by the evaluation formula in reference (5) using maximum shear strain, natural circular frequency (calculated by the curve fitting of the transfer function) and the damper temper-

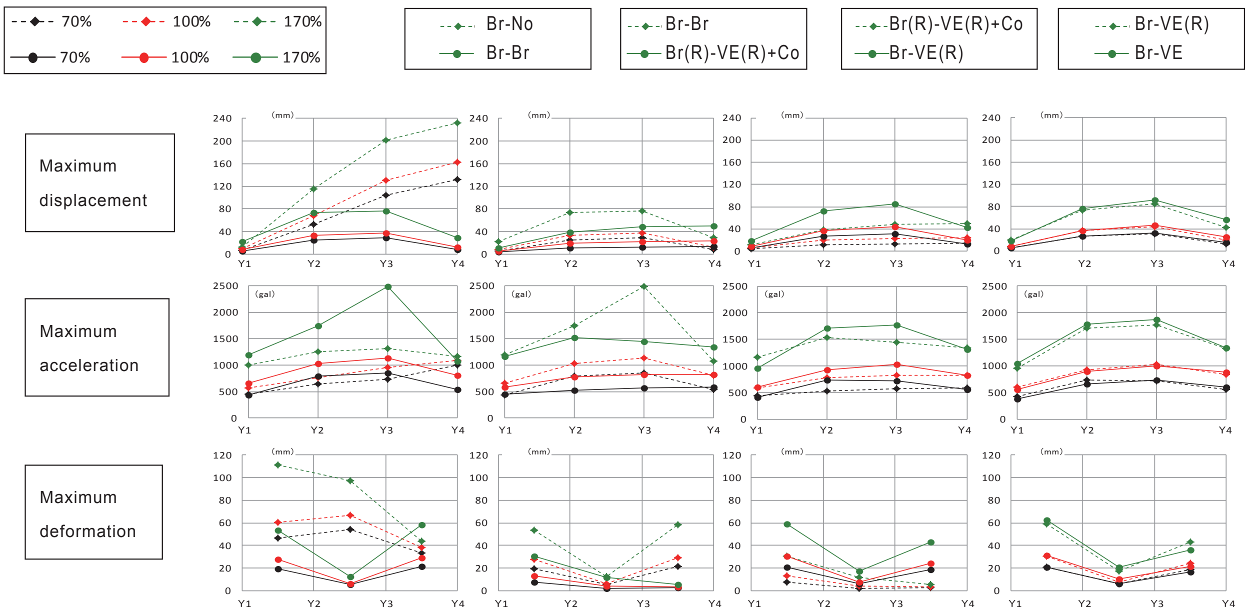


Fig. 8. Maximum Displacement, Acceleration, and Deformation
(top row:displacement, middle row:acceleration, bottom row: deformation)

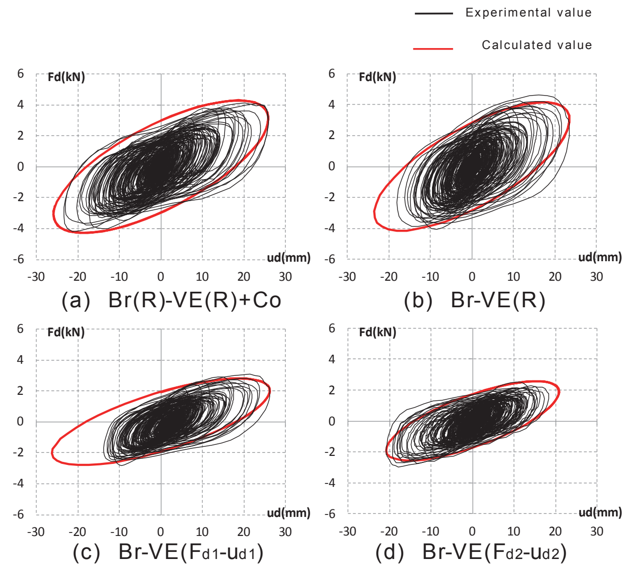


Fig. 9. Correlation between the Load and Deformation for the Damper (BCJ-L2-170%)

Table 3. Temperature Increase and Amount of Absorbed Energy of the Damper (BCJ-L2-170%)

Specimen name	Temperature increase	Amount of absorbed energy
Br(R)-VE(R)+Co	9.22 [°C]	5.61 [kN・m]
Br-VE(R)	6.83 [°C]	5.07 [kN・m]
Br-VE	7.22 [°C]	5.98 [kN・m]

ature increase (Table 3) is also shown. The oval shapes of the experimental values are almost congruent with that of the calculated values. The dampers are considered to have behaved almost as expected. Increased damper temperature causes the viscoelastic body to soften, resulting in a tendency to increase the maximum response. The damper temperature increase was within 10°C if the shear strain was about 250% (Table 3). The damper hysteresis showed stable loops. Figure 10 shows the correlation between the damper force and damper periphery deformation (ua - ud). The damper periphery was hardly deformed, and the rigidity was very high compared with that of the damper. The damper joints and peripheral components were in an ideal situation (extremely rigid, as rigid as steel). Figure 11 shows the correlation between the load and deformation of the aseismic braces. For both the Br-Br and Br(R)-VE(R)+Co specimens, buckling of the aseismic braces was confirmed due to the significant decrease in rigidity during the compression process. The Br-Br specimen gradually shifted to the negative axial force. The compressed side of the aseismic brace is considered to have turned plastic. Meanwhile, the Br(R)-VE(R)+Co specimen showed stable repetitions, and the behavior was within the elasticity range. Thus, the aseismic brace is considered to have retained its integrity even after the completion of the experiment.

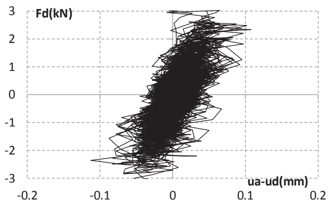


Fig. 10. Joint Rigidity (Br(R)-VE(R)+Co BCJ-L2-170%)

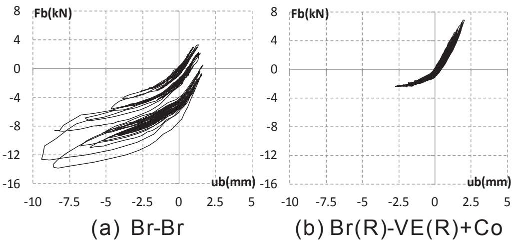


Fig. 11. Correlation between the Load and Deformation of the Aseismic Brace (BCJ-L2-170%)

5. Verification of Construction

Regarding VE(R), the viscoelastic damper design whose effectiveness was confirmed in the experiment, we verified construction in an actual building. The viscoelastic body used in the experiment was 5 mm thick. In the verification, the viscoelastic body was 10 mm thick. One damper was set up per location. The building was a commercial facility in Kanegasaki Town, Iwate Prefecture, Japan. A total of 12 dampers were set up at intervals of 9 m or less on existing cable racks (width: 70 and 100 cm, suspension length: 626~1,394 cm). The installation procedure was as follows: The metal fittings for preventing buckling were attached to the suspension bolts before the dampers were installed. Then, extension metal fittings were used to adjust the overall length of the dampers. Photo 2 shows the situation after construction. Two workers spent about seven hours in total to complete the construction (about 30

Photo 2. Setup Status

min/location). The workability was confirmed to be good.

6. Conclusion

In the shaking table experiment, we confirmed the damping effectiveness of viscoelastic dampers on cable racks. Compared with aseismic braces, dampers reduce response acceleration and response displacement in a well-balanced manner when the input seismic motion increases (Table 4).

Table 4. Comparison between the Load and Deformation of the Aseismic Brace (BCJ-L2-170%)

Item		Br-No	[A] Br-Br	[B] Br-VE	Reduction rate (B-A)/A
70%	Displacement (mm)	132	29.6	31.5	6%
	Maximum acceleration (cm/s^2)	998	856	737	-14%
	Deformation (mm)	46.4	21.4	20.5	-4%
100%	Displacement (mm)	162	38.1	44.0	15%
	Maximum acceleration (cm/s^2)	1092	1135	1029	-9%
	Deformation (mm)	66.7	29.1	30.6	5%
170%	Displacement (mm)	232	76.7	84.6	10%
	Maximum acceleration (cm/s^2)	1312	2490	1774	-29%
	Deformation (mm)	111	58.5	59.0	1%

Suppressing deformation and reducing acceleration help reduce the load on the suspension base. The dampers are expected to reduce the risk of falling cable racks compared with the conventional design. Using this system, we confirmed the workability on an existing building assuming seismic reinforcement, and achieved commercialization. We will establish a method to predict effectiveness based on dynamic simulation, and promote popularization of this construction method.

• Nsys is a trademark or registered trademark of Negurosu Denko Co., Ltd.

Technical Term

*1 BCJ-L2: A simulated seismic waveform created by the Building Center of Japan assuming a large earthquake (an input seismic motion for design). The maximum velocity and maximum acceleration input at 100% are 57.4 cm/sec and 355.7 cm/sec^2, respectively. The seismic intensity of 6 Upper on the seismic scale was subject to measurement.

References

(1) S. Sudo: 60th Tohoku environmental facilities Study Group / Symposium "Towards building equipment damage report in the Great East Japan Earthquake and the future," pp. 9-11 (2012.3)

(2) A. Sumi, T. Teramoto, M. Oomiya, M.Shinozaki: Study on the earthquake resistance of the electrical equipment cable rack, the institute of electrical installation Engineers Journal Vol.24, pp.804-810 (2004.10)

(3) Buildeing center of Japan ed. Building equipment seismic design and construction guidelines. 2014 edition (2012.7)

(4) The Japan Society of Seismic Isolation ed. Manual for design and construction of Passively-Controlled Buildings, Third Edition. P193

(5) T. Nomura, K. Kohara, S. Senda : Development of wooden framework construction method for seismic dampers, mechanical properties and modeling of the 1 brace type. Summaries of technical papers of annual meeting Architectural Institute of Japan. C-1, pp. 469-470 (2009.7)

Contributors The lead author is indicated by an asterisk (*).

T. NOMURA*

• General Manager, Housing Products Engineering Department, Sumitomo Riko Company Limited

Y. KAWABATA

• Housing Products Engineering Department, Sumitomo Riko Company Limited

T. TAKADA

• Project Manager, Housing Products Engineering Department, Sumitomo Riko Company Limited

T. IKEDA

• Acting General Manager Product Development Sec., NEGUROSU DENKO CO., LTD.

E. ASATSUMA

• Acting Manager Product Development Sec., NEGUROSU DENKO CO., LTD.

J. FUNAHASHI

• Associate Director Engineering Dept., NEGUROSU DENKO CO., LTD.