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STUDY ON A SLIDING-TYPE BASE ISOLATION SYSTEM -TRI-AXIAL SHAKING TABLE TEST AND ITS SIMULATION-

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SUMMARY

To investigate the behavior of sliding-type base isolated structures, tri-axial shaking table tests of a scaled base isolated structure and its simulation were carried out. It was made clear experimentally that this system had good isolation effects when subjected to three dimensional strong motions. And the response behavior was well simulated by one dimensional and three dimensional analysis.

INTRODUCTION

Authors developed a sliding-type base isolation system to reduce horizontal seismic acceleration, which was named TASS system (TAISEI SHAKE SUPPRESSION SYSTEM). Slide occurs between sliding bearings and bearing plates and Coulomb damping is generated to absorb seismic energy.
Tri-axial shaking table test and its simulation were conducted to investigate the behaviour of base isolated structures with this system and to confirm the base isolation effect.

OUTLINE OF TESTS

Test Specimen   A scaled specimen was a 2 ×2 span, 1 story steel frame with the scaling factor of 1/8, which represented a four-story reinforced concrete building with the natural period of 0.3 sec in case of fixed-base condition. Two kinds of sliding bearing and two kinds of bearing plate were used in combination. Sliding bearings are rigid-type and elastic-type. A rigid sliding bearing is composed of PTFE (Poly-Tetra Fluoru Ethyrene) plate encased in a steel frame. An elastic sliding bearing is a laminated Chroloprene rubber bearing with a PTFE plate at its bottom. The fundamental period of the prototype building is 1.0sec when mounted on elastic sliding bearings. Bearing plates were mirror-finished SUS plate in most cases and PTFE coated steel plates in some limited cases. PTFE coated steel plates were used with elastic sliding bearings to have the lower coefficient of friction. The test specimen and isolator are shown in Fig. 1. Scale law and dimensions of the test specimen are shown in Table 1 and Table 2.

Method of Experiment The test specimen was excited by tri-axial shaking table. EL CENTRO 1940 and HACHINOHE 1968 were used for input waves. At first, horizontal uni-axial excitation was carried out to see the fundamental response characteristics of this base isolation system and then bi-axial and tri-axial excitations were carried out. Input maximum acceleration or velocity was set at three levels; 30Gal, 25 cm/s, 50cm/s. At 30Gal input, slide did not occur. Maximum 25cm/s and 50cm/s inputs correspond to strong and very strong ground motions.

RESULTS OF TESTS

Fundamental Response Values Response values of three kinds of combination of sliding bearing and bearing plate under uni-axial excitation by EL CENTRO are shown in Fig.2. In case of rigid sliding bearings, no isolation effect can be obtained when input acceleration level is 30 Gal and no slide occurs. But when input level increases and slide occurs, acceleration mitigation effect becomes clear. In case of elastic sliding bearings, mitigation effect of maximum response acceleration can be obtained by period-lengthening effect of the bearings, even when input acceleration level is 30 Gal and no slide occurs. The mitigation effect of maximum acceleration gets clearer as the input level increases. This tendency is more apparent for elastic sliding bearings on PTFE coated bearing plates. Maximum displacement of the base was 2.4cm for elastic sliding bearings on PTFE coated bearing plates, which was equivalent to 21.2cm for the prototype building and within designed allowable displacement 30cm. Residual displacements of the base were all within 2.4cm expressed in the value of the prototype building.

Response Values by Bi-axial and Tri-axial Excitation Comparisons of response values of uni-axial and multi-axial excitation are shown in Fig. 3 for elastic sliding bearings. Maximum accelerations of the frame had little difference among these three excitations. Maximum displacements of the base by bi-axial excitation were a little larger than those by uni-axial excitation and almost equal to those by tri-axial excitation. Therefore multi-excitation has not much influence on the response characteristics of the specimen.

The Change of Transfer Function Transfer functions, which are expressed as the ratios of the acceleration of the frame top to that of the shaking table, are shown in Fig. 4 for rigid sliding bearings and elastic sliding bearings. In the case of rigid sliding bearings, the peak at the natural frequency was sharp when input acceleration was 30 Gal and slide did not occur. But this peak disappeared and the amplification ratio was less than 1.0 for most frequencies when input velocity was 50cm/s. This means that the sliding-type base isolation has no resonant frequency. In the case of elastic sliding bearings, such a tendency is visible too, but not more distinctive than that in the case of rigid sliding bearings.

The Coefficient of Friction The coefficient of friction was evaluated by inertia force-displacement relationship of the sliding bearings and horizontal springs. The inertia force-displacement relationship for three kinds of combination of sliding bearing and bearing plate are shown in Fig. 5.
The coefficients of friction of rigid sliding bearings and elastic sliding bearings were from 0.10 to 0.15. On the other hand, the coeffient of friction of elastic sliding bearings on PTFE coated bearing plates was smaller as about 0.05.

Ratios of Torsion Ratios of torsion were evaluated as the ratio of horizontal acceleration component by torsional response to the translational component in the case of uni-axial excitation and tri-axial excitation. The results are shown in Table 3 for the elastic sliding bearings.

Ratios of torsion in the case of uni-axial excitation was 0.09~0.13 for three input levels. Accordingly, the difference of the coefficient of friction among nine sliding bearings was small. Ratios of torsion in the case of tri-axial excitation was also as little as 0.12~0.13 for three input levels. This means that the change in axial force of nine sliding bearings did not induce the torsional response of the specimen.

SIMULATION ANALYSIS

One Dimensional Analysis One dimensional lumped mass model shown in Fig. 6 (a) was used for the simulation analysis by uni-axial excitation. The shear force-displacement relationship of sliding bearings and horizontal springs was modeled as bi-linear type. Model constants were determined by the results of 30 Gal low input level. The coefficient of friction was 0.12 and constant. The ratios of damping were 1% for the steel frame and 8% for the isolator. Comparison of analytical results with experimental results are shown in Table 3 and in Fig. 6 (b),(c).

Response acceleration of the frame and displacement of the base were well simulated in x-direction. So the analytical inertia force-displacement relationship of isolation devices had a good agreement with the experimental one. It is adequate to use the constant coefficient of friction.

Three Dimensional Analysis Three dimensional model is shown in Fig. 7 (a). The frame was modeled as a three-dimensional beam on a rigid base plate, under which nine sliding bearings and four horizontal springs were attached. Model constants were determined as same as those of one dimensional model. Comparison of simulated results with experimental results are shown in Table 3 and in Fig. 7 (b), (c) in the case of bi-axial excitation by EL CENTRO 50cm/s for elastic sliding bearings.

Response acceleration of the frame and displacement of the base in both directions were simulated well. The orbit of displacement of the base in x-y direction by simulation had a good agreement with that by experiment.

CONCLUSION

1) It was made clear experimentally that this system had good isolation effects when subjected to three dimensional strong motions.

2) It was also confirmed that change in axial force of sliding bearings by rocking vibration and vertical excitation gave little influence on the torsional response.

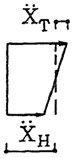
3) The response characteristics were well simulated by one dimensional model and three dimensional model.

Table 1 Scale Law

		Scale
Length	λ_L	1/8
Weight	λ_W	1/250
Time	λ_T	$1/\sqrt{8}$
Displacement	λ_L	1/8
Velocity	λ_L / λ_T	$1/\sqrt{8}$
Acceleration	λ_L / λ_T^2	1.0
Pressure of isolator		1.0
Period	λ_T	$1/\sqrt{8}$

Table 3 Ratios of Torsion for Elastic Sliding Bearing

Input level	Ratio of torsion	
	Uni-axial	Tri-axial
30 Gal	0.09	0.12
25 cm/s	0.13	0.13
50 cm/s	0.11	0.13



Ratio of torsion $= \ddot{X}_T / \ddot{X}_H$

$\ddot{X}_T$: Horizontal acceleration by translational response

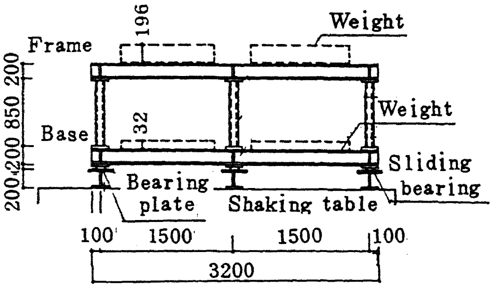
$\ddot{X}_H$: Horizontal acceleration by torsional response

Table 2 Dimensions of The Test Specimen

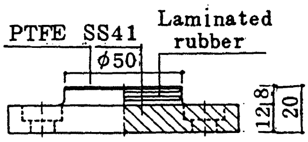
		Test specimen	Prototype building
Size of frame		3m×2.25m×1.25m	24.0m×18.0m×12.8m
Elastic sliding bearings		φ7.0~φ3.5cm	≒φ60cm (N=200t)
Rigid sliding bearings		φ4.0~φ2.0cm	≒φ35cm (〃)
Period of frame		0.11 sec	0.3 sec
Elastic sliding bearings		0.35 sec	1.0 sec
Total weight		10.1 t	2500 t
Pressure of sliding bearings of side columns	Ridig sliding bearing	177 kg/cm²	200 kg/cm²
	Elastic sliding bearing	64 kg/cm²	70 kg/cm²

Table 4 Comparison Between Experimental Maximum Values and Analytical Maximum Values

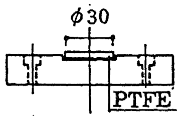
			X(NS)-direction		Y(EW)-direction	
			Experiment	Analysis	Experiment	Analysis
Uni-axial excitation	Acceleration of frame	Gal	222	238	188	201
	Displacement of base	cm	1.8	1.7	1.0	1.0
	Input acceleration	Gal	488		324	
Bi-axial excitation	Acceleration of frame	Gal	223	201	201	178
	Displacemen of base	cm	1.9	1.8	1.4	1.3
	Input acceleration	Gal	501		353	



(a) Elevation of specimen

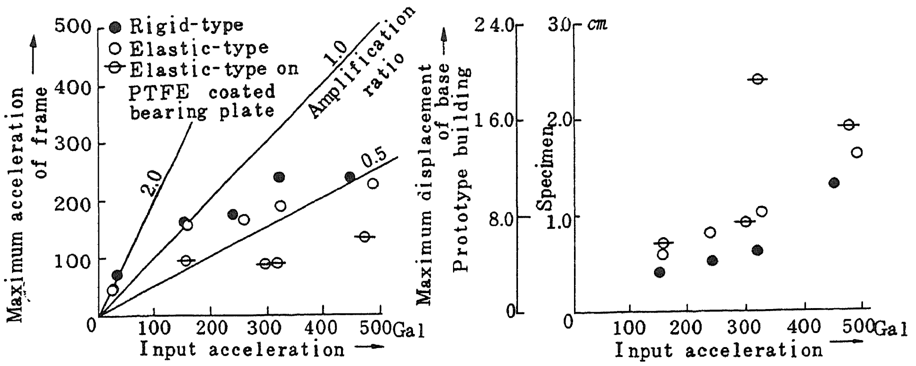


(b) Elastic sliding bearing



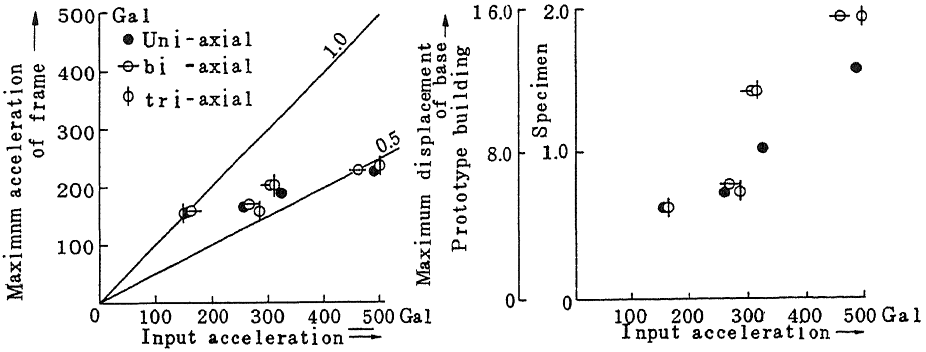
(c) Rigid sliding bearing

Fig.1 Specimen



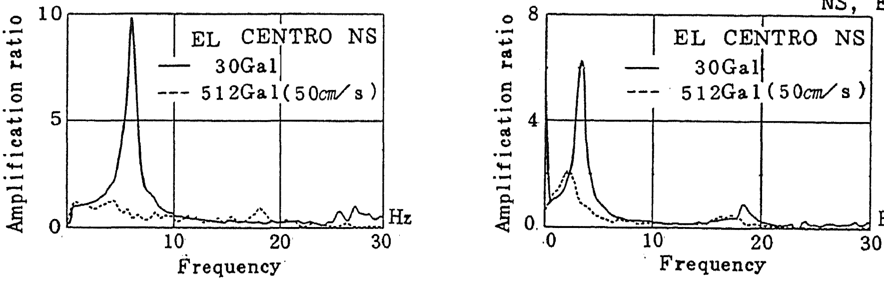
(a) Maximum acceleration of frame (b) Maximum displacement of base

Fig.2 Response Results of Three Kinds of Sliding Bearing and Bearing Plate under Uni-axial Excitation by EL CENTRO NS, EW



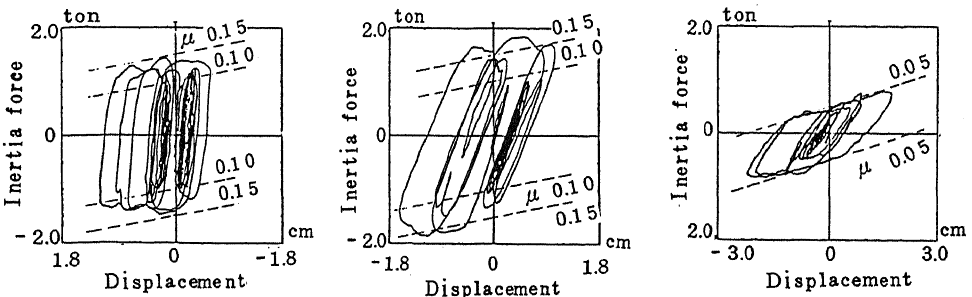
(a) Maximum acceleration of frame (b) Maximum displacement of base

Fig.3 Response Results under Uni, Bi, Tri-axial Excitations by EL CENTRO NS, EW, UD



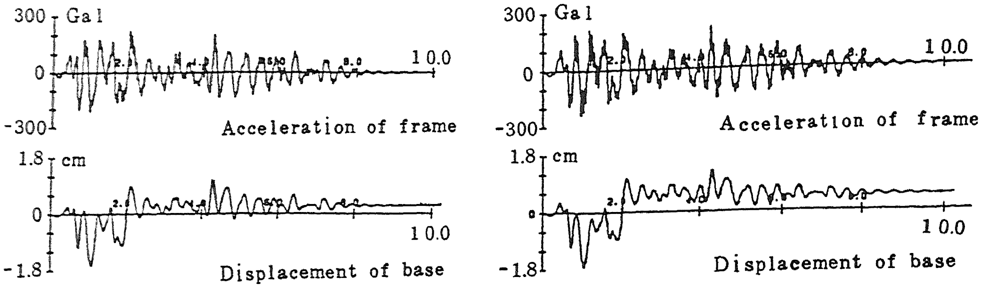
(a) Rigid sliding bearing (b) Elastic sliding bearing

Fig. 4 Transfer Function



(a) Rigid sliding bearing (b) Elastic sliding bearing (c) Elastic sliding bearing on PTFE coated bearing plate

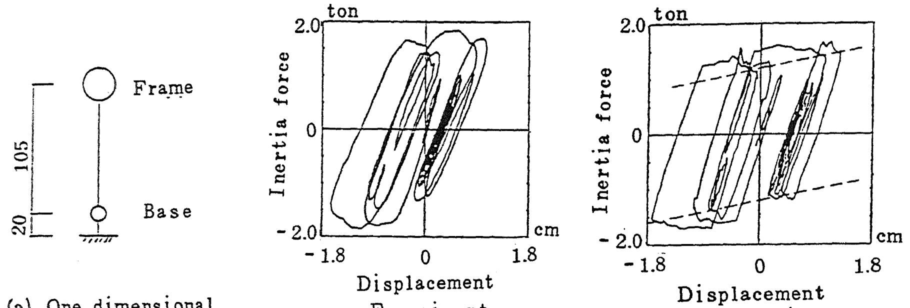
Fig.5 Inertia Force-Displacement Relationship of Isolation Devices



Experiment

Analysis

(b) Response acceleration of frame and displacement of base



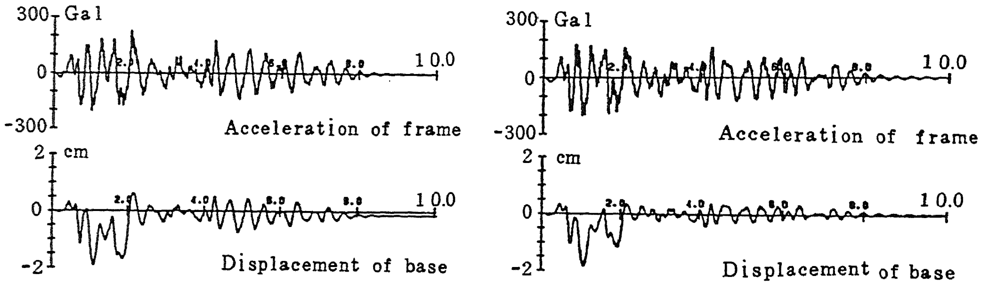
(a) One dimensional lumped mass model

Experiment

Analysis

(c) Inertia force-displacement relationship of isolator

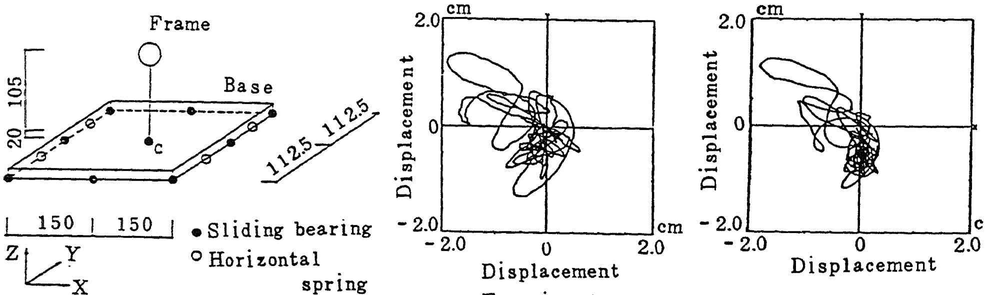
Fig.6 Simulation Analysis by One Dimensional Model under Uni-axial Excitation by EL CENTRO NS 512Gal (50cm/s)



Experiment

Analysis

(b) Response acceleration of frame and displacement of base



Experiment

Analysis

(a) Three dimensional model

(c) Displacement orbit of base

FIg.7 Simulation Analysis by Three Dimensional Model under Bi-axial Excitation by EL CENTRO X(NS): 512Gal Y:(EW) 314Gal