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FEASIBILITY STUDY ON BASE-ISOLATED BUILDING

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SUMMARY

In recent years, buildings that employ base isolation system have been successively constructed in Japan although not all of the base-isolated structure related problems have been solved. To deal with this situation, the Architectural Institute of Japan established the Subcommittee of Base-isolated Structure in November 1986, with the primary aim of providing structural engineers with the right perception and effective advice regarding base-isolated structure. Examinations using existing buildings have been under way by the Model Design Working Group of the Subcommittee, chiefly aiming at the solving of the problems at issue when designing a base-isolated structure. In this paper, the example designs performed by the Working Group will be introduced and, at the same time, the use of base-isolated structure greatly expanding the freedom of design described.

INTRODUCTION

Since 1979, studies on base-isolated construction have been conducted by the writers. When studying the elasto-plastic properties of a structure, it is difficult to properly evaluate the results of model experiment in accordance with the scale effect, and this leads to an idea that a actual scale experiment is necessary to study the elasto-plastic properties. Based on this idea, a proof test with the use of an existing house (Refs. 1 and 2) and a vibration test with the use of a full scale building (Ref. 2) mounted on a large-sized vibration table (10.2 x 7.4m) were performed. The existing house is a 2-storied reinforced concrete base-isolated construction and was built in 1982 in the city of Yachiyo, Chiba Prefecture, Japan. Acceleration seismographs have been set continually in the house's foundation, first floor and roof since its completion to observe earthquake motion. This observation is still under way. Of the record of earthquake registered to date, one occurred off the east of Chiba Prefecture on December 17, 1987, was of the greatest. During the earthquake, the maximum acceleration registered in the foundation was 131 gal. The roof responded at 35 gal. The ratio of maximum acceleration was about 1/4.

This experimental house triggered off an all-out study on base-isolated construction throughout Japan. Today, over ten base-isolated buildings have been constructed. The Model Design Group solves the problems involving practical design methods of the superstructure and the devices of base isolation.

In this paper, tow buildings will be chosen from among the model design buildings as interesting study targets and simultaneously examinations will be compiled.

RESPONSE OF CONVENTIONAL STRUCTURE

One of the buildings chosen is an apartment house constructed of steel and reinforced concrete. It consists of eleven stories and one penthouse, with eaves height of 31.75m. The floors above the 6th floor are set back in the longitudinal direction like a staircase. Figs.1 and 2 show the floor's plan and elevation. This building is hereinafter called the T-Type Building. Another building is a warehouse of steel construction, with three stories, and eaves height of 20.0m. With the live load of $1.5t/m^2$ and each floor height of 6.5m, the warehouse is equivalent to a 6-storied building from the viewpoints of load and scale. The first floor in the longitudinal direction is provided with a transportation access, preventing a well balanced arrangement of braces, and therefore it is of rigid frame. Figs.3 and 4 show its plan and elevation. This building is hereinafter called the S-Type Building. To facilitate the analysis of earthquake response, both buildings are designed with a mass-spring system. The restoring characteristics of tri-linear type is adopted for the T-Type Building, and bi-linear type for the S-Type Building. Damping factor is assumed to be 2% for both buildings. Tables 1 and 2 show the weight and rigidity of each building.

At present in Japan, the accelerations observed in the past at El Centro, Taft, and Hachinohe are used primarily as the analysis input earthquake motion, and usually its maximum amplitude is standardized with its maximum velocity. However, earthquake has its own spectral characteristics, and therefore the natural frequency of a structure creates the intensity of input energy. For this reason, the standardization of input level by the intensity of input earthquake does not mean the standardization of the strength of the building. Here, using an idea that velocity responds almost uniformly to a natural period of one second or more, the magnitude of earthquake input is standardized using the input energy level equivalent to this. Concretely, input level was standardized by correcting the magnitude of amplitude and the time axis of input acceleration. The acceleration of El Centro (north-south component) and that of Hachinohe (north-south component) are used as an input earthquake acceleration.

Figs.5 and 6 show the distribution of the maximum acceleration response value and maximum story-to-story displacement obtained by the calculation of response. There figures reveal that the individual stories become plasticized.

BASE ISOLATION DEVICES

The results of laminated rubber's compressive shear test revealed that if the secondary shape factor is 5 or more, the horizontal spring constant little varies with the fluctuation of the vertical load, where the secondary shape factor(D/nt) is the value obtained by dividing the diameter of the laminated rubber by the overall thickness of laminated rubber and the primary shape factor(D/4t) is the value obtained by dividing the restraint area of rubber lamina by the free surface area. With reference to the test results (Ref. 3), the laminated rubber to be used in this study is assumed to be of $150kg/cm^2$ or less in unit compressive stress and 5 or more in the secondary shape factor. The spring constant of the laminated rubber was determined with reference to the formula proposed by P.B. Lindley (Ref. 4).

The lead damper and steel damper as shown in Figs.7 and 8 are used to restrain the deformation of the base isolation device and to make the characteristic of frequency insensible.

INSTALLATION OF BASE ISOLATION SYSTEM TO CONVENTIONAL STRUCTURES

In this section, the installation of the base isolation system to conventional structure is examined. A laminated rubber is set underneath a column. A lead damper is used for the T-Type Building, and a steel damper for the S-Type Building. The dampers are so arranged that the centroid of the superstructure concur with the center of rigidity of the base isolation system. The laminated rubber is linear(rigidity=Ki) and the dampers have the restoring characteristics of perfect elasto-plastic type(rigidity=Kd and yield strength=Qy). The earthquake response analysis model consists of the conventional type model plus a base isolation layer. The primary natural period without damper is 4.2 seconds for the T-Type Building, and 3.8 seconds for the S-Type Building. The earthquake acceleration to be used for the calculation of responses is identical to one which was used for the analysis of the conventional model.

Next, the superstructure is re-designed with reference to the earthquake response analysis results. The T-Type Building is of the box rigid frame having wide columns arranged in the longitudinal direction, and of the shear wall frame with the partition wall designed as shear walls in the transverse direction. With braces arranged at the perimeter of the S-Type Building, the rigidity of the building is improved. Figs.9 and 10 compare the cross section of main members before and after designing.

RESPONSE ANALYSIS OF BASE-ISOLATED STRUCTURE

The weight and rigidity of each floor of buildings are shown in Tables 3 and 4. The base isolation system redesigned to meet the change of design of the superstructure. The superstructure is a shear type concentrated mass model. The responses of earthquake are analyzed by using this model, but, with the aim of evaluating the base-isolated structure, the input accelerations used are the original accelerations observed at El Centro (north-south component) and at Hachinohe (north-souse component). In addition, both the time axis and amplitude as corrected are used as an input acceleration. Figs.11 and 12 show the distribution of maximum acceleration and maximum story displacement. The figure indicates that the responses of the buildings are small and the superstructure is in the elastic region. The maximum displacement of the base isolation system is 13.3cm (S-Type) and 14.5cm (T-Type) in case of the El Centro acceleration, and 14.3cm (S-Type) and 11.5cm (T-Type) in case of the Hachinohe acceleration.

CONCLUSIONS

The adoption of the proposed base isolation system results in a considerably small response value of the superstructure and, at the same time, allows freer building design. Although not detailed in this paper, the concurring of the centroid of a building with the center of rigidity of this base isolation system will enable the amount of rotaitional response to be sufficiently neglected in the stage of design.

The input earthquake motion to be used for the designing of base-isolated structures is deliberated at present by the Subcommittee for Base-isolated Structure. However, the proposed base isolation system would be capable of dealing with any input acceleration if properly adjusted. Base-isolated construction can offer various potentials, and a greater understanding on the part of administration would be necessary for this system to develop further in Japan, thereby enabling the erection of stone masonry buildings in the near future in earthquake-prone Japan.

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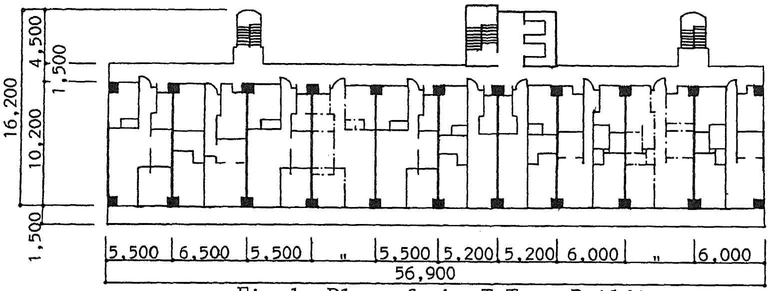


Fig.1 Plan of the T-Type Building

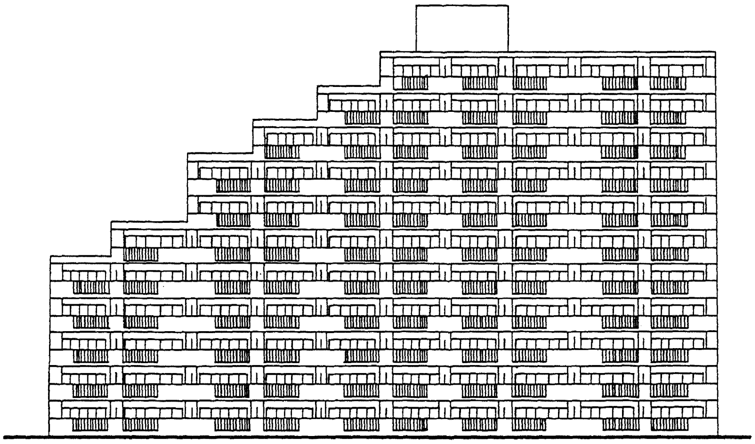


Fig.2 Elevation of the T-Type Building

Table 1 Analytical Parameter for the Conventional T-Type Building

STORY	WEIGHT (t)	K1 (t/cm)	K2 (t/cm)	K3 (t/cm)	$\delta y1$ (cm)	$\delta y2$ (cm)
11	548.2	1571.8	264.5	7.9	0.1192	1.15
10	557.0	1930.4	279.4	9.6	0.1424	1.70
9	635.2	2488.6	387.9	12.4	0.1383	1.70
8	713.3	2857.2	447.5	14.3	0.1489	1.88
7	717.4	3122.0	491.7	15.6	0.1604	2.05
6	808.5	3654.2	612.9	18.3	0.1545	1.95
5	891.7	4188.6	717.3	20.9	0.1576	1.90
4	897.7	4676.4	833.1	23.4	0.1562	1.86
3	897.7	5458.0	972.4	27.3	0.1447	1.77
2	897.7	6147.8	1120.4	30.7	0.1432	1.63
1	897.7	10680.	1938.4	53.4	0.0939	0.99

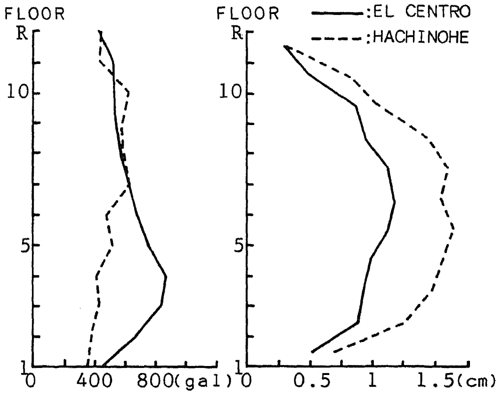


Fig.5 Max. Response Value of the Conventional T-Type Building

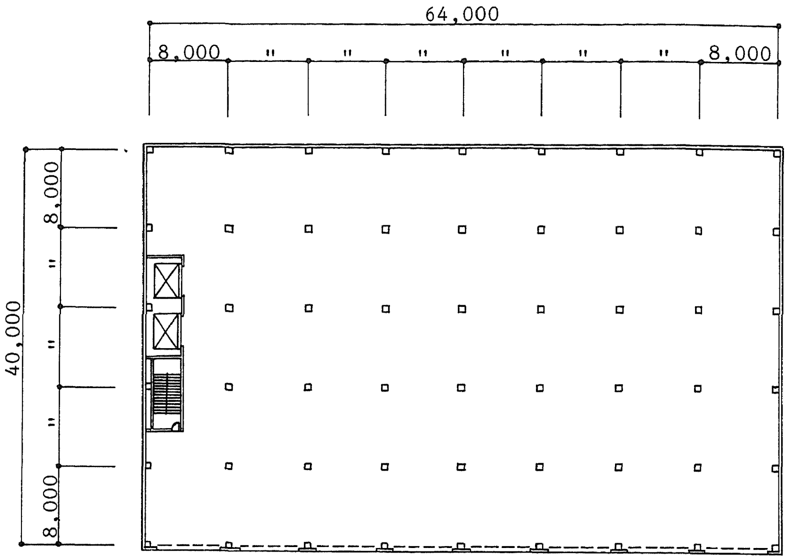


Fig.3 Plan of the S-Type Building

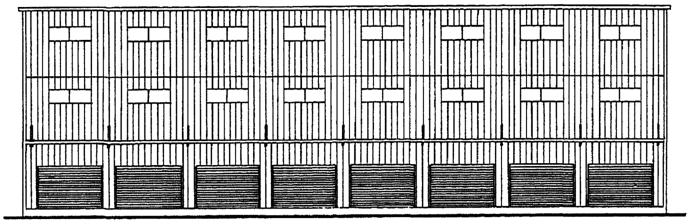


Fig.4 Elevation of the S-Type Building

Table 2
Analytical Parameter for the Conventional S-Type Building

STORY	WEIGHT (t)	K1 (t/cm)	K2 (t/cm)	δy (cm)
3	1133	219.6	109.8	7.342
2	3688	387.0	193.5	6.075
1	3688	522.7	261.4	7.183

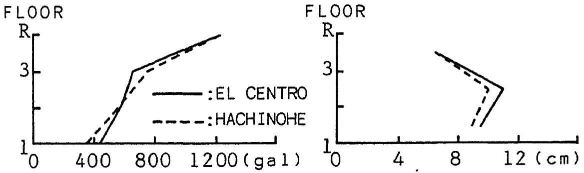


Fig.6 Max. Response Value of the Conventional S-Type Building

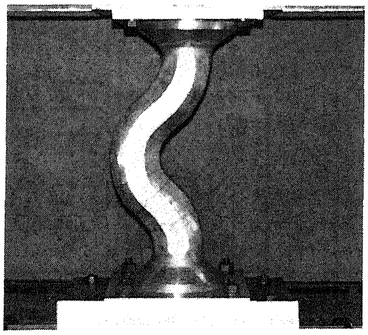


Fig.7 Lead Damper

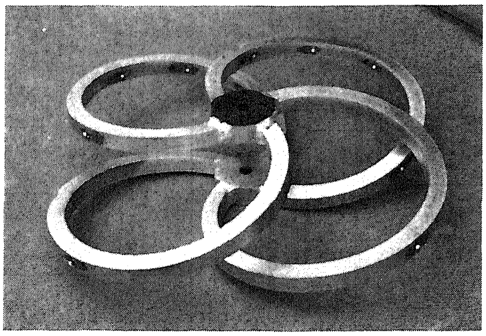
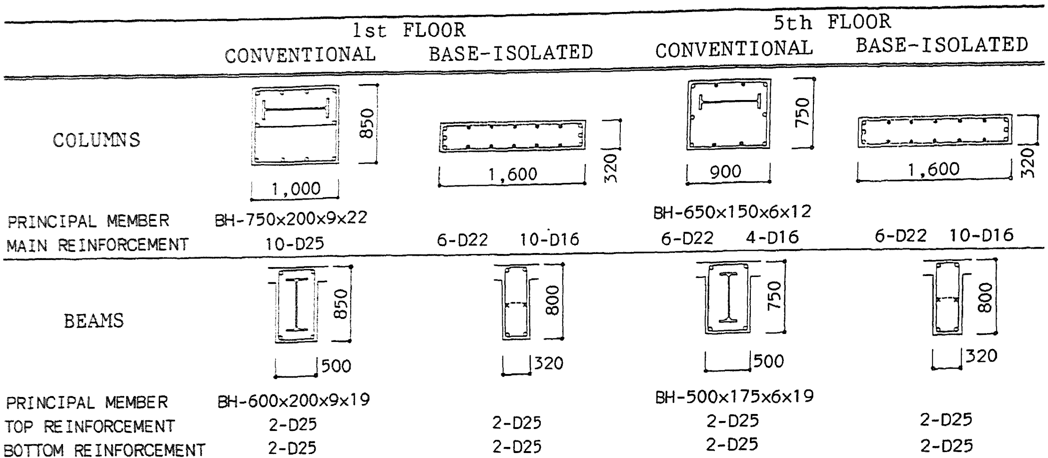


Fig.8 Steel Damper



	1st FLOOR CONVENTIONAL	1st FLOOR BASE-ISOLATED	5th FLOOR CONVENTIONAL	5th FLOOR BASE-ISOLATED
COLUMNS				
PRINCIPAL MEMBER	BH-750x200x9x22		BH-650x150x6x12	
MAIN REINFORCEMENT	10-D25	6-D22 10-D16	6-D22 4-D16	6-D22 10-D16
BEAMS				
PRINCIPAL MEMBER	BH-600x200x9x19		BH-500x175x6x19	
TOP REINFORCEMENT	2-D25	2-D25	2-D25	2-D25
BOTTOM REINFORCEMENT	2-D25	2-D25	2-D25	2-D25

Fig.9 Comparison of the Cross Section of the T-Type Building

COLUMNS		
STORY	CONVENTIONAL	BASE-ISOLATED
3	□-500×500×16	□-400×400×12
2	□-500×500×22	□-400×400×16
1	□-500×500×22	□-400×400×16

BEAMS		
FLOOR	CONVENTIONAL	BASE-ISOLATED
R	H-390×300×10×16	H-294×200× 9×14
3	H-582×300×12×17	H-390×300×10×16
2	H-692×300×13×20	H-390×300×10×16

Fig.10 Comparison of the Cross Section of the S-Type Building

Table 3
Analytical Parameter

STORY	WEIGHT (t)	RIGIDITY (t/cm)
11	512.5	1378.6
10	499.0	2033.2
9	567.8	2512.7
8	636.5	2889.7
7	637.9	3121.1
6	715.5	3493.3
5	783.7	3795.2
4	784.8	3952.8
3	784.9	4190.1
2	784.9	4788.3
1	784.9	7715.7
B	819.8	Ki=19.0 Kd=396.9 Qy=184.9

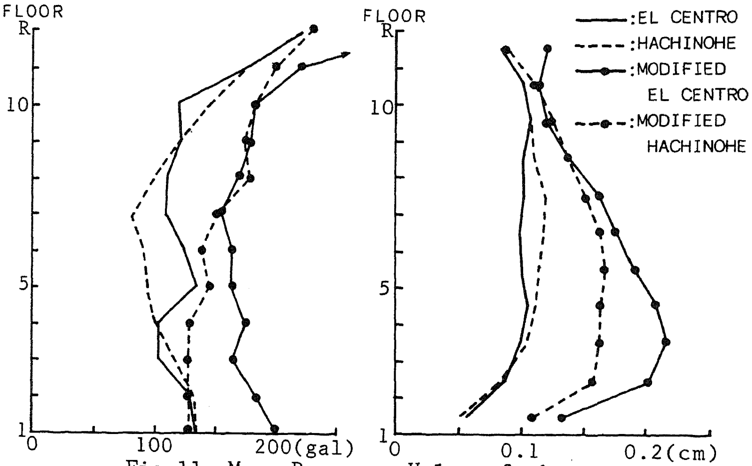


Fig.11 Max. Response Value of the Base-isolated T-Type Building

Table 4
Analytical Parameter

STORY	WEIGHT (t)	RIGIDITY (t/cm)
3	1133	1667
2	3688	3269
1	3688	1923
B	4777	Ki=37.4 Kd=148.0 Qy=444.0

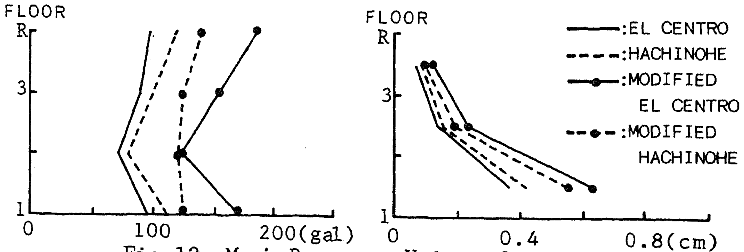


Fig.12 Max. Response Value of the Base-isolated S-Type Building