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PERFORMANCE OF SEISMIC ISOLATED BUILDINGS DUE TO 2005 WEST OFF FUKUOKA EARTHQUAKE IN JAPAN

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ABSTRACT :

Offshore in the sea of Genkai, west of Fukuoka Prefecture, the earthquake of magnitude 7.0 on the Richter scale occurred around 10:53 on March 20th, 2005. A seismic intensity VI (JMA) was observed partially of Fukuoka City and Saga Prefecture due to this earthquake. Damage occurred in a lot of houses on the Genkai Island near the epicenter, and the damage of cracking of the building, and the crack of the glass, etc. occurred also in the Fukuoka urban area. After the earthquake generated this area in 1898, 107 years ago, there is no occurrence of an earthquake, and Fukuoka was called a city where an earthquake does not occur. But in Japan there is no area which an earthquake does not occur. Japanese long history is marked by disastrous earthquakes.

Seismic Isolation System has the ability to mitigate against earthquakes. From the many recent earthquakes in Japan, people have become aware of the benefits of the Seismic Isolation System. 13 seismic isolated buildings have built in the Fukuoka city. Remarkable performance has been shown during this earthquake. It is confirmed that positive behaviors were shown by seismograph records also in the seismic isolated building located near the fault. In this paper presents the response behavior of the Seismic Isolated buildings due to the earthquake.

KEYWORDS: Seismic Isolated Buildings, Response Behavior, 2005 West Off Fukuoka Earthquake

1. INTRODUCTION

A 7.0 magnitude earthquake occurred offshore in the sea of Genkai, west of Fukuoka Prefecture, on March 20th, 2005, resulting in an earthquake which hit Fukuoka city at a seismic intensity VI or less by Japan Metrological Agency. Figure 1 shows the earthquake's epicenter which was centered off the west coast of Fukuoka Prefecture. Many houses were damaged on Genkai Island near the epicenter, and in Fukuoka City it caused damage such as cracks in the walls and broken glass panels in some buildings. (Photo 1) According to an investigation based on archived documents concerning earthquakes which had been generated in Fukuoka Prefecture in the past, a magnitude between 5 and 6 earthquake which occurred on the Itoshima peninsula in 1898 was recorded. The 2005 earthquake is the largest one to have occurred in this region since modern earthquake observation started in Japan in 1904, and it was the first earthquake to occur since the previous one 107 years ago.

Thirteen seismic isolated buildings have been built in Fukuoka City at the time of the earthquake. The outlines of these buildings are shown in Table 1. It shows that the construction of seismic isolated buildings has proceeded in Fukuoka City since the Great Hanshin-Awaji Earthquake of 1995. These buildings have various functions, used as offices, apartments, hospitals and hotels and diverse seismic isolation members are used in these buildings. Figure 1 shows the locations where the main seismic isolated buildings were built in Fukuoka City and their locations relative to the Kego fault. Building C is located nearest to the Kego fault, and the greatest earthquake motion was observed there. In this paper, the results of the investigation of the performance of these seismic isolated buildings during the earthquake are reported.

2. CONDITION OF SEISMIC ISOLATED BUILDINGS AT THE TIME OF THE EARTHQUAKE

The outlines of the investigation conducted immediately after the occurrence of the 2005 earthquake are shown below. In this regard, however, although this investigation was mainly based on the buildings' appearance, information in the cases when we could enter inside of the buildings and when the performance of the seismic isolated buildings could be obtained are also shown.

2.1 Building A

According to the custodian of the building, at first he mistook the shock of the earthquake as being vibrations caused by JR trains passing near the building. Shelves did not overturn. Damage was not recognized in the seismic isolation members, and no considerable trace of deformation in the seismic isolation layer was observed.

2.2 Buildings B1 - B4 and H

These seismic isolated buildings are of the same apartment complex. Any deformation of the seismic isolation layer is presumed to be small, because they are distant from the epicenter. According to one resident living on the 8th floor of one of the buildings, furniture did not overturn and everything was as usual.

2.3 Building C

Building C stands near the Kego fault. Photo 2 shows the appearance of the building, and Photo 3 shows the damage of the entrance area. It is considered that the damage which occurred on the tiles of the staircase because the clearance between upper and lower is small. The width of the damage on the staircase is approximately 25cm, and it is presumed that larger displacement than that occurred. An orbit drawn by the angle of an iron sheet placed on the access to a side door was found (Photo 4). Although no displacement orbit in the south side remains, the movements of the seismic isolated buildings were greater in the direction of south-north than east-west, and it reached a maximum of approximately 30cm. The observed acceleration was greater in the direction of south-north than east-west, and the maximum acceleration of 203gal was observed at 65m underground, 489gal at the basement of seismic isolation layer, 238gal on the 1st floor and 234gal on the highest floor (the 7th floor). The maximum response acceleration was damped by half against the input acceleration.

In an earthquake proof building standing near Building C (SRC structure, 14 story apartment building, constructed in 1999), extensive damage occurred to nonstructural elements. Photo 1 b) shows an example of the damages. There were many units of this apartment in which the doors could not be opened or closed.

2.4 Building D

In this Building, an earthquake observation had been conducted. The accelerations were recorded at 45 gal on the 1st floor and 71 gal on the roof floor, respectively, in reference to the maximum acceleration recorded as 146 gal at the basement of the seismic isolation layer (in the direction of east-west). A section of curbside near the entrance moved 15cm to the south, which corresponds to the observed record of maximum displacement of 14.5cm. The acceleration at the superstructure was damped to 1/3 - 1/2, which exemplifies that the seismic isolation worked effectively. It was reported that the shock of the earthquake on the office building on the highest floor was small and no bookshelves and books overturned.

2.5 Building E

This building is a small-scale communication facility, where nobody resides. Damage was not observed based on its appearance.

2.6 Building F

As shown by the appearance of the building in Photo 5, this is a large-scale hospital. The entrance bridge of the southern side is an expansion structure. However, the expansion part of handrail did not work well during the earthquake, and as that result, the handrail and exterior wall were damaged (Photo 6). From the observed acceleration record at the time of the earthquake, it is judged that this did not affect the seismic isolation capability of the building. An inpatient on the 6th floor said that she noticed the slow horizontal motion during the earthquake, but there was no damage or overturning of shelves. In an adjacent hospital ward, which is an earthquake-proof building, bookshelves overturned and cracks were generated in the wall. Photo 7 shows a displacement orbit drawn by an orbiter installed in the seismic isolation layer. The deformation volume of the seismic isolation layer was larger in the direction of south-north than east-west, and the deformation was repeating in approximately two cycles with the amplitude within the maximum displacement of 15 cm.

2.7 Building G

This building stands approximately 600m east from the Kego fault. From a trace remaining in the seismic isolation clearance, it was presumed that there was a maximum deformation of approximately 10 - 12cm in the direction of south-north and approximately 7cm in the direction of east-west. According to the workers in this hotel, they felt a slow horizontal motion, however, there were no claims from the ten groups of guests staying in the hotel. Elevators stopped for five minutes but automatically recovered and there was no furniture overturned. No damage to the seismic isolation members was observed and almost no residual deformation was recognized.

2.8 Building I

Deformation of the seismic isolation layer of this building is presumed to be approximately 10cm. The seismic isolation clearance, which is jump-up type, returned to almost its original condition. The observed maximum acceleration in the horizontal direction was damped to 91-118gal on the 1st floor and was greater amplified to 145-167gal on the 12th floor as compared to 121-139gal in the basement of seismic isolation layer. However, it was reported that the horizontal movements of the earthquake were slow and there was no damage such as overturning of furniture and emergency shutting down of computers.

2.9 Building J

This building stands approximately 200m west of the Kego fault. It was reported that although slight damage was observed in the seismic isolation clearance, but no furniture overturned in the offices and rice bowls stacked up to 20cm did not collapsed in an eatery on the 10th floor. Deformation of the seismic isolation layer was approximately ± 10cm in the direction of south-north.

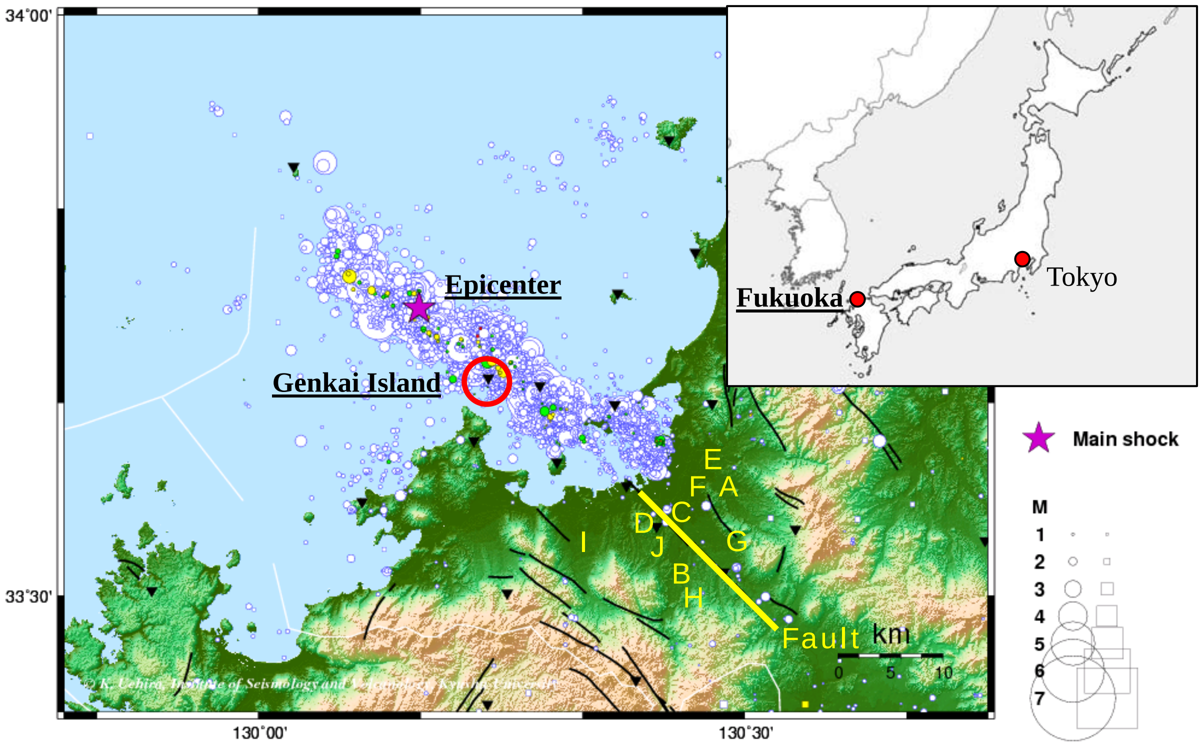

Figure 1 Seismicity Map of Fukuoka City
(Institute of Seismology and Volcanology, Faculty of Science, Kyushu University)

a) Shear Cracks of Columns

b) Damage of Nonstructural Members

Photo 1 Damage of Non-seismic Isolated Building

Table 1 Outlines of Seismic Isolation Buildings in Fukuoka City

Name	Location	Usage	Story	Structure	Devices	Construction Year
A	Hakata Ward	Dormitory	4	RC	HDR	1995
B1	Minami Ward	Apartment	14	RC	NRB＋SD+LD	1996
B2			14	RC	LRB	
B3			12	RC	LRB	
B4			6	RC	HDR	
C	Chuo Ward	Office	7	RC	HDR	1996
D	Chuo Ward	Office	9	SRC	NRB+SD+LD	1996
E	Hakata Ward	Communication Facility	2	RC	LRB	1997
F	Higashi Ward	Hospital	11+B1	SRC+S	NRB+SD+LD	1998
G	Chuo Ward	Hotel	13	RC	NRB+SD+LD	1999
H	Minami Ward	Apartment	13	RC	NRB+SD+LD	2000
I	Nishi Ward	Office	12	S	HDR+SL	2001
J	Chuo Ward	Office	10	S	NRB+SL+LD	2003

HDR: High Damping Rubber Bearing, **NRB**: Natural Rubber Bearing,
LRB : Lead Rubber Bearing, **SL** : Friction Slider, **SD** : Steel Damper, **LD** : Lead Damper

3. OBSERVATION RECORDS OF SEISMIC ISOLATED BUILDINGS

3.1 Seismic Observation Record of Building C

3.1.1 Outline of the Building C

This building is 7 stories above the ground, 29.2m in height, and is a reinforced concrete structure. It is a base seismic isolation structure for the building's weight of approximately 6,800tons. The high damping laminated rubber bearings (19 of 750mm and 2 of 900mm in diameter, 21 HDRs in total) are used as seismic isolation members. Table 2 shows the outline of the laminated rubber bearings used there. Shear elastic modulus G of all laminated rubber bearings is approximately 6kg/cm^2 (0.6MPa).

The first natural period of superstructure under elasticity is presumed as 0.45 seconds in the direction of X, and 0.70 seconds in the direction Y. The equivalent period as natural period of seismic isolation, when the response deformation of seismic isolation layer is 30cm, is presumed as being approximately 3 seconds.

3.1.2 Observed Acceleration Record of Building C

Seismic observations are performed at four locations such as 65m underground (above the foundation of Vs=500m/s), at the basement of the seismic isolation layer (1.8m under the grounds surface), on the 1st floor and the 7th floor. Table 3 shows the observed maximum accelerations. From the observation record in the horizontal direction, the acceleration at the basement of seismic isolation was amplified to 2.5 times that at 65m underground, and the acceleration of the superstructure was damped to less than 1/2 of that at the basement. The acceleration in the vertical direction at the superstructure was damped to 1/1.3-1/1.5 against that at the basement. Generally speaking, the acceleration response in the vertical direction is amplified in a seismic isolation structure. However, according to this record, the seismic isolation also worked in a vertical direction to some extent. Figure 2 shows acceleration records in the direction of north-south. The records on the 1st floor and 7th floor were almost the same, which means that the superstructure swayed as a rigid body and the swaying period was approximately 3 seconds.

3.1.3 Deformation of the Seismic Isolation Layer of Building C

Figure 3 shows the relative displacement of the seismic isolation layer. An absolute displacement record was calculated through integration of the acceleration data observed at the basement and in the flooring of the 1st floor. A relative displacement record of the seismic isolation layer was obtained from the difference between both response deformations. From comparison of this Figure 3 with Photo 4, although the maximum deformations on the north side were in approximate correspondence with each other, the orbits before and after these maximal deformations were drawn in different behaviors. It is presumably that because, as shown in Photo 4, the iron sheet was just placed, the motion before and after the maximum deformation was too fast to leave its orbit. The maximum deformation of the seismic isolation layer was 30cm, which shows that the seismic isolation layer was affected by the deformation to the extent of that predicted at the time of design. It also shows that the seismic isolation layer moved linearly in the direction of north-east.

Photo 2 Appearance of Building C

Photo 3 Damage of the Entrance Area of Building C

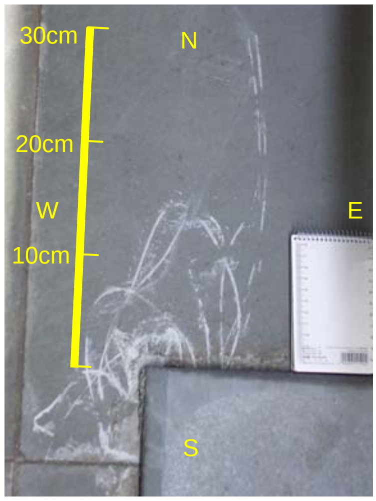

Photo 4 Orbit of Building C

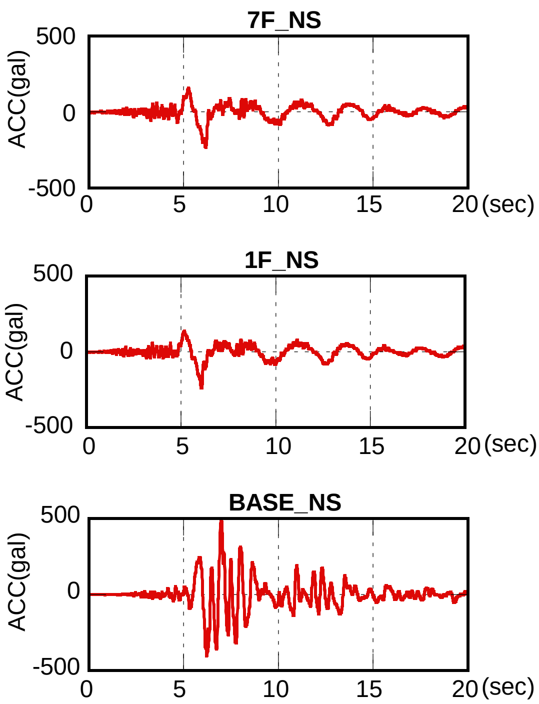

Figure 2 Acceleration Records of Building C(NS-dir.)

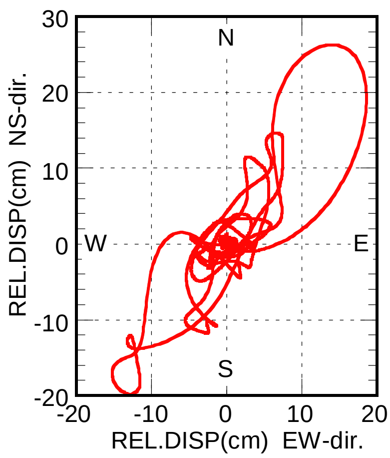

Figure 3 Relative Displacement of Seismic Isolation Layer of Building C

Table 2 Outline of HDR of Building C

Diameter	Number	Compressive Stress
750mm	19	4.7～9.7MPa
900mm	2	9.3MPa

Table 3 Maximum Accelerations of Building C (gal)

Location	NS-dir.	EW-dir.	UD-dir.
7th Floor	233.8	126.1	172.2
1st Floor	237.6	140.0	151.6
Basement	488.8	310.8	225.8
Underground	202.8	124.5	85.9

3.2 Seismic Observation Record of Building F

3.2.1 Outline of the Building F

This building is located in the East Ward of Fukuoka City, is 11 stories above ground, one story underground, and is a reinforced concrete structure. It is a large-scale hospital which has a horizontal area of approximately 109m by 72m.

Its seismic isolation layer is installed under the 1st underground floor and it consists of 116 natural laminated rubber bearings, 66 steel dampers (ϕ70mm) and 48 lead dampers (ϕ180mm). Table 4 shows the outline of the laminated rubber bearings. The diameter of the laminated rubber bearings is 800mm-1,200mm, and they are under relatively high compressive stress (average stress: 11.9MPa).

The 1st natural period of the superstructure under elasticity is 0.65 seconds in the direction of X and 0.80 seconds in the direction of Y. The equivalent period as natural period of seismic isolation, when response deformation is 30cm, is presumed as being 3.6 seconds.

3.2.2 Observed Acceleration Record of Building F

Seismographs are installed on the surface of the free field, at the basement of the seismic isolation layer, and on the 1st underground floor (B1), the 1st floor, the 5th floor and the 11th floor. Two seismographs are installed in the direction of east and west on each the 1st floor, the 5th floor and 11th floor for the observation of torsional response, and 27 components are observed in total. Table 5 shows the observed maximum accelerations. They are shown in average values of two accelerometers of each floor in this table, because the differences between the maximum accelerations recorded by two accelerometers installed at each floor from the 1st floor to the 11th floor were only approximately ±10%.

The accelerations in the horizontal direction were damped to 82gal-95gal on the B1-5 floors against 195gal at the basement in the direction of north-south, all less than half. The accelerations were damped to 45gal-61gal against 175gal in the basement in the direction of east-west, approximately 35%. The acceleration in the UD direction was 126gal at the basement and was amplified to some degree in the superstructure.

Figure 4 shows the acceleration record in the direction of north-south. The acceleration record remains as almost the same form in on each of B1-11 floors, which means that each floor moved slowly in the same behavior. From the response acceleration record, it can be perceived that the superstructure moved slowly.

3.2.3 Deformation of the Seismic Isolation Layer of Building F

Figure 5 shows the relative deformation of the seismic isolation layer obtained by the acceleration record observed as in the case of Building C. The shockwaves of Building F moved in the direction of south-north, and it was revealed that deformations of approximately ±15cm occurred two or three times. This Figure 5 corresponds approximately to the orbit of Photo 7, and it was determined that the performance of the seismic isolation layer could be estimated from the integration of the acceleration record.

Photo 5 Appearance of Building F

Photo 6 Damage of Handrail of Expansion Bridge

Table 4 Outline of NRB of Building F

Diameter	Number	Maximum Compressive Stress
800mm	27	14.5MPa
900mm	42	14.7MPa
1000mm	31	14.7MPa
1100mm	11	14.5MPa
1200mm	5	13.3MPa

Table 5 Maximum Accelerations of Building F

(gal)

Location	NS-dir.	EW-dir.	UD-dir.
11^{th} Floor	112.1	93.7	446.5
5^{th} Floor	94.8	61.3	172.2
1^{st} Floor	81.8	47.7	132.3
B1	84.9	45.1	153.7
Basement	195.2	175.4	125.9

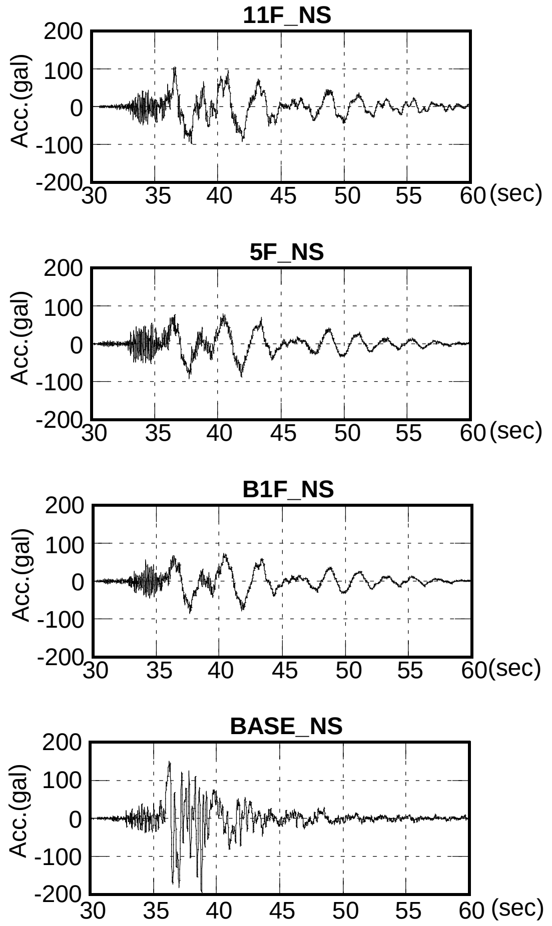

Figure 4 Acceleration Records of Building F(NS-dir.)

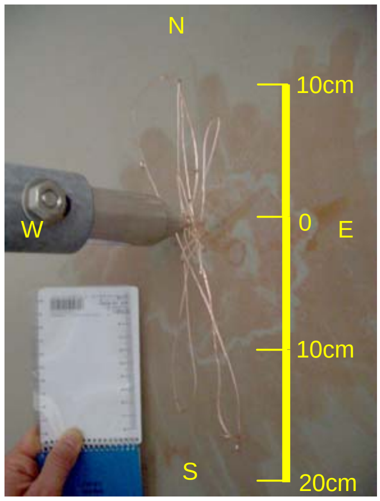

Photo 7 Orbit of Building F

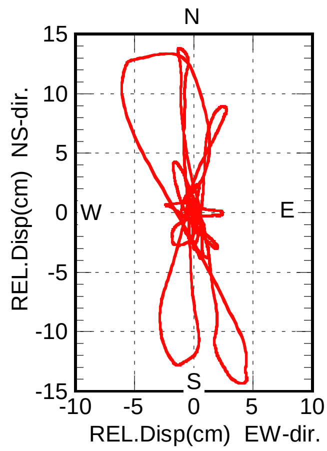

Figure 5 Relative Displacement of Seismic Isolation Layer of Building F

4. CONCLUSION

There were large accelerations which resonated from the earthquake which occurred off the west coast of Fukuoka Prefecture. Up to present, these were the greatest acceleration data ever recorded in Japan, affecting seismic isolated buildings in Fukuoka City. However, no extensive damage was reported in any of the buildings, thus it was verified that the seismic isolation members performed as anticipated. One building showed slight damaged to its seismic isolation clearance, and utmost attention should be paid in designing an expansion part.

Figure 6 shows the maximum response accelerations observed in seismic isolated buildings. The horizontal axis shows the maximum acceleration at the basement of the seismic isolation layer and the vertical axis shows the ratio of the maximum accelerations (amplification factors) of the 1^{st} floor (1FL) and the highest floor (RFL) against that of the basement of the seismic isolation layer. Examples of observed results from each of the Niigata Prefecture Chuetsu Earthquake and the Great Hanshin-Awaji Earthquake are added to this Figure. From all observed results, it is revealed that the accelerations of the superstructure were more greatly damped than those of the basement (input acceleration) and that the larger the escalation of the basement, the greater the effect of seismic isolation becomes. It is very important to collect such basic observational data as it is necessary for the better development of seismic isolation structures.

Moreover, it is very useful to record the responses of seismic isolated buildings to the shockwaves of earthquakes in order to evaluate the effectiveness of buildings' seismic isolation layers. Furthermore, even without a seismograph, the displacement of a seismic isolation layer can be traced by way of an orbiter.

We anticipate that our study on the response performance of seismic isolated buildings will be helpful for future development and diffusion of seismic isolation methods for constructing buildings in the future.

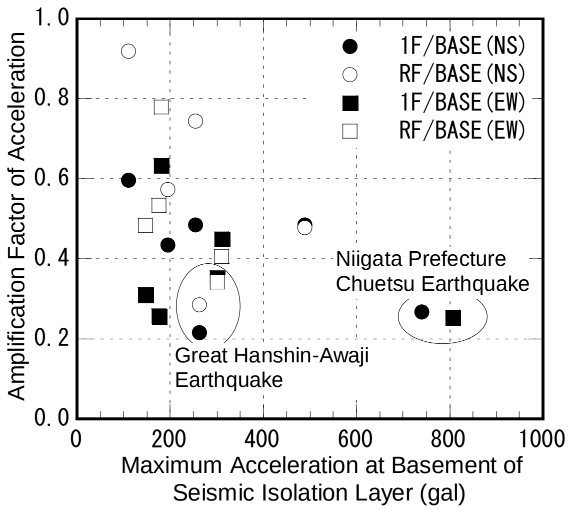

Figure 6 Amplification Factor of Observed Acceleration of Seismic Isolated Buildings

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REFERENCES

T. Irie, T. Mazda (2005). Response of Seismically Isolated Structure in Daimyo Area at West off Fukuoka Prefecture Earthquake, *Summaries of Technical Papers of Annual Meeting*, AIJ, **B-2**, 663-664

S. Shirinashihama, I. Hayashi et al. (2005). Seismic Response of a Base-Isolated Building in Fukuoka City during the 2005 West off Fukuoka Prefecture Earthquake, *Summaries of Technical Papers of Annual Meeting*, AIJ, **B-2**, 665-666

H. Morimoto, Quick Report on the Behavior of the Isolated Buildings during the Earthquake of the West off Fukuoka Prefecture in 2005, *MENSHIN*, JSSI, **48**, 52-55