SHAKING TABLE TEST ON BASE ISOLATED HOUSE MODEL

by

Hiroyuki Yamanouchi [1], Mitsumasa Midorikawa[2] and Masanori Iiba[3]

ABSTRACT

Base isolation is very effective on keeping safety during earthquakes(reduction of acceleration response at floors and inter-story drifts of structure, etc.). In case of houses, it is difficult to elongate a period of building by laminated rubber bearing isolators because of the light weight of building. In addition to rubber bearing devices, sliding and rolling type devices are needed to be developed or applied. In this paper, the effects of base isolation on response of houses and mechanical characteristics of various kinds of seismic isolators will be discussed. Shaking table tests of base isolated house models were carried out. Various kinds of isolators, such as rubber , sliding , and rolling bearings were tested. The effect of these isolators on the response of a superstructure during earthquakes has been demonstrated, through the comparison with response for a non-isolated house. It is shown that the response of houses is remarkably dependent on characteristics of isolators.

Key words : Base Isolation,

House,

Shaking Table Test,

Earthquake Response,

Effect of Isolation

1. INTRODUCTION

Many structures suffered from the 1995 Hyogoken-Nanbu Earthquake. Some at buildings have collapse of 1st or intermediate stories[1]. Engineers and researchers recognized the necessity for countermeasures against earthquakes. Since the earthquake occurred in the gray dawn (5:45am) , there were many persons which were dead and injured at their houses.

Two buildings with base isolation were constructed in Kobe City. The observed earthquake motion in the buildings showed the effect of base isolation on reduction of acceleration response[2]. After the earthquake, many low- and medium-rise buildings with isolators have been designed and constructed. But base isolation of individual houses has not become popular.

Base isolation is very effective on keeping safety during earthquake(reduction of acceleration response, at floors and inter-story drift response, and protection from overturning of furniture, etc.). In order to promote construction of base isolated houses and development of isolator devices for houses, required performance for base isolated houses has to be clarified. Building Research Institute has a project on this theme in collaboration with house builders and isolator device companies [3].

Base isolated buildings in Japan and current issues for spreading base isolated houses are summarized, and shaking table test results of base isolated house models are discussed. Various kinds of isolators, such as rubber, sliding , and rolling bearings were tested.

2. RECENT TENDENCY OF BASE ISOLATED BUILDINGS IN JAPAN

Figure 1 illustrates the number of base isolated

1) Director, Codes and Evaluation Research Center, Building Research Institute, Ministry of Construction, 1, Tatehara, Tsukuba-shi, Ibaraki-Ken, 305-0802, Japan

2)Associate Director for International Codes and Standards, Codes and Evaluation Research Center, ditto

3)Head, Geotechnical Division, Department of Structural Engineering , ditto

buildings in Japan by fiscal year. The number of buildings is classified by building use. The number from 1985 to 1994 (before 1995.Jan.17 Hyogoken-Nanbu Earthquake, JMA M7.2) is summed up. Table 1 shows kinds of isolators by year. As isolators, lead rubber, high damping rubber, and natural rubber bearings with lead and steel dampers have been much used.

Table 1 Kind and Number of Isolators Utilized for Buildings in Japan

Type of Device	1985-1994	year 1995	1996	1997	total
HDB	13	26	79	36	154
LRB	18	20	49	27	114
NRB+LD+SHD	2	14	37	24	77
LRB+NRB	4	2	21	10	37
NRB+SHD	17	0	2	0	19
LRB+SL	9	0	1	2	12
NRB+LD	4	1	2	5	12
NRB+SL	3	3	0	2	8
NRB+VD	5	1	0	0	6
Others	7	19	34	27	87
total	82	86	225	133	526

LRB:Lead Rubber Bearing SL:Sliding Bearing LD:Lead Damper
HDB:High Damping Rubber Bearing SHD:Steel Hysteresis Damper
NRB:Natural Rubber Bearing VD:Viscous Damper

The number of base isolated buildings in 1995 is almost equal to the sum of that in the past. The number increased in 1996. Before the Hyogoken-Nanbu Earthquake there are offices and research centers for building use. On the other hand, residential buildings, offices and hospitals have been designed after the earthquake.

The reason why base isolated buildings have been constructed after the earthquake seems that the effects of base isolation were demonstrated through the 1994 Northridge Earthquake in USA and the 1995 Hyogoken-Nanbu Earthquake. The earthquake motions of base isolated building (6-story, steel-reinforced concrete structure) constructed in the mountainous area were observed as shown in Fig. 2. The ratio of the maximum response acceleration of 1st and 6th floors to that of foundation in the east-west direction are 0.35, 0.34, respectively [2). As the building is constructed on very stiff soil ground, the ground motion contains much high frequency component. Unfortunately there was no base isolated building in the area of much damaged on buildings, road and rail ways, and the

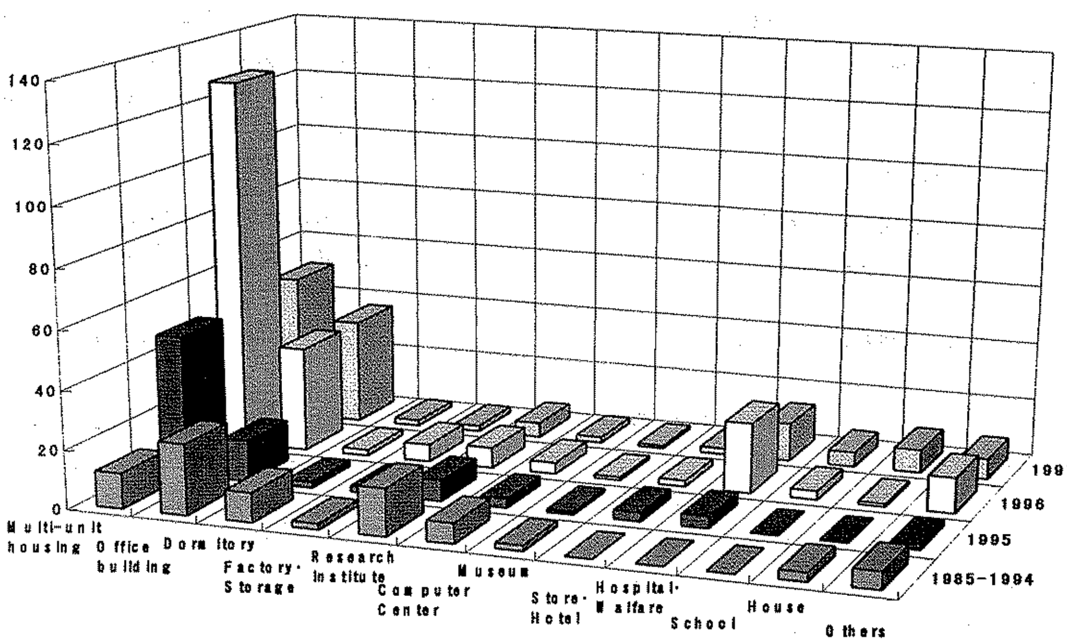

Fig.1 Number of Base-isolated Building and Building Use

reclaimed ground along the sea coast.

3. ISSUES OF SAFETY AND SPREAD OF BASE ISOLATED HOUSE

In order to promote the development of isolator devices and spread base isolated houses, the required performance for base isolated houses shall be made clear. Many issues shall be necessary to be discussed. Following items are taken into consideration for the performance of base isolated houses.

1)Weight of building is relatively small.

In addition to laminated rubber bearing devices, sliding and rolling type devices are needed to be developed.

2)Countermeasures against wind is important.

Even if the behavior of building during earthquakes is sufficient, it is not acceptable that the habitability in daily life and during strong wind will be insufficient.

3)Reinforcement of 1st floor and foundation is added.

In case of houses without base isolation, weight of buildings is transferred to foundations through sills. As the sills are put on the foundation, the sills are not necessary to support the weight of floors. In case of base isolated houses, girders are necessary to support the weight of 1st floor. The dimensions of

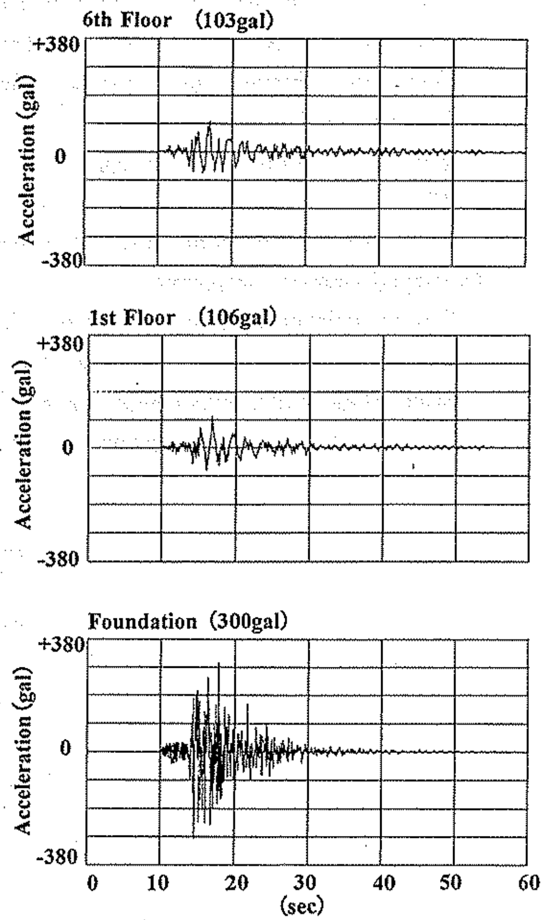

Fig.2 Earthquake Motion Records(EW-direction)in Base-isolated Building in 1995 Hyogoken-Nanbu Earthquake(Ref.2)

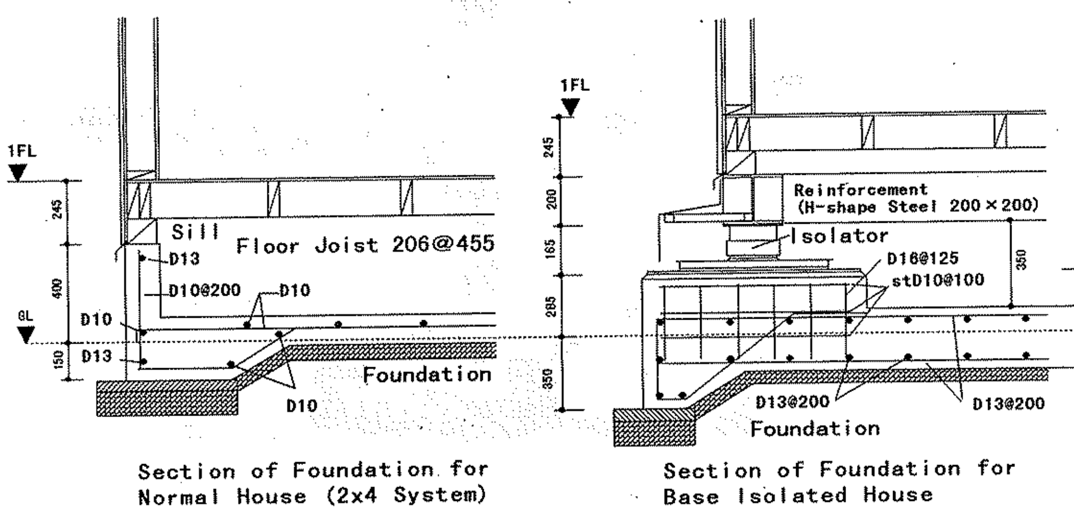

Fig. 3 Section of Isolated Story and Foundation

girders are large with increasing distance between concentrated load acts on the foundation, use of isolators. The weight of building is transferred to the foundation through the isolators. Since the individual and mat foundations, or reinforcement of continuous foundation shall be considered.

Figure 3 illustrates a section of 1st floor and foundation for ordinary and base isolated houses.

4)Cost performance is important.

Cost for isolation is considerably large. The effort shall be made to reduce the cost for isolation. Standardization of isolator devices and simplification of building confirmation system are necessary.

In Article 38 of the Building Standard Law of Japan, there is a description of special material or methods of construction as follows ; the provisions of this chapter of those of order or ordinances based thereon shall not apply to building using special building materials and methods of construction unanticipated thereunder , in cases where the Minister of Construction determines that the said building materials or methods of construction are equivalent or superior to the specified in the said provision [5]. As it is judged that the building with base isolation have special materials , the permission of the Minister of Construction is necessary for structural

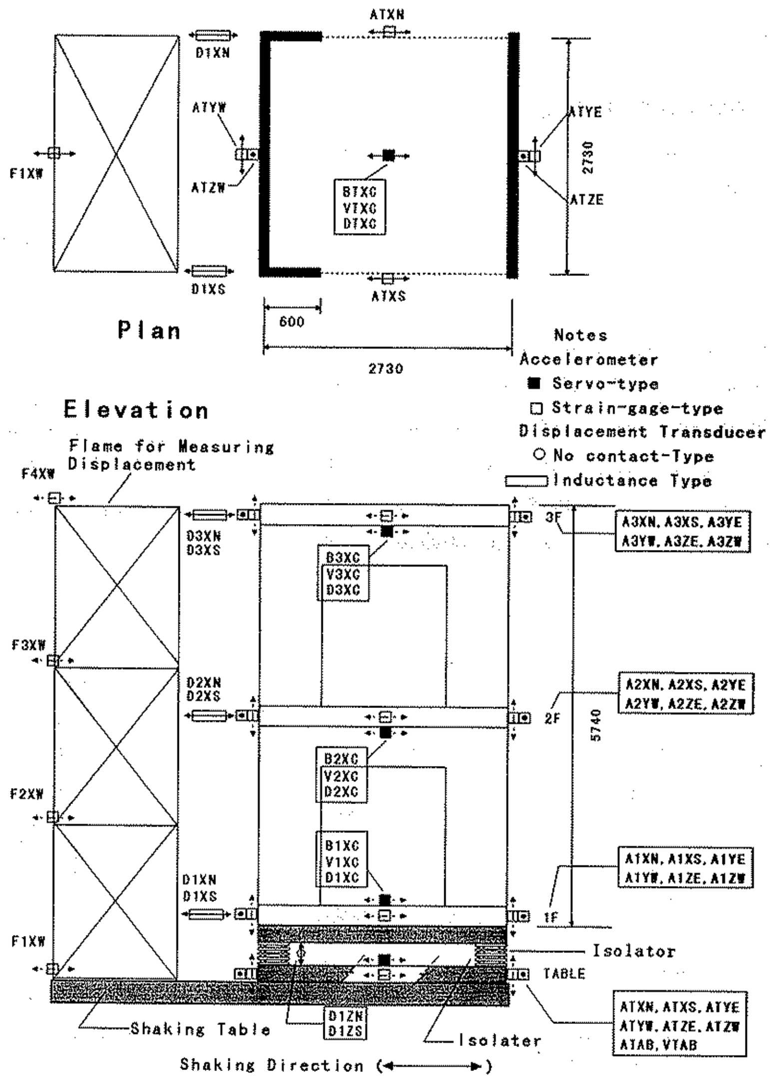

Fig.4 Test Specimen and Arrangement of Transducers

safety of the buildings.

4. SHAKING TABLE TEST ON BASE ISOLATED HOUSE MODELS

4.1 Test Specimens

To solve the issue that houses are relatively light, the shaking table test on base isolated model with isolators of different mechanical properties was carried out. Effects of isolation on response of houses will be discussed.

A specimen for house model is a wood frame(2 x 4 inches structure) with 2 stories (story height 2.7m and 2.73 x 2.73m in plan), as shown in Fig. 4. The house model has two plywood plates with 60cm in width and 9mm in thickness to keep stiffness in the vibrating direction. The natural period and damping ratio of the house model with fixed base are 4.2 Hz and about 3%, respectively.

The experiment was conducted on the base isolated specimens with various kinds of isolators. Typical isolators used in the test are shown in Fig. 5. One is the rubber bearing device with multi layers(Device A). The second is the sliding bearing device which is called the Friction Pendulum System(Device E). The third is the rolling bearing devices (Device G).

The isolators were installed at each corner of the house and between two steel frames. In the case of the rubber bearing isolators, an additional weight (about 8 tons) was attached in the steel frame to elongate a natural period of isolated models. In order to measure relative displacement of the specimens, there was a tall frame in neighborhood of the specimen.

4.2 Excitation and Measurement

Methods of excitation to the specimen are as follows.

1)Free vibration

Characteristics of the model (natural frequency and damping ratio) will be obtained by free vibration with initial displacement at roof floor.

2)Shaking table excitation

a) White noise random vibration

To clarify fundamental characteristics of the model (resonant property), the wave form with white noise in frequency domain were used as input motion.

b)Earthquake excitation

To evaluate seismic behavior of the base isolated models and situation in the house, several earthquake motions were used. As earthquake motion records, suchas, El Centro(1940, NS component), Taft (1952,EW), Hachinohe Harbor(1968,NS) and Meteorological Marine Observatory at Kobe(1995, NS, JMA Kobe), were selected. Maximum amplitude of the earthquake excitation was adjusted by maximum velocity of

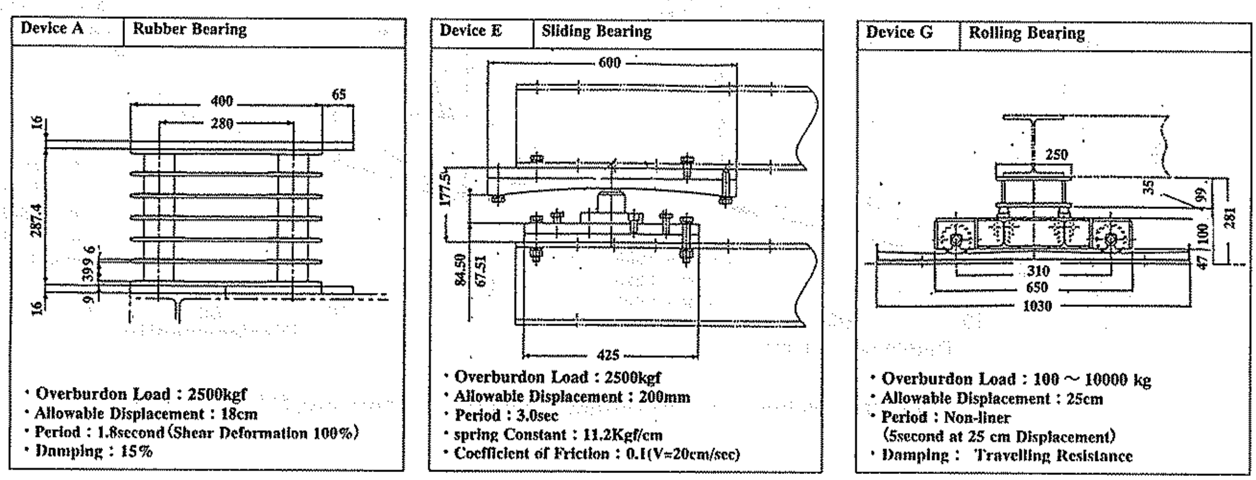

Fig. 5 Representatives for each kind of Isolators

displacement of isolated layer with sliding system(E) is smaller than those with another systems(A and G). The sliding system is effective to reduce the displacement of isolator.

Inter-story drifts of superstructure are shown in Fig. 11. The story drifts of 1st and 2nd story without base isolation subject to the Kobe Earthquake of 50cm/s are 1/128 and 1/196, respectively. In case of isolated houses with devices A, E and G, they are 1/410 and 1/443, 1/385 and 1/500, and 1/1220 and 1/1282, respectively. As the inter-story drifts of isolated house are 0.1 to 0.4 times of those of non-isolated house, the base isolation will be sure to protect from not only severe damage on structural elements but that on non-structural elements.

5. CONCLUSIONS

Required performance for base isolated house are discussed in the research activities in collaboration with house builders and isolator companies. There are a lot of issues to be solved to spread base isolation of houses, compared with those of low-and medium-rise buildings.

To solve the issue that houses are relatively light, the shaking table test on base isolated model with isolators of different mechanical properties was carried out. The effect of these isolators on the response of superstructure during earthquakes has been demonstrated. It is shown that the response of houses is remarkably dependent on characteristics of isolators.

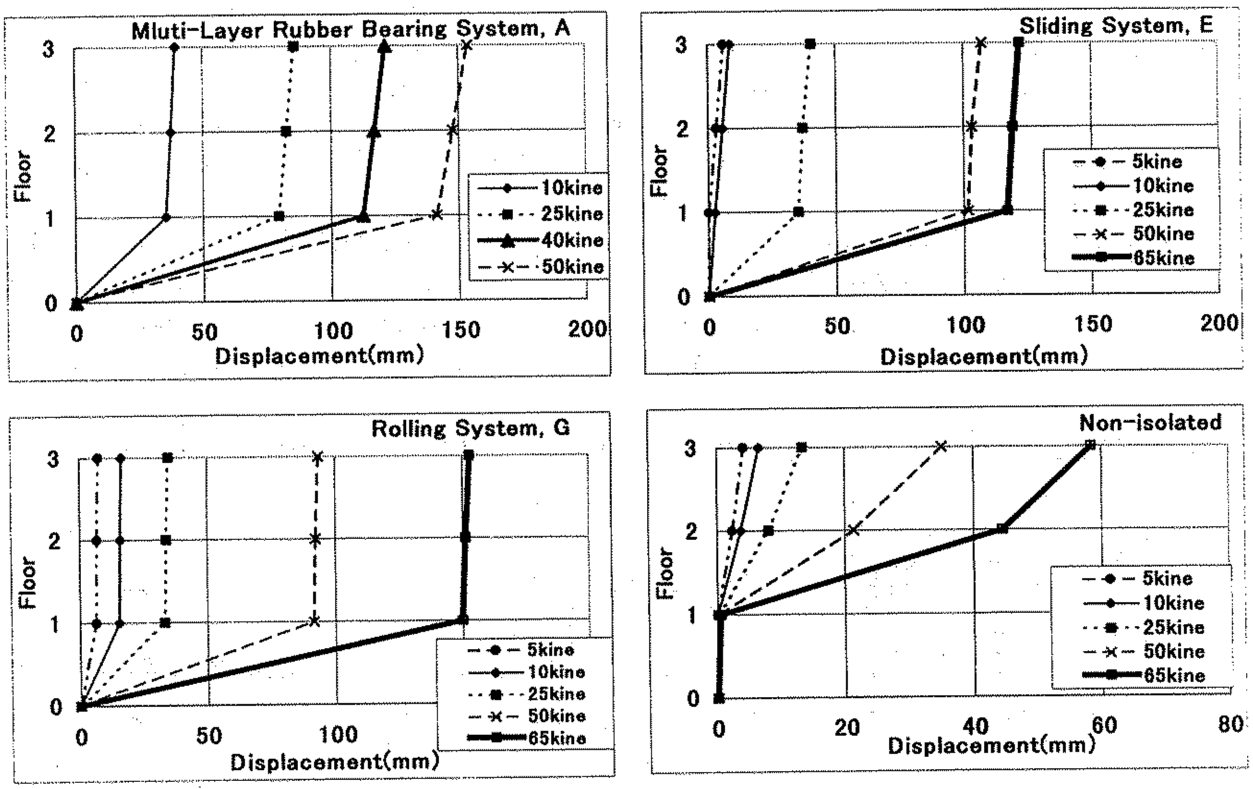

Fig. 10 Distribution of Maximum Displacement Response(JMA Kobe NS)

ACKNOWLEGDEMENT

The shaking table test and date analysis were conducted under the committee on cooperative research "Development of seismic isolated house(chaired by Mr. Shoichi Yamaguchi, president of Tokyo-Kenchiku structural Engineers). The authors express our sincere thanks to the members of the committee.

REFERENCES

1. Building Research Institute : A Survey Report for Building Damages due to the 1995 Hyogo-ken Nanbu Earthquake, 1996 March
2. The Building Center of Japan : Base isolated Buildings -Technical development and Earthquake Motion Observation Records Part 2-, 1995 June (in Japanese)
3. Yamanouchi H., M. Midorikawa and M. Iiba (Editor) : Research and Development on Base Isolation Technology for House -Survey of Knowledge and Shaking Table Test on House Model, for Evaluation of Performance on Base isolated House-, Kenchiku Kenkyu Siryo No. 89, 1997 March (in Japanese)
4. Date by the courtesy of Building Center of Japan
5. Building Guidance Division & Urban Building Division , Housing Bureau, The Ministry of Construction(Editor) : The Building Standard Law of Japan, The Building Center of Japan , 1990 Sep.

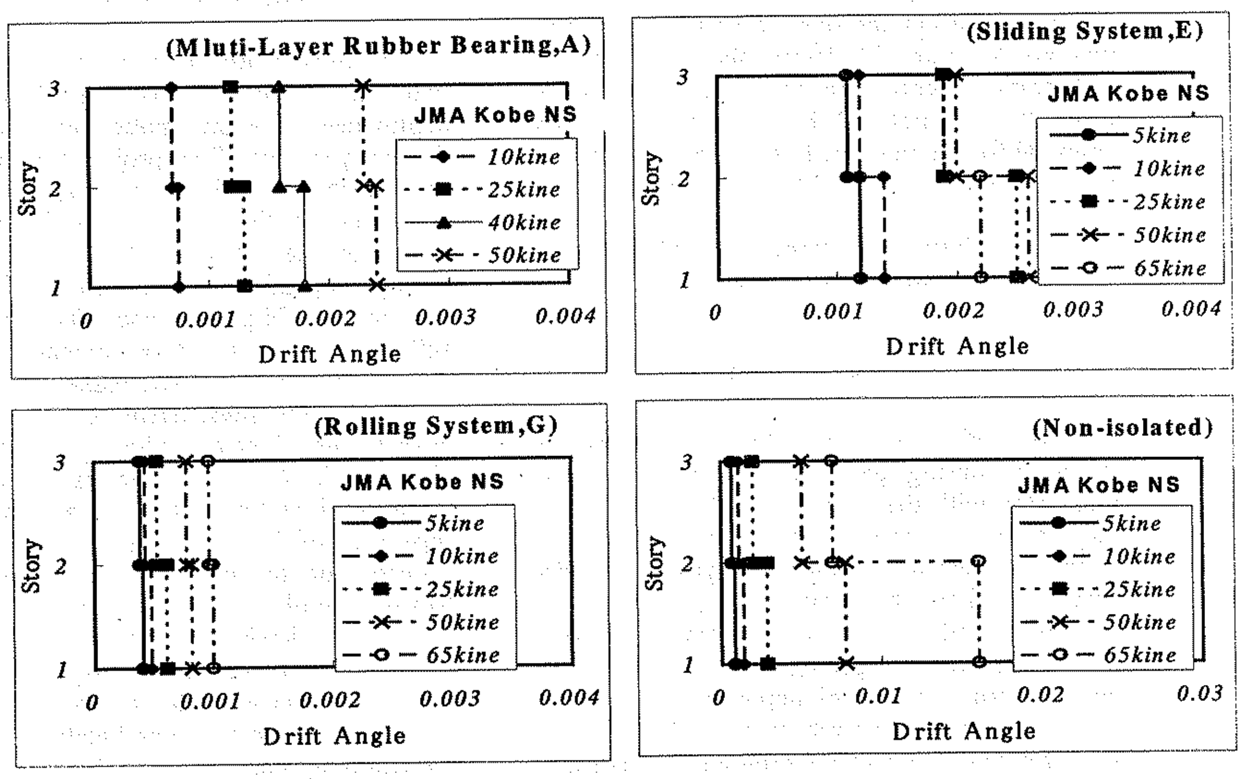

Fig. 11 Inter-story Drifts of House (JMA Kobe NS)