EFFECTIVENESS OF BASE-ISOLATED BUILDING STRUCTURE SUBJECTED TO THE HYOGO-KEN NANBU EARTHQUAKE

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Paper No. 1533. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ABSTRACT: The effectiveness of a base-isolated building structure is evaluated through the investigations of the observed records subjected to the Hyogo-ken Nanbu Earthquake. The base-isolated building of 3-story RC structure and the ordinary building of 3-story steel frame structure have located about 34.5 km distance from the epicenter of Hyogo-ken Nanbu Earthquake. On the base-isolated building, the maximum accelerations of horizontal components, x-direction (N334E) and y-direction (N64E) were 198 cm/s^2 (Gal) and 273 Gal at the roof floor, respectively. While on the steel building , those were 965 Gal and 677 Gal, respectively. The maximum accelerations of vertical component were same level for both building. The base-isolated building have shown good performance for reductions of acceleration (especially, for horizontal components) under this strong earthquake.

KEYWORD: base-isolated building, Hyogo-ken Nanbu Earthquake, high damping rubber bearing, observed records, reductions of acceleration

1. INTRODUCTION

The Hyogo-ken Nanbu Earthquake (M=7.2) occurred at 5:46 a.m., January 17, 1995 [1]. Ground motion and structural response records for this earthquake were obtained at the laboratory building of Technical Research Institute of Matsumura-Gumi Corporation (TRIMC). This building as shown on Photo.1 is the first construction of base-isolated building in the Kansai area (west part of Japan), and was deigned in TRIMC. This base-isolated building is jointed to the ordinary type of 3-story steel frame structure at the each floor with expansion joints. The site of those buildings have located about 34.5 km distance from the epicenter of the Hyogo-ken Nanbu Earthquake as shown in Fig 1.

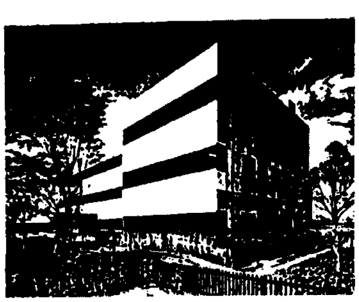


Photo. 1 Base-isolated building

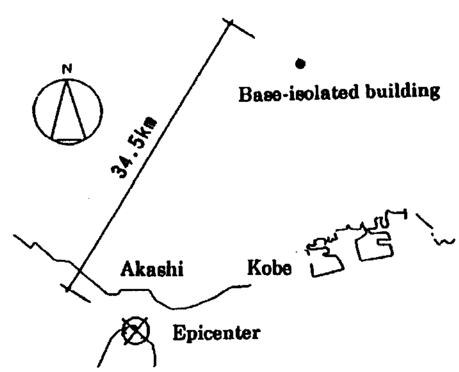


Fig. 1 Location of the isolated building

2. STRUCTURAL DESIGN

2.1 Outline of the base-isolated building

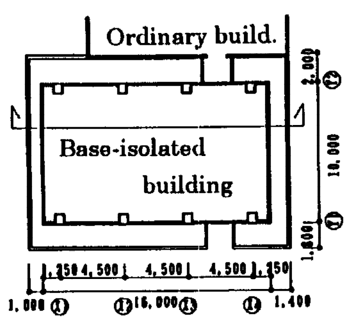
The outline of the base-isolated building is shown in Table 1.

Table 1 Outline of the base-isolated building

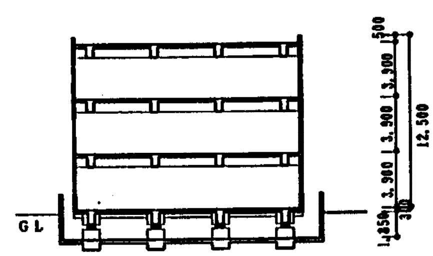
Name of building	Laboratory Building ,Technical Research Institute Matsumura-Gumi Corporation
Location	Kanokodai Minami-machi, Kita-ku, Kobe, Japan
Structure area	160 m^2
Total area	480 m^2
Above ground	3 stories
Eaves height	12.0 m
Max. height	12.5 m
Foundation bed	Designed ground level-2.8 m
Main structure	RC (3 stories)
Isolator	High damping rubber bearing

2.2 Upper structure and Foundation structure

The plan and the cross section are shown in Fig 2a and Fig 2b. This building is based on sandstone and mud-stone by the direct foundation. The allowable bearing capacity of soil for permanent loading is 50 tf./m^2, and the allowable bearing capacity of soil for temporary loading is 100 tf./m^2.



2a Plan



2b Section

Fig. 2 Outlook of the base-isolated building

2.3 Configuration of isolator

The high damping rubber bearing devices (MRB-LHD) are adopted for as the isolator. The 4 pieces of rubber bearing of ϕ 600 mm (LHD-060) and the 4 pieces of ϕ 700 mm (LHD-070) were located (8 pieces in all) as shown in Fig 3.

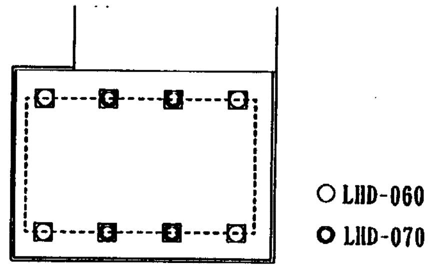


Fig. 3 Arrangements of isolator

The specifications of high damping rubber bearing are shown in Table 2.

Table 2 Specification of high damping rubber bearing (MRB-LHD)

Specification	LHD-060	LHD-070
Rubber diameter(mm)	600	700
Rubber thickness (mm)× Layers	6.5×21	7.5×18
External rubber(mm)	8	8
Internal steel plate(mm)×Numbers	2.2×20	2.2×17
External steel plate (center ,outside)	25,20	25,20

The isolators were designed as that the equivalent·natural period (Teq.) is 2.4 seconds at designed shear strain γ =150%, and the natural frequency in vertical direction is 13 Hz or more.

2.4 Expansion joints with periphery

The base-isolated building is jointed to the neighbor office building at each floor with the expansion joints. The covering walls of the passage-way between the two buildings are adopted with string course sheet lining which are used for train. These were designed to have the clearance about 40 cm in all horizontal directions and about 5 cm in the vertical direction. The covered passage-way each floor is designed as that the steel plate fixed to skeleton of office building with hinges was laid on the floor of the laboratory building (Base-isolated building). The stainless steel plate was applied to the contact parts so as to ensure smooth sliding.

3. OUTLINE OF EARTHQUAKE RESISTING DESIGN

3.1 Concepts of a seismic design

Three types of seismic motions are used as the input motions for the a seismic design of the base-isolated building. Those are 1) EL CENTRO 1940 NS, and, TAFT 1952 EW, 2) HACHINOHE EW which are adopted for investigations of the relatively long period component prevails and 3) The artificial seismic wave which is arranged in consideration of local property of northern Kobe area. As the intensity for input motion corresponding to the levels 1,2 and 3 ,those seismic motion are adjusted into maximum are velocity 20,40 and 60 cm/s, respectively. The classifications of those are defined in Japan as shown in Table 3.

Table 3 Concept of input seismic motion levels

Level	Concept
1	Earthquake to which the building may more during its service life
2	Earthquake of highest class which can be
3	Earthquake for allowable seismic safety

Each part of the upper building, isolator and foundation structure of the isolated building has the required a seismic performance at specific input level so as to ensure the seismic safety of base-isolated building.

3.2 Analytical model

A four stories numerical model is assumed as an equivalent shear type of sway-locking model for the base-isolated building structure. The characteristics of restoring force for each story is defined as the tri-liner type, and it is considered the relation between shear force and displacement of each story as is used for incremental load analysis. As the isolator has the spring characteristics in horizontal direction, the sway spring characteristics is defined as a modified bilinear types corresponding to its shear strain level, and the locking spring characteristics considered as flexible type.

3.3 Numerical results

The natural periods of the base-isolated building are shown in Table 4. Those values are simulated from primary numerical analysis. In this table, δ means horizontal deformation of isolator and γ means horizontal deformation ratio (%) by the total thickness of rubber sheets.

Table 4 Natural periods of the base-isolated building

Deformation of base-isolator	First (s)	Second (s)
Equivalent stiffness δ =1.4 cm (γ = 10%)	1.208	0.239
Equivalent stiffness δ = 10 cm (γ = 74%)	1.903	0.243
Equivalent stiffness δ = 20 cm (γ =147%)	2.335	0.243
With fixed column base	0.378	0.151

From numerical analysis by using 3-types of ground input motions by each input level, the maximum dynamic responses of the base-isolated building are calculated as shown in Table 5. In this table, the maximum responses, which are concerned with shear force ,deformation angle and displacements of isolator, are shown from the results 3 kinds of input motion for each level.

Table 5 Results of earthquake response analysis

Response	input	X direction	Y direction
Maximum shear force coefficient of lower of upper building	20 cm/s	0.107(TAFT EW)	0.106(TAFT EW)
	40 cm/s	0.252(HACHINOHE EW)	0.144(HACHINOHE EW)
	60 cm/s	0.260(HACHINOHE EW)	0.254(HACHINOHE EW)
Maximum deformation angle of story	20 cm/s	1/1915(TAFT EW)	1/1873(TAFT EW)
	40 cm/s	1/1407(HACHINOHE EW)	1/1146(HACHINOHE EW)
	60 cm/s	1/279(HACHINOHE EW)	1/233(HACHINOHE EW)
Displacement of base-isolated story	20 cm/s	7.28(HACHINOHE EW)	6.28(HACHINOHE EW)
	40 cm/s	15.37(HACHINOHE EW)	15.22(HACHINOHE EW)
	60 cm/s	33.04(HACHINOHE EW)	33.13(HACHINOHE EW)

4. OBSERVED RECORDS AT THE HYOGO-KEN NANBU EARTHQUAKE

4.1 Consideration for observed response of the base-isolated building

Figure 4 shows the arrangements of seismograph on the base-isolated building.
Figure 5a ,5b and 5c show the recorded accelerations at Hyogo-ken Nanbu Earthquake. By comparing the upper floor responses with foundation motions, it is found that the observed response of the 1st floor and the roof floor are showing long period characteristics.
The maximum accelerations corresponding with Fig 5 are shown in Table 6. In this table, the each value shown in parenthesis means the magnification ratio by the acceleration of foundation level, and the notation of NS and EW mean N334E and N64E, respectively.

Table 6 Maximum accelerations (Gal)

Location of seismograph		NS	EW	UD
Laboratory (base-isolated)	Roof floor	198(73%)	273(103%)	334(144%)
	1st. floor	148(54%)	253(95%)	266(115%)
	Foundation	272(100%)	265(100%)	232(100%)
Office(ordinary)	Roof floor	965(355%)	677(255%)	368(158%)

By comparing the maximum accelerations at roof floor (shown in Table 6) of the base-isolated building with the steel flame ordinary building, remarkable effects for reductions of amplifying response on the upper floor are gained on the base-isolated building .
However, as shown in Fig 5c, the accelerations on the UD direction are not different between both responses of the base-isolated building and the ordinary building.
Those are shown that high damping rubber bearing could not take effect in the UD direction .
The maximum velocity on the foundation level are calculated as 20.5 cm/s (NS) , 32.2 cm/s (EW), 8.7 cm/s (UD) from the observed acceleration records, respectively .
Figure 6 shows the velocity response spectrum at the foundation level.
The predominant period for the horizontal directions are appeared on about 0.8 s. and about 1.5 s.; and those for the vertical direction are appeared on about 0.45 s. and about 0.9 s. Those results show the characteristics which this earthquake included by enormous input level and relatively long period motions. Those characteristics had been considered as severance for the

base-isolated buildings ,practically, it was found that the base-isolated building could conquer to this earthquake.

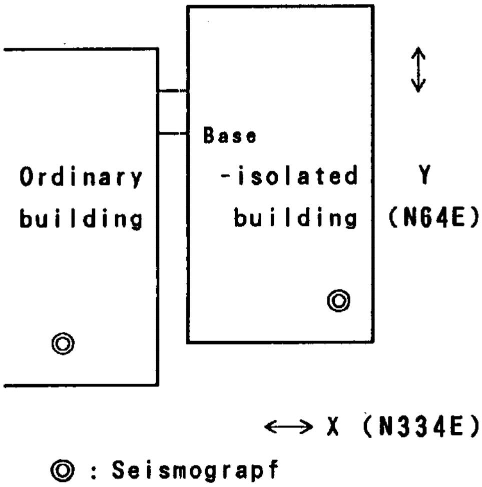


Fig. 4 Arrangement of seismograph

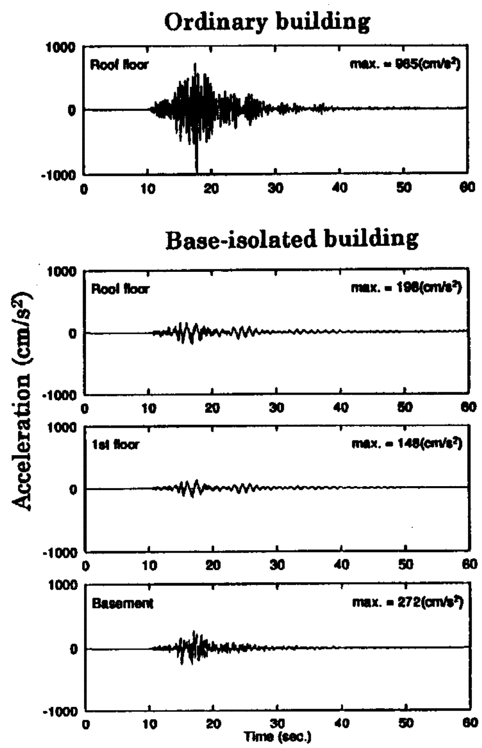


Fig. 5a Recorded accelerations (NS)

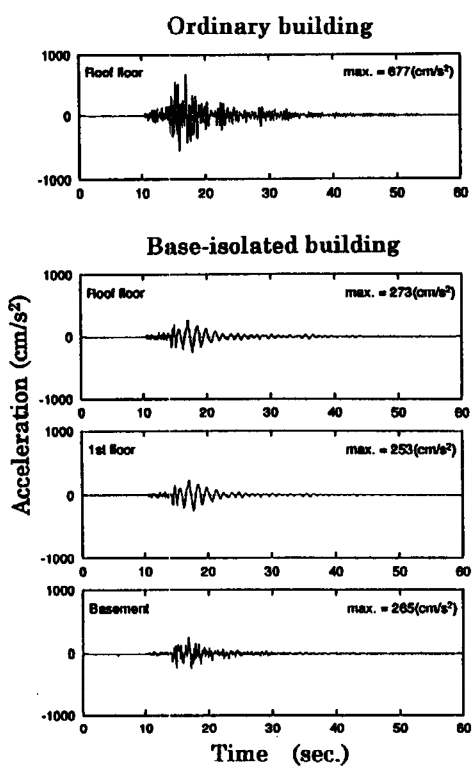


Fig. 5b Recorded accelerations (EW)

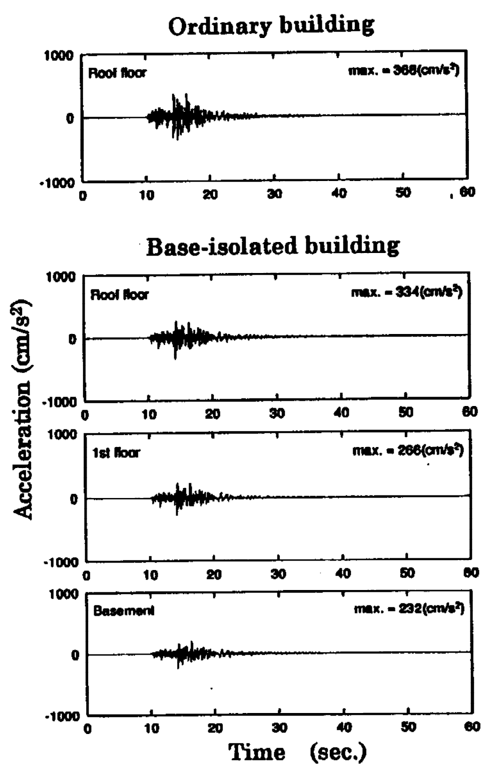


Fig. 5c Recorded accelerations (UD)

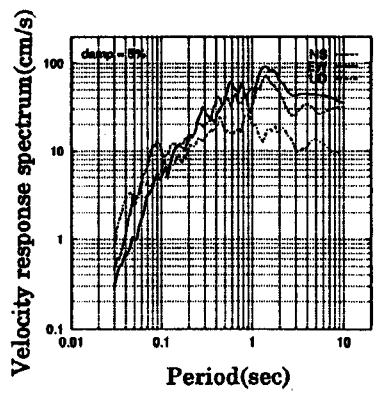
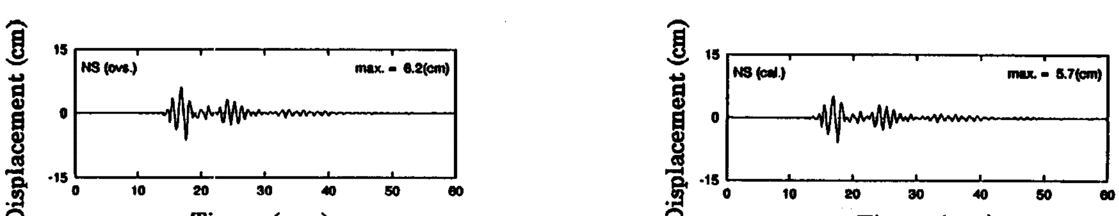


Fig. 6 Velocity response spectrum on foundation

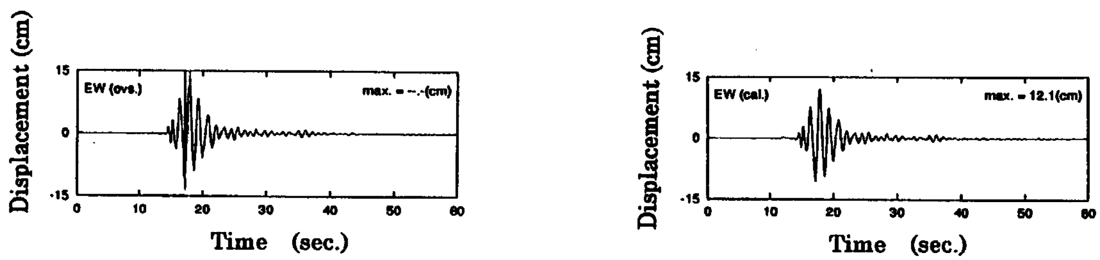
4.2 Behaviors of isolator

Figure 7a and 7b show the horizontal deformations of NS and EW direction between upper plate and lower plate of the high damping rubber bearing, respectively.
Maximum amplitude of isolator are about 6 cm (NS) and about 12 cm (EW).
Those deformations of isolators are directly observed via laser displacement sensor.
To conform those records, the integrated displacements calculated by using accelerations records are shown in those figures. By comparing the direct records with the calculated value, good accordance are gained. In Fig 8b ,the direct record is saturated because that the deformation of isolator was beyond the limit of sensor (10 cm)
The Photo. 2 is the scratch locus on the stainless steel plate of expansion joint at the 1st. floor. This locus which accidentally can show locus is the relative horizontal deformations of the rubber bearing .
From this locus the relative horizontal deformations of the rubber bearing about 6 cm (NS)and 12 cm (EW), respectively.
The reason for large displacement of the rubber bearing is considered as follows:
a. The equivalent natural periods of this base-isolated building was 2.4 second for the designed shear strain 150%, However this value is fairly short periods.
b. This earthquake occurred at the cold season and the base-isolated building is used rubber bearing which is sensitive to the temperature.
c. The input motion was containing the relatively long period component that the predominant period was about 1.5 sec.
d. The input motion level was enormous large (maximum velocity 20.5 cm/s (NS), 30.2 cm/s (EW)).



Direct records via laser displacement sensor
Calculated values from integration of acceleration records

Fig. 7a Deformations of isolator (NS)



Direct records via laser displacement sensor Calculated values from integration of acceleration records

Fig. 7b Deformations of isolator (EW)

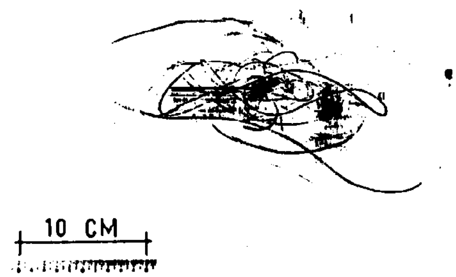


Photo. 2 Scratch locus corresponding the displacement isolator

5. CONCLUDING REMARKS

Through the investigations of the observed records subjected to the Hyogo-ken Nanbu Earthquake in the base-isolated building and the ordinary type building, following items are found.

a. On the ordinary building ,those are shown significant amplification of the response.
On the base-isolated building, the maximum acceleration of horizontal component was not amplifying or was reduced on the upper floor by comparisons the foundation level.

b. The maximum acceleration of vertical component are the same level for both buildings, those are amplified . The high dumping rubber bearing can not take effect in the UD direction.

c. The maximum amplitude of the rubber bearing are recorded as about 90 % (EW) of the total thickness of rubber sheets. And the upperbuilding had no damage, because of the maximum acceleration reduced. As concluding remarks ,it appeared that this base-isolated building shows good performance for reducing structural response for this big earthquake .

ACKNOWLEDGMENTS

The authors gratefully thank to Prof. Yutaka Inoue ,Prof. Eizaburo Tachibana and Assist Prof. Yoichi Mukai for their guidance and assistance on those researches.

REFERENCE

[1] Preliminary Reconnaissance Report of the 1995 Hyogoken-Nanbu Earthquake: Edited Architectural Institute of Japan (AIJ), 1995