AN EXPERIMENTAL STUDY ON DYNAMIC BEHAVIOR OF A CABLE TRAY SYSTEM USING A LARGE SHAKING TABLE

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Abstract

The cable tray system is used to distribute the electric cable in various buildings. In the case of large-scale facilities, the mass of the cable becomes 100 kg/m at most, the collapse of the cable tray system has a possibility of loss of human life and business continuity. The objective of this paper is to understand the seismic performance of the cable tray system by the large scale shaking table.

These experiments were conducted as part of a joint research project between Tongji University and a laboratory in Japan at the International Joint Research Laboratory of Earthquake Engineering (ILEE) established by Tongji University. The leader is Prof. Kasai at Tokyo Tech. and co-leader is Prof. Huanjun JIANG at Tongji University.

The cable tray system tests were carried out twice, Phase-1 and Phase-2 test as shown. As for the Phase-1 Test, three long cable tray systems which have different seismic elements Type B, Type A and Type SA were tested and the distribution of each seismic elements was set to minimum amount required in Japanese design guideline. In each types have same braces in cable tray longitudinal direction but different seismic element in transverse direction. As for the Phase-2 test, the cable tray was arranged in L-shape and had two joint parts, horizontal joint part and vertical rising part.

In this paper, performance of specimens is discussed by referring to displacement distribution, acceleration distribution, fracture behavior of the cable tray and relationships between shear force and displacement of each seismic elements. Dynamic properties of the cable tray system such as equivalent periods and damping ratios are also discussed.

Keywords: Nonstructural Components; Cable Tray; Shake Table Test

1. Introduction

Many nonstructural components were severely damaged during the Tohoku-oki Earthquake[1)] on March 11, 2011, with 68% of the damage report of electrical wiring coming from the hanging type cable tray system. The cable tray system is used to distribute the electric wiring in various buildings in Japan. In the case of large-scale facilities, the cable mass can measure up to 100 kg/m. The collapse of the cable tray system can lead to the loss of human life. Moreover, it is important to mitigate the damage of the cable tray system in order to recover from seismic damage early. However, while this area has been investigated in the past [2), 3)], the dynamic behavior of the cable tray system remains to be examined.

The objective of this paper is to understand the seismic performance of the cable tray system by the large scale shaking table.

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2. Cable Tray System

2.1 Outline of cable tray system

The cable tray system is a part of wiring electric cable and transmission cable and is suitable for wiring a large amount of cable. Fig. 1 indicates the outline of the cable tray system. The horizontal plane is composed of main-beam and sub-beam in a reticular pattern, and the beams are partially welded to each other. The hanging bolt is connected to inserted nut on a slab or metallic member on a steel frame and supports the weight of the cable tray. The seismically resistant element should be configured at a minimum of 12-meter intervals, and the regulation is proposed by the recommendation of The Building Center of Japan and The Institute of Electrical Installation Engineers of Japan. In this paper, the distance between two main beams is 1,000 mm as large-scale type; the length of the hanging bolt is also 1,000 mm.

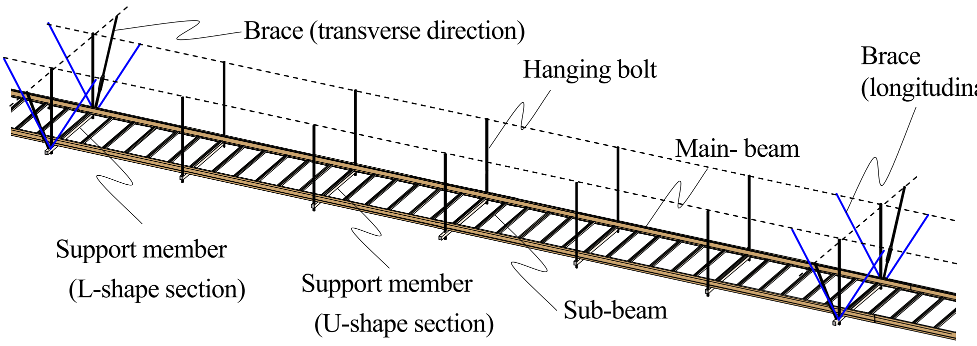


Fig. 1 – Outline of cable tray system (Type-B)

2.2 Three types of seismic resistant elements

There are three types of seismic resistant elements: Type-B, Type-A, and Type-SA, as shown in Fig. 2. Each type has the same braces in cable tray longitudinal direction but a different seismic element in the transverse direction. Type-B is composed of the hanging bolts and braces both in the cable tray longitudinal and transverse direction. The cable tray support member is an L-shape angle (L-50 × 50 × 6), and the braces are turnbuckle braces. The Type-A and Type-SA are composed of L-shape angles (L-75 × 75 × 6), and the high-tension bolts connect each member. The members are seismically designed, assuming a horizontal acceleration 0.6 G for Type-A and 1.0 G for Type-SA.

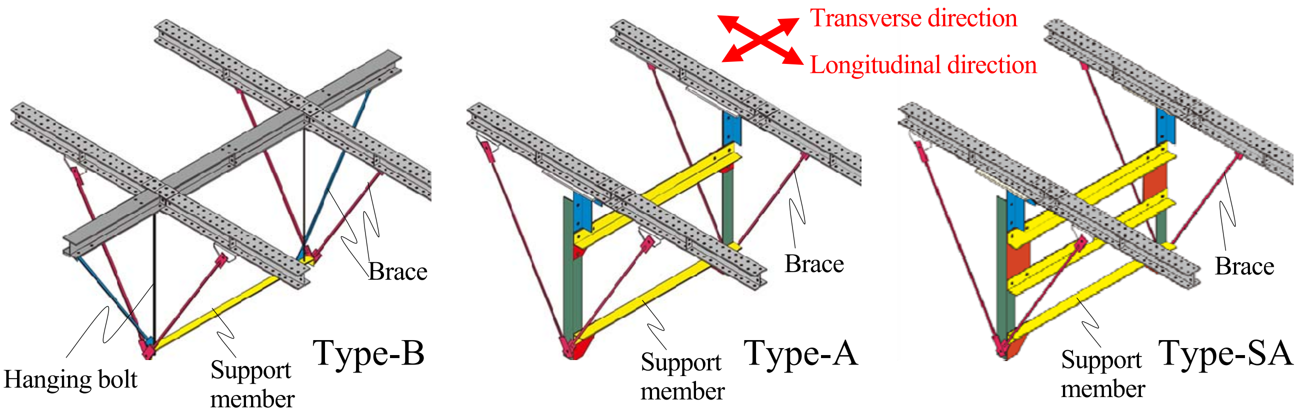


Fig. 2 – Three types of seismic resistant elements

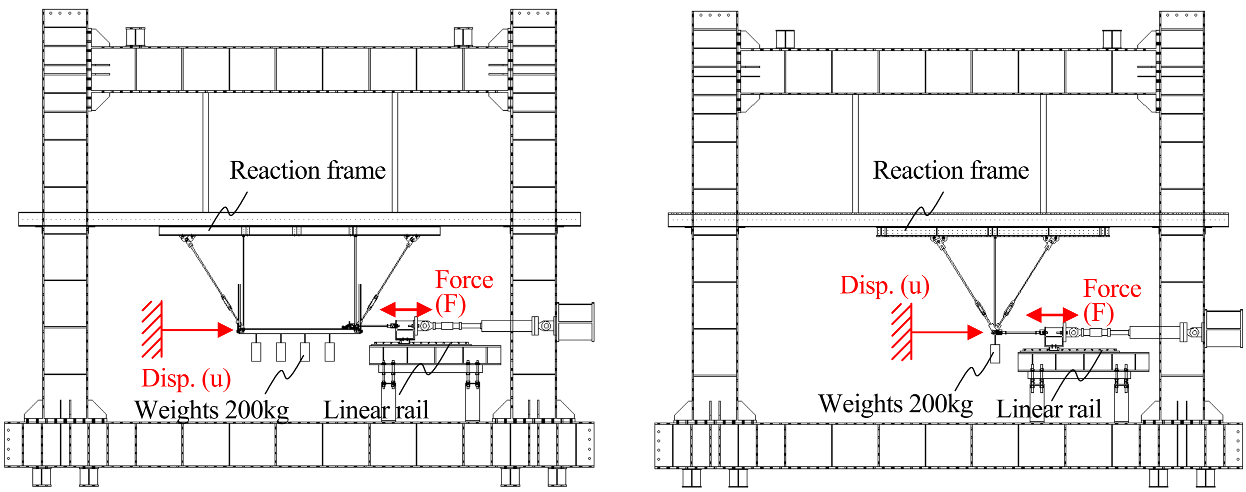
3. Static Test of Seismic Resistant Elements

Before the shake table tests, the static test of the three types of seismic resistant elements was carried out in order to understand their seismic performance.

3.1 Static test outline

The setup of static tests is shown in Fig 3. The specimen is suspended from the steel frame, and the cable tray support member is subjected to horizontal force by the oil jack through the link bar. A 200 kg weight was then suspended from the cable tray support member.

The load step is incremental cyclic loading, and the oil jack is controlled by the absolute displacement (deformation angle = 1/400, 1/200, 1/100, 1/50, 1/33, 1/25 rad., respectively). In each displacement, two cycles are loaded.



(a) Cable tray axis longitudinal direction (b) Cable tray transverse direction

Fig. 3 – Setup of static tests

3.2 Static test result

Fig. 4 shows the relationships between lateral force and displacement in each seismic-resistant type and both directions. Regarding the cable tray transverse direction, the braces of Type-B are buckled around 4 kN horizontal force, resulting in decreased stiffness. Type-A and Type-SA demonstrated high energy dissipation hysteresis without contracting local damage. In the case of cable tray longitudinal direction, the total maximum forces of longitudinal direction are higher than those in transverse direction. Type-A and Type-SA showed similar behavior.

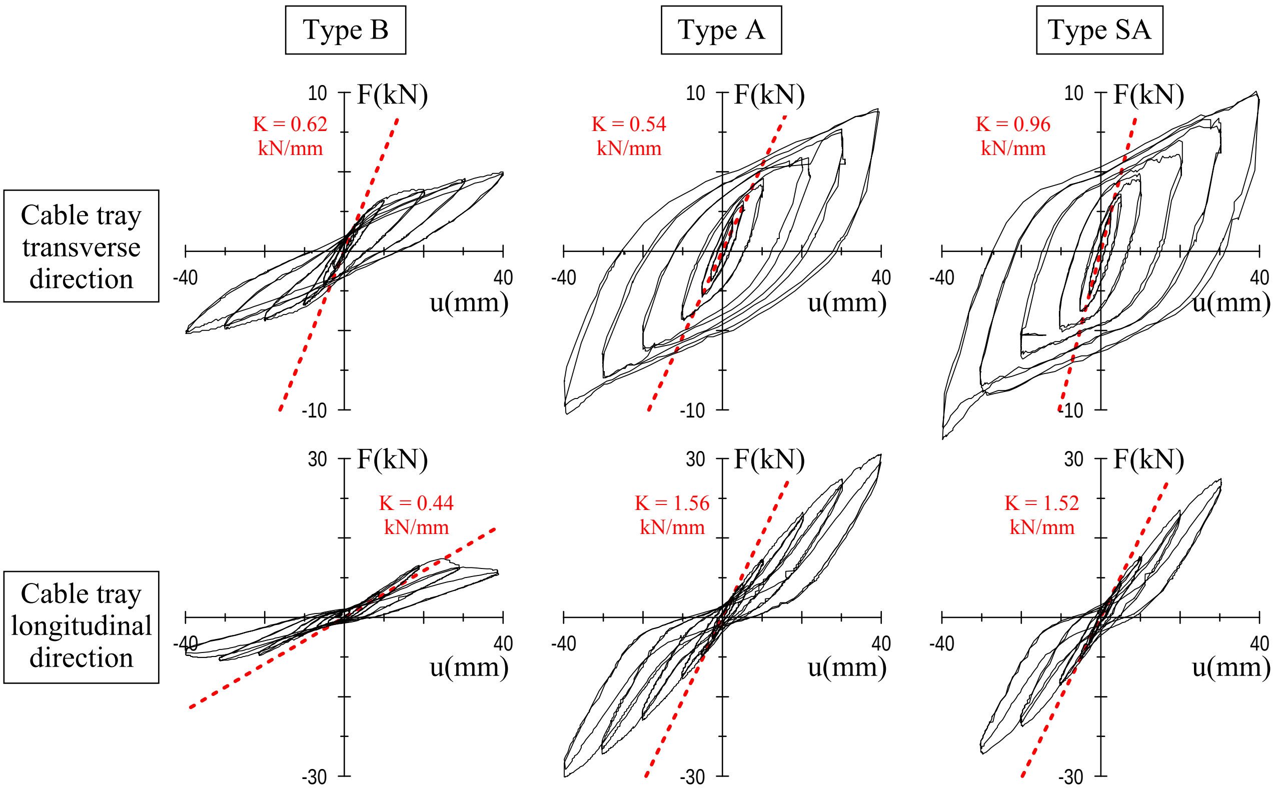


Fig. 4 – Relationships between lateral force and displacement

4. Shake Table Test Scheme

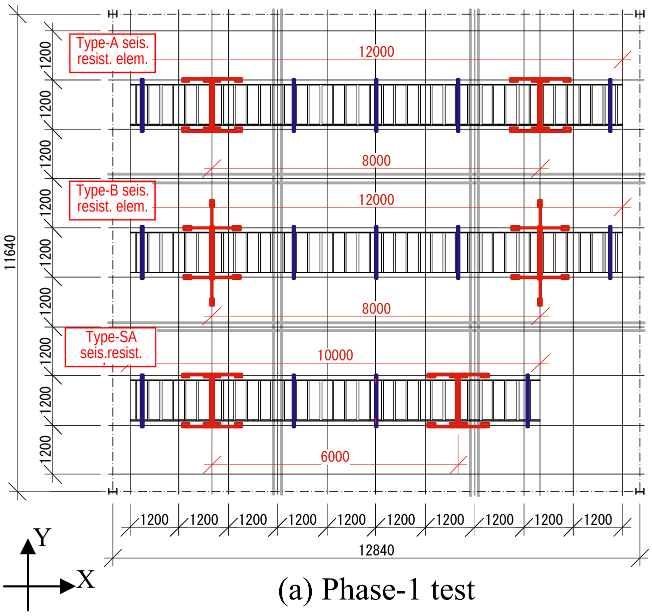
4.1 Test concept and specimens

A rigid platform (natural frequency is approximately 9 Hz) that has a 11.64 m × 12.84 m plane was built on the shake table, and was then suspended. There are two phases of the cable tray shaking test. Fig. 5 shows the cable tray configuration for each phase.

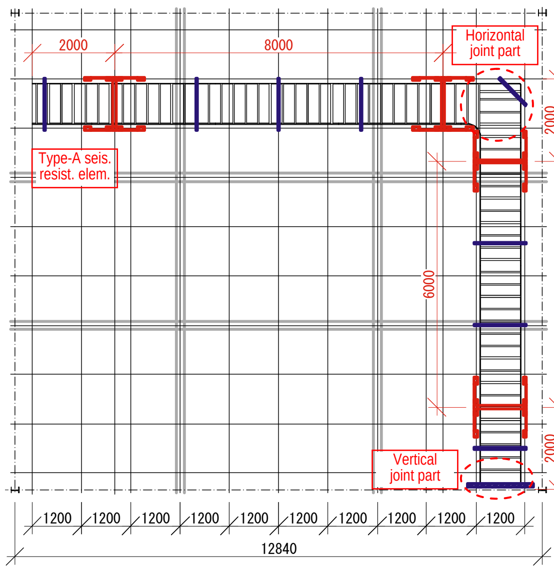
The Phase-1 test focused on three types of seismic resistant elements. There are three cable tray lines, and each line has different seismic elements (see Fig. 6). Seismic elements are configured at 8-meter or 6-meter intervals and are based on Japanese standards. This also means that each seismic element was set to the minimum amount required in the Japanese design guidelines. In the case of Type-B and Type-A, 16 m long cable trays were assumed. Therefore, the weights for the 2 m cable tray were installed on both edges.

The Phase-2 test focused on joint parts where the cable trays are horizontally and vertically connected (Fig. 7). Type-A is used for seismic elements. As described in chapter 5, the joint parts were sufficiently stiffer than the other parts and did not almost have any damage during the tests.

Instead of cable, φ16 steel rebar is set to cable tray as a mass. Fig. 8 shows the steel rebar. The total distributed mass is 106.2 kg/m, including the cable tray. The steel rebar is cut at 2 m intervals to prevent restraining cable tray behavior and tightening to sub-beams by the nylon bands at both edges. To duplicate cable slippage on the cable tray, there are rubber sheets between the steel rebar and cable tray.

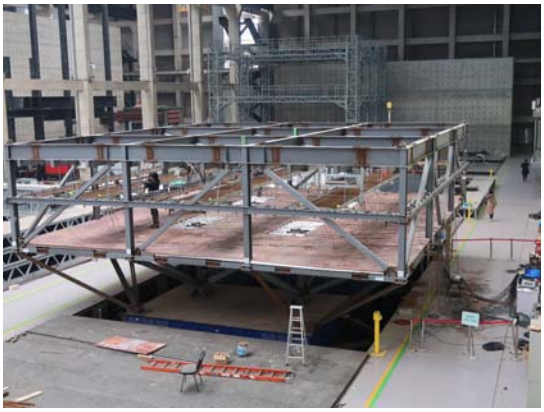


(a) Phase-1 test

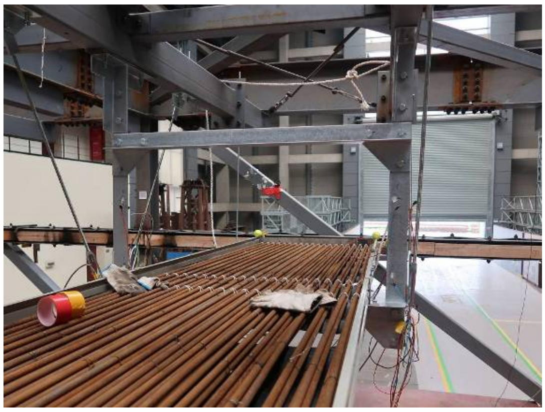


(b) Phase-2 test

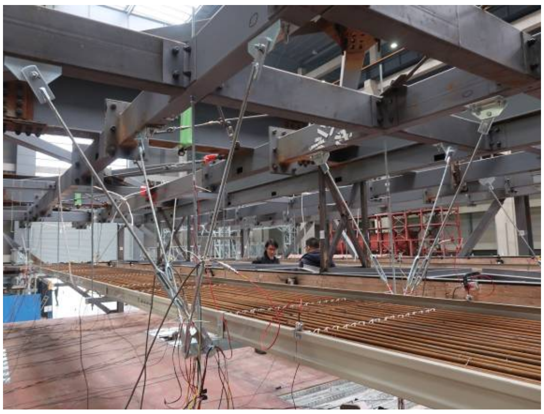
Fig. 5 – Cable tray configuration



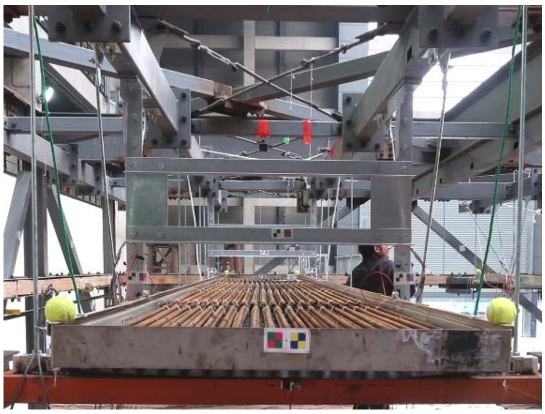
(a) Profile of Phase-1 test



(b) Type-A



(c) Type-B



(d) Type-SA

Fig. 6 – Phase-1 test and each seismic resistant element

(a) Profile of Phase-2 test

(b) Cable tray

(c) Horizontal joint

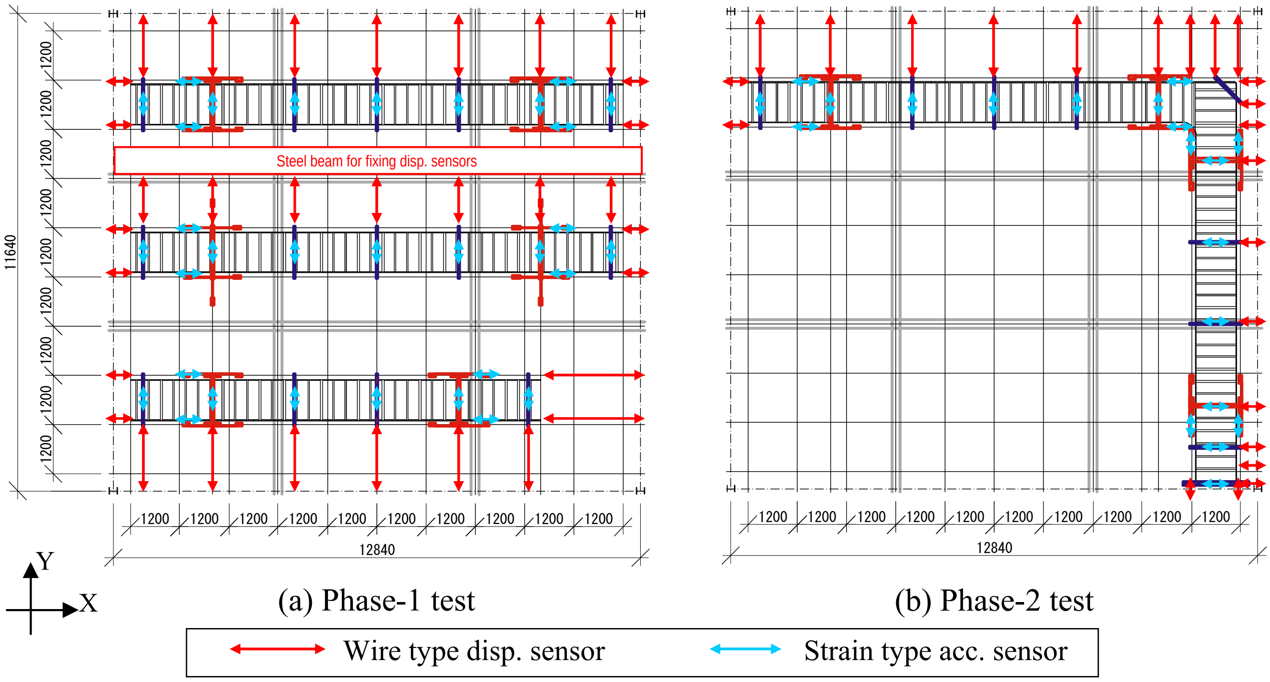
(d) Vertical joint

Fig. 7 – Phase-2 test and each joint parts

Fig. 8 – Steel rebar for distributed mass

4.2 Measurement scheme

The measurement scheme of the shake table test is shown in Fig. 9. At each support member, relative displacements and absolute accelerations are measured by the wire type displacement sensors and strain type acceleration sensors, respectively, to understand the global behavior of the specimen. Absolute acceleration of the shake table and the platform are measured as loading information. Although many strain gages are installed to understand the local behavior, their results are excluded in this report.

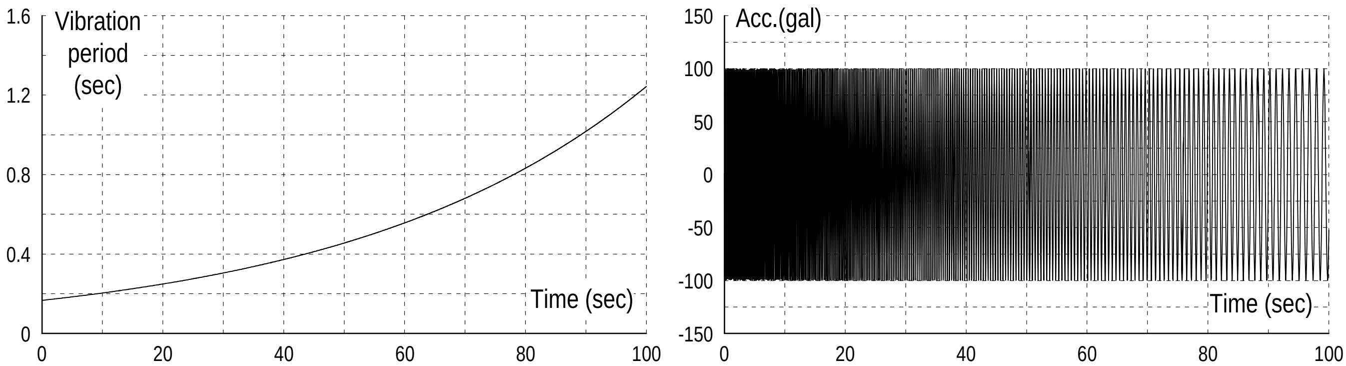


(a) Phase-1 test (b) Phase-2 test

Fig. 9 – Measurement scheme

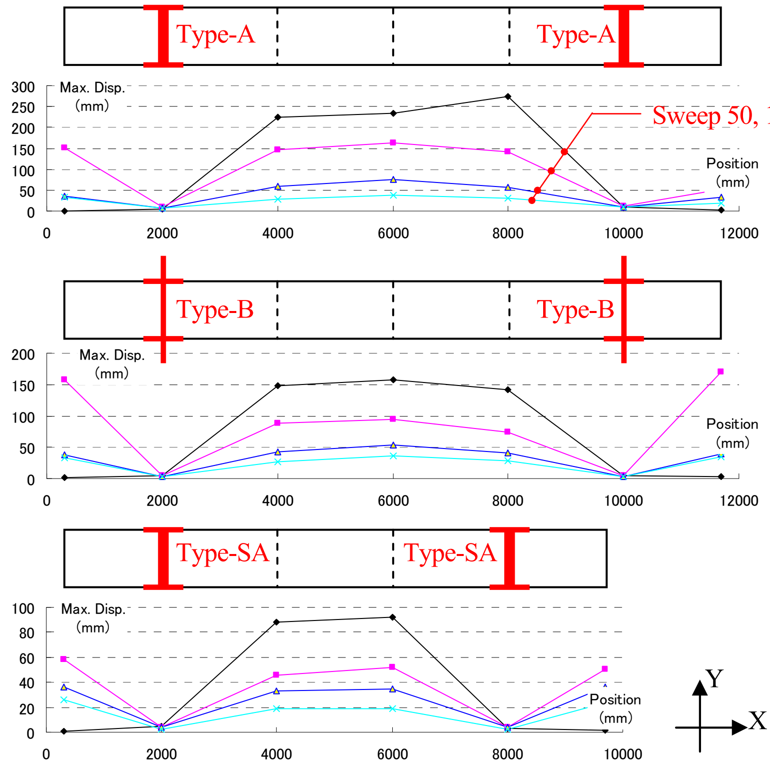
4.3 Input table motions

Sweep waves of constant acceleration were used for input table motions. The sweep wave changes from a high frequency of 6.0 Hz to a low frequency of 0.8 Hz at two octaves/min. The total time duration is 100 seconds. In the Phase-1 test, the specimens are subjected to only Y-direction waves. In the Phase-2 test, the specimen is subjected to three patterns: X-direction only, Y-direction only, and both X- and Y- directions. Additionally, artificial earthquake motions, and the top floor response of 30-story stick models were used to verify the seismic behavior.



(a) Variation of frequency (b) Example of acc. time history (100 gal)

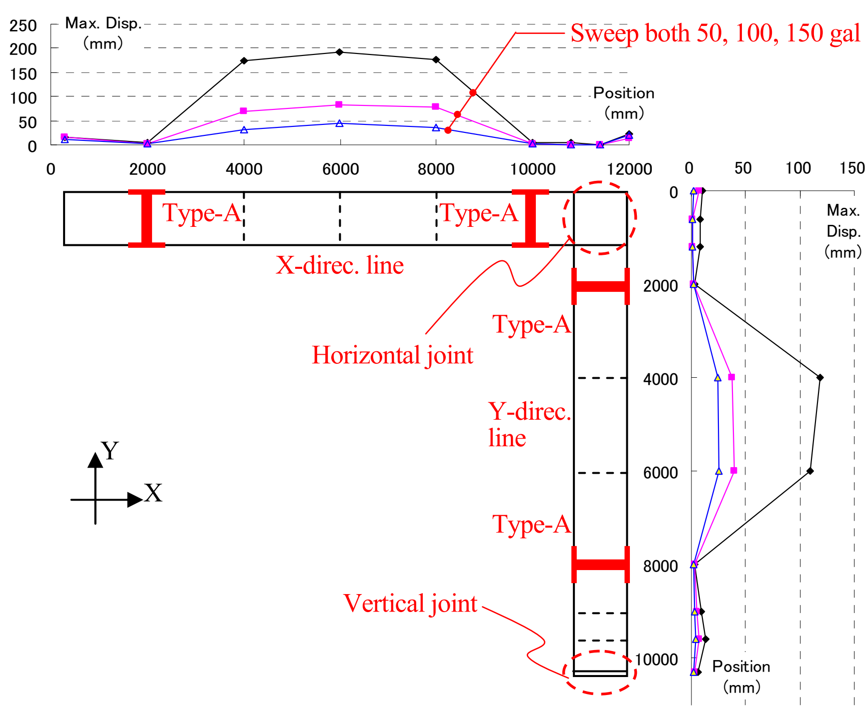
Fig. 10 – Sweep wave



Name	X	Y	Type-A center	Type-B center	Type-SA center
	gal				
WN	50	50	2.15Hz, 3.5%	2.23Hz, 4.4%	2.94Hz, 4.3%
Sweep	0	50	38.1mm	36.8mm	18.9mm
WN	50	50	2.12Hz, 3.3%	2.17Hz, 4.8%	2.91Hz, 4.7%
Sweep	0	100	75.2mm	53.0mm	33.4mm
WN	50	50	1.88Hz, 6.2%	2.04Hz, 4.7%	2.76Hz, 4.8%
Sweep	0	150	163.1mm	94.8mm	45.4mm
WN	50	50	1.57Hz, 10.8%	1.80Hz, 9.2%	2.73Hz, 5.1%
Sweep	0	200	234.7mm	157.7mm	88.3mm
WN	50	50	1.18Hz, 11.2%	1.43Hz, 16.9%	2.07Hz, 10.7%

WN: White noise

(a) Phase-1 tests



Name	X	Y	X-direc. line	Y-direc. line
	gal			
WN	50	50	2.23Hz, 3.4%	2.92Hz, 3.8%
Sweep	50	0	25.1mm	23.1mm
Sweep	0	50	43.9mm	25.9mm
Sweep	50	50	45.0mm	24.4mm
WN	50	50	1.90Hz, 6.2%	2.90Hz, 3.7%
Sweep	100	0	19.1mm	37.8mm
Sweep	0	100	75.5mm	13.6mm
Sweep	100	100	83.4mm	37.9mm
WN	50	50	1.79Hz, 7.3%	2.80Hz, 4.1%
Sweep	150	0	18.8mm	107.9mm
Sweep	0	150	177.5mm	0.9mm
Sweep	150	150	191.6mm	118.5mm
WN	50	50	1.40Hz, 13.2%	2.20Hz, 12.9%
Sweep 200 X, Y & Both			-	-
WN	50	50	1.21Hz, 10.5%	1.77Hz, 10.8%

WN: White noise

(b) Phase-2 tests

Fig. 11 – Maximum displacement, natural frequency and damping ratio

Before and after sweep waves, the white noise wave, which has maximum acceleration 50 gal, was input each time to evaluate the dynamic properties of each specimen, such as natural frequency and damping ratio. Natural frequencies and damping ratios were computed by curve-fitting the idealized transfer function assuming steady-state response to the empirical transfer function estimated from acceleration data. The amplitude of the empirical transfer function is the ratio of Fourier spectrum amplitude spectra at the center of each seismic element and top of the platform. An example of transfer function amplitude, along with the fitted idealized curve, is shown in Fig. 10.

5. Shake Table Test Results

5.1 Peak responses and dynamic properties

Fig.11 shows peak responses of each specimen under sweep waves. Maximum displacements, natural frequencies and damping ratios at the center of seismic elements (means cable tray position) listed in the figure. In the case of the Phase-2 test, there are no displacement records because the displacement sensor was removed before the 200 gal sweep waves.

It is clear that the cable tray deformations are large, and the displacements at the seismic resistant element and the joint parts are small. In the case of the Phase-1 test, displacement is the largest in Type-A and the smallest in Type-SA. The initial frequency is almost 2.2 Hz and 2.9 Hz corresponding to 8 m intervals and 6 m intervals, respectively. The value of the natural frequency decreased as more deformations were experienced. The initial damping ratio is almost 4% in all specimens. The value of the damping ratio gradually increased as more deformations were experienced.

5.2 Behavior of seismic resistant elements

As for the Phase-1 test, Fig. 12 shows the comparison of seismic resistant elements between shake table tests and static tests. The vertical axis of the shake table test is calculated by the inertia force, which is obtained as the product of cable tray distributed mass and distributed accelerations. As for the Type-B, the static test stiffness was lower than the shake table test stiffness because it was expected that the static test displacement included the reaction frame deformation. In the case of also Type-A, the two hystereses do not correspond to each other, and the reason for this is still being evaluated. Regarding the Type-SA, the curves are almost the same between the static test and the shaking table test.

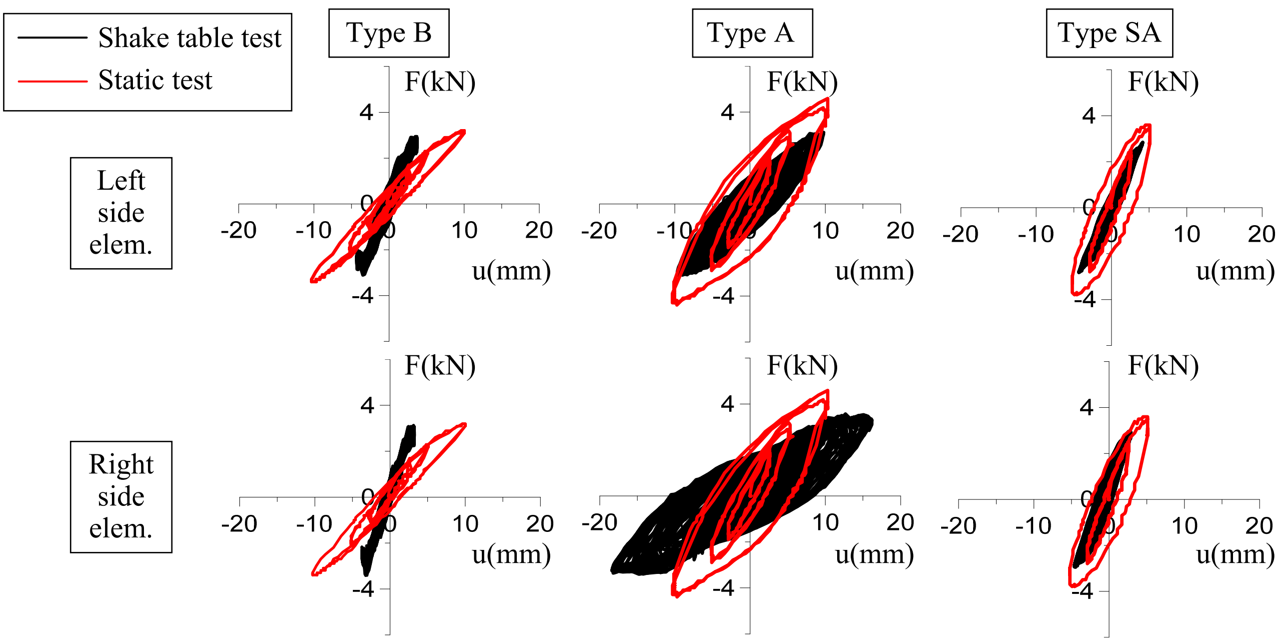


Fig. 12 – Comparison of seismic resistant elements between shake table tests and static tests

6. Conclusions

1) Static loading tests of the three types of seismic resistant elements were conducted using a full-size specimen, and their non-linearity behavior was evaluated in both cable tray longitudinal and transverse direction.

2) Large scale shake table tests of hanged cable tray were conducted. There were two phases, Phase-1 test focused on three types of seismic resistant element, and Phase-2 test focused on joint parts that were connected to the cable trays horizontally and vertically. In each test, the dynamic behavior, such as displacement distribution, natural frequency, and damping ratio, was determined.

7. References

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