Progression of Seismic Isolation Design during these 20 Years in Japan

(Session 4 : Improved Hazard Mitigation Activities)

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1. Introduction

"Seismically isolated" is called "Menshin" in Japanese. "Men" means "isolation", "Shin" means "seismic ground motion", so Menshin means "to Isolate from Seismic Ground Motions".

The reasons why Menshin has developed drastically in Japan will be explained and the present state of Japanese Menshin and expansions of its application will be introduced.

Japanese Menshin started with an experiment, the "Yachiyodai" Menshin house[1] in January 1983. After this, a lot of critical loading experiments to devices have done. Dozens of Menshin buildings are designed in the 1980s. After the Kobe earthquake in 1995, more than 100 Menshin buildings were designed every year, resulting in 1700 Menshin buildings(for house is 3000) presently (Fig.1.1, [2]).

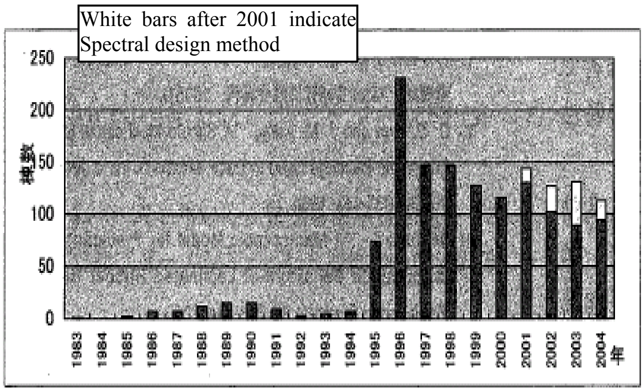


Fig.1.1(a) Number of Menshin Buildings(without houses)

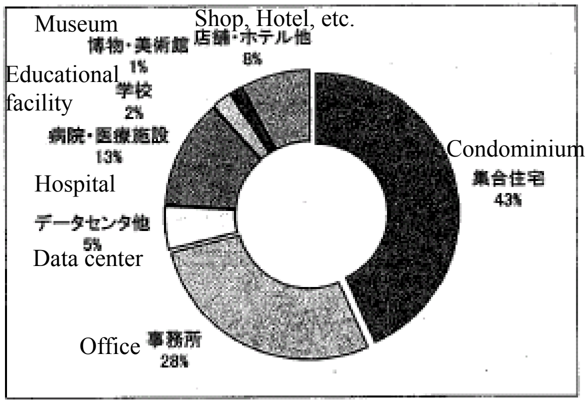


Fig.1.1(b) Purpose of Menshin buildings

1. Development of Menshin technologies during these 20 years

1.1 Reformations of Menshin devices

To make the mitigation seismic force to upper structures more, a longer Menshin period was considered. Using rubber material with a smaller modulus G, higher vertical pressure σ of the isolator gives superior performance. This is explained by formula (1) with a supposition of rigid upper structure.

$$T_f = 2\pi\sqrt{\frac{W}{K_f \bullet g}} = 2\pi\sqrt{\frac{1}{g}\bullet\frac{Hr}{G}\bullet\frac{W}{As}} = 0.2\sqrt{\frac{Hr}{G}\bullet\sigma} \qquad (1)$$

$$(K_f = \frac{G \bullet As}{Hr})$$

where T_f : Menshin Period, G : Shear Modulus, σ : Vertical Pressure, Hr:Total Thickness of Rubber, W:Supporting Vertical Load, As:Shear Area of Rubber, g:Gravity, K_f:Horizontal Stiffness

In the early stages of Menshin designs, pressure σ = 4 - 6 N/mm^2, rubber modulus G =0.6 - 0.8 N/mm^2. Menshin designers had a little number of experiments and tended to be conservative when deciding on the pressure σ . This resulted in the Menshin period being 2 - 3 second. This is shown in the "Introduction to Menshin" (published by "Japan Society of Seismic Isolation"-JSSI in 1995).

Menshin designers demanded a smaller modulus G and higher pressures σ of the isolator to the device providers and demanded specifying the critical properties. Providers replied with preparing the large experiment equipments for isolator tests. Lower G rubber (G is 0.29 - 0.34 N/mm^2) materials are turned to practical use. Other, reformations shown in Fig.2.3 had been done[3][4][5]. These isolators are not brake over 400% of shear strain under double of the long term vertical pressure. This corresponds to 60-100cm in deformation. The critical properties - limits of relation of deformation and pressure - of isolators were determined statistically by a lot of examinations.

Due to reformations below, Menshin buildings with longer period can be designed. For example, using G=0.44N/mm^2 rubber to vertical pressure σ=15N/mm^2, Menshin period is generally ensured beyond 4 second that is less susceptible to the ground motion characters of earthquakes[7]. Thus, we can do the design that suffers no damages under "the maximum considered earthquake ground motion", and Quake-free design in earthquake-prone country can be gotten.

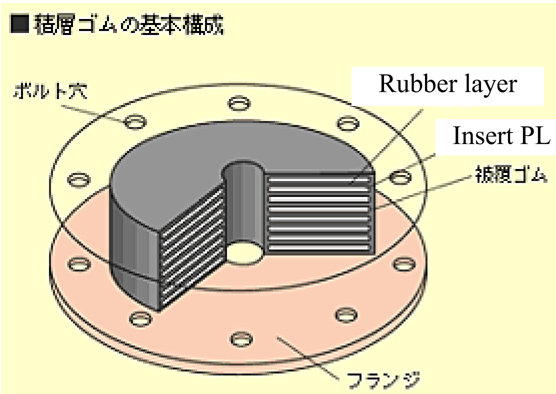


Fig.2.1 Reformations of the Isolator

Reformations:

Material of rubber →	lower modulus
Thickness of a rubber's layer→	half
Number of rubber's layers →	double
Insert steel plates →	thicker
Diameter of center hole →	smaller
Vertical pressure →	larger
Creep displacement →	to be clear
Critical properties →	to be clear

2.2 Frequently used Menshin devices in Japan

The three kinds of devices are about 1/3 shear respectively – natural rubber bearing with separated dampers, high-damped rubber bearing (HRB), lead-core rubber bearing (LRB). Steel and lead dampers are major as the separated damper. Oil dampers are also frequently used. The merits of this way are that designers can easier understand and easier design with arbitrarily deciding quantity of dampers because the function of supporting building with linear restoring spring and the function of damping are separated. The latest HRB and LRB are now easy to construct and can give Menshin period of 4 second and over as shown pervious section. From the author's point of view total cost of Menshin systems, the lowest is HRB, the highest is LRB, but the differences are little. The sliding isolators with an infinite period itself are also turned to practical use to support low to high rise buildings.

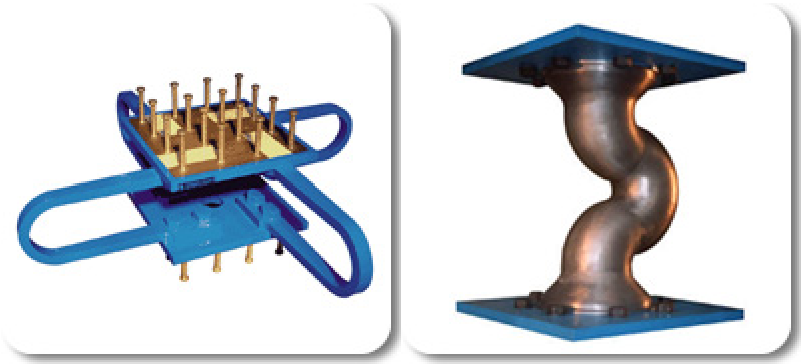


Fig.2.2 Steel damper (left)
and Lead damper(right)

Steel damper
Width 1853mm
Yielding load 112kN-608kN

Lead damper
Height 960mm
Yielding load 220kN

2.3 Why do Menshin buildings increase drastically in Japan?

Top 20 construction companies (general contractors) promoted Menshin eagerly. Menshin was adopted by research facilities and companies used Menshin in their own buildings which they could show to their clients. Moreover, they built huge shaking tables to demonstrate Menshin technology since the motion under earthquake is easy to see. They publicized the advantages of Menshin and utilized this special technology for business.

Price of isolators (rubber bearings) dropped. Natural rubber bearings were especially lower because of a large number of entry providers who discounted pricing. This is a reason that the way of separate dampers which become popular in Japan. – The price started at 10000yen per ton of supported vertical load in the early stages and dropped to 2000-3000yen.

Steel-frame and steel-bar reinforced concrete (SRC) is applied in more than 10 story building which is unique to Japan. Since Menshin can utilize RC leaving out the steel-frame, the total construction cost can be reduced. This is one reason why Menshin is used in many condominiums.

Designers' point of view, Menshin designers developed their ability and spread the message through the "Architectural Institute of Japan (AIJ)" and the "Japan Society of Seismic Isolation (JSSI)" activities.

After the 1995 Kobe earthquake, fear of frequent occurrences among the nation and drew attention to Menshin even further.

Menshin will increase because of the needs for public institutions, hospitals, and general to continue operations during earthquakes. In addition, increases in the price of steel, environmental impacts, Menshin is further supported as Menshin buildings need less architectural (structural) materials and are long life.

3. Benefits to the U.S.

We Japanese designer have roughly two things of benefits of the U.S.

Even though the idea of Menshin existed, if the ground motion of earthquake was not known, the behavior of the Menshin building would not be known. In the U.S., in 1940 EL CENTRO, in 1952 TAFT earthquakes were observed by strong motion recorders (1968 in Japan, HACHINOHE is observed). These data and Housner's response spectrum and his theory of constant velocity make clear the potentiality that Menshin buildings shall be possessed. In 1986 "the maximum considered earthquake ground motion" should be 50 cm/s of those PGV in time domain[8]. This was determined by the "Nonprofit Corporation : Building Center of Japan". Designs from EL CENTRO, TAFT, HACHINOHE and etc earthquakes were normalized to

50cm/s.

Roles of opening of the analysis codes in the U.S. were useful. The spectral design method is used in the U.S., while the numerical integration method employed in Menshin designs in Japan because of no assumption of building regulations. Majority of the analysis codes were made in the U.S., for example, code “ANSR” was given additional functions and was applied in Menshin as the main solver of the dynamic analysis. Code “SHAKE” is now used widely as the analysis of soil deposit in Japan. We respect the contributions made by the U.S. in opening up studies all over the world.

As the synthetic technologies of earthquake, elemental Menshin technology and design technology, designs and constructions of Menshin buildings started from the 1980s in Japan. As same as other Japanese industrial products, Menshin technology is based on basic technology adopted from other countries and the application was rapidly developed in Japan– extreme “Japan-like” technology.

In Japan, Menshin built buildings have not suffered strong earthquakes. The U.S. made a great contribution to this. A perfect success of the USC University Menshin hospital in Los Angels under the Northridge earthquake in 1994 deserves to be special mention[9]. During the earthquake staff were performing brain surgery; the surgery was completed with only minor interruptions due to the earthquake. Other hospitals in the same vicinity had fatal damages and they were not able to accept any incoming patients. This has encouraged us and we had a firm belief in Menshin. Based on the success of the hospital in the U.S. the authors’ decided to design the first hospital in Japan the “Hoshigaura hospital” using the technology of Menshin[10].

4. Expansion of Menshin application

Responding the high performance of Menshin devices, Menshin designers are aiming the higher technological level. Japanese Menshin gets another stage from 20 years ago.

4.1 Application for high rise buildings

Menshin is used in high rise building beyond 60m in height. A high rise building with long natural period itself combined with Menshin that has a period of 2 or 3 seconds is nonsense and dangerous due to resonance. The height of the building is restricted by the regulations in Japan. But 1996 the “Sendai MT building”[11] office having 85m height was designed with a special permission from the minister exceptionally. Menshin period is over 5 seconds versus the 1.8 second of the upper structure. Menshin seems effective if the Menshin period is 2-3 times will be higher when

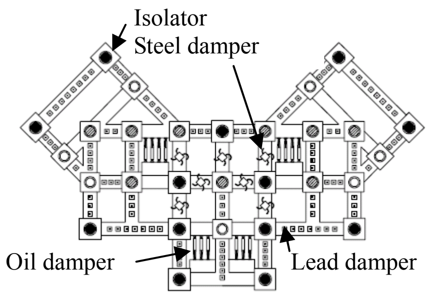


Fig.4.1 (a) Plan (Menshin device floor)

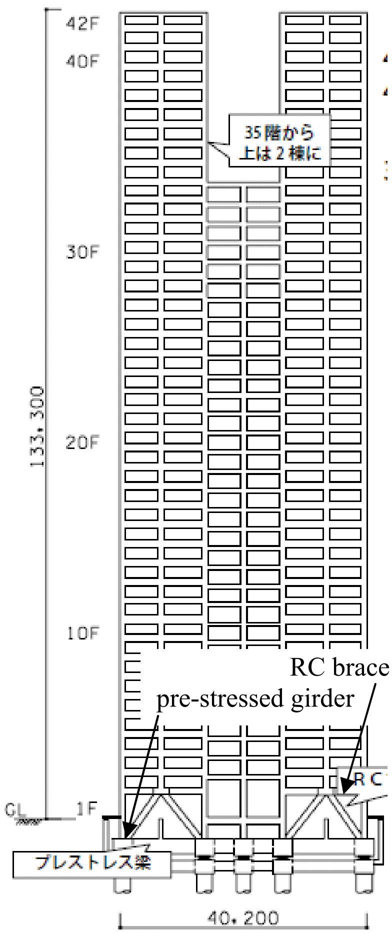


Fig.4.1 (b) Elevation of frame

compared to the upper structural period. Next year the "San-nomaru" condominium designed by the authors as the first residential building beyond 60m. The Menshin period is 4.2 second compared to the upper structure's 1.8 seconds. In 2000, Menshin was applied to a 133m 42 story building the "Kuzuha" (Fig.4.1). Menshin period is 5.4 second compared to the upper structure's 3.1 seconds.

4.2 Examples of Menshin designed building with the latest Menshin devices

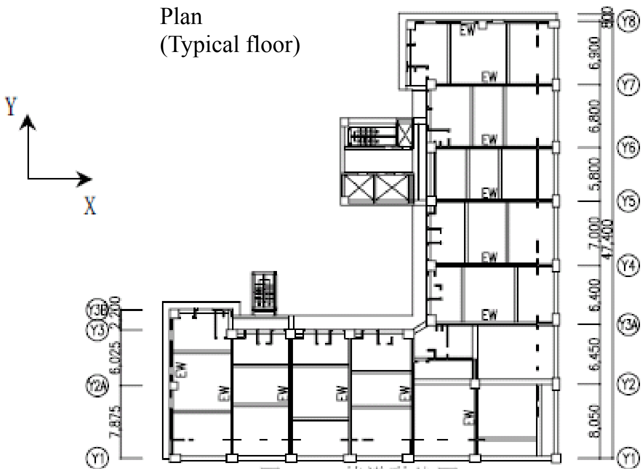
The following section introduces buildings that have used the latest Menshin devices.

(1) A 3 story building the "Yamanashi IT" having 9000m^2 of floor space is supported by only 4 isolators (Fig.4.2). The truss structure is skillfully used and the weight of all the building is concentrated on the 4 lead cored rubber bearings (LRB) which have diameter of 1200mm each. This makes column-free for a ground floor.

(2) L-shaped plans and large eccentricities in high rise upper structure which has intermingled moment resistant frames and shear walls is realized by using the Menshin technology by the authors(the "Sakai-Kaimachi")[13]. Pay attention to the Y direction, the right side consists of moment resistant frames and the left is shear walls structure. When this structure is planed without Menshin, building needs to be separated to be 2 buildings by expansion joints due to the excessive torsion caused by different quakes between right and left.

Fig.4.2 (a) Steel frame under construction

Fig.4.2(b) Isolator(LRB) and fireproof wall



20 story condominium
Reinforced concrete
Menshin devices:
Natural Rubber bearings
High-Damped rubber bearings
(900-1300mm of diameters, σ =12.8N/mm^2)
Oil dampers
Menshin period: 4.6 sec. vs. upper's 0.76 sec.

Fig.4.3 L-shaped plan with intermingled moment resistant frames and shear walls

(3) Menshin provides an unusual outward appearance (the "Prada-Aoyama"[14],Fig.4.3). The structural members contain no columns, only slender braces which charge both vertical and lateral forces. This building

is prepared for a boutique which deals in high-quality articles. If it was designed without Menshin, the braces would become too thicker and windows would be too smaller. The architectural design would be spoiled. This building has 7 stories (Steel structure) and 2 basement floors (SRC structure) and is 32.5m in height, and the area of 1^{st} floor is $369m^2$ having a total area of floor space equal to $2860m^2$.

The first building won the JSSI prize, and third building won both the JSSI and JSCA prize.

Fig.4.4(a) a boutique with an unusual outward appearance   Fig.4.4(b) Inside

5. An example of Menshin design

A Menshin designed building will be explained taking the "San-nomaru" as an example[15]. According to the vertical forces (long term vertical pressure σ =10-15N/mm^2), 50 natural rubber isolators with modulus G=0.34 or 0.44N/mm^2 were arranged at the bottom of all columns. Then the Menshin period (based on the post-yield stiffness) was estimated 4.2 second assuming a rigid upper structure. The Menshin is expected to be valid due to the Menshin period being 3 times of the upper structure's 1.2 seconds. Both steel dampers and lead dampers were chosen (lead dampers vibrate little under conditions of wind). For the isolator, there was no high-damped and no lead-core isolators were provided this ensured the Menshin periods then. Parametric studies about amount of dampers with mass-spring seismic response analyses were carried out to judge if the Menshin is actually effective and to find the damper's yielding force. The yielding force of the damper was found to be 2.2% of weight of the upper structure. Input motions for the design were normalized to 25 or 50 cm/s in PGV, EL CENTRO 1940 NS, TAFT 1952 EW, HACHINOHE 1968 NS&EW, and an artificial earthquake with 52.6 cm/s. For these input motions, table 5.1 was settled for criteria. Horizontal clearance to the ground was secured to 55cm to give enough space.

Table 5.1 Criteria for seismic design

	Level1(25cm/s)	Level2(50cm/s)*
Upper structure	Under Short term allowance stress Under 1/600 of story drift	No yielding structural member Under 1/300 of story drift
Menshin devices	Under 200% of strain(320mm) as the isolators' stiffness are linear	

*Level2: The maximum considered earthquake ground motion

In addition, the ultimate load (ductility) of the upper structure, tensile limit of isolators, and vibration under wind were checked. After completion, observation of strong motion continued [16] (Fig.3.4).

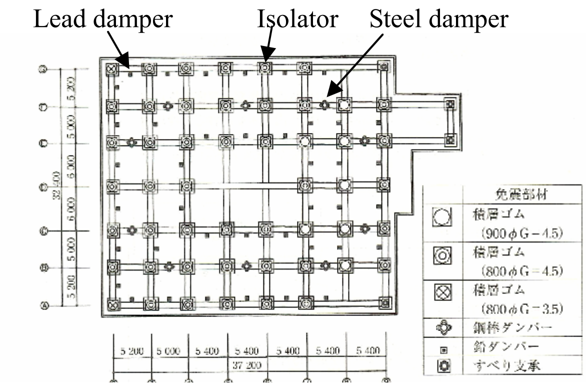


Fig.5.1 Arrangement of Menshin devices

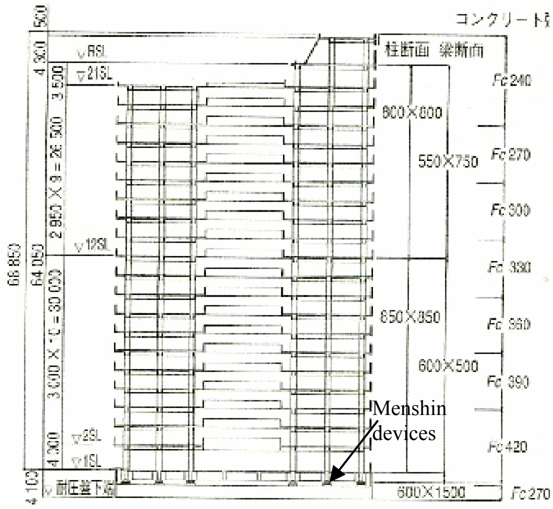


Fig.5.2 Elevation of the structure

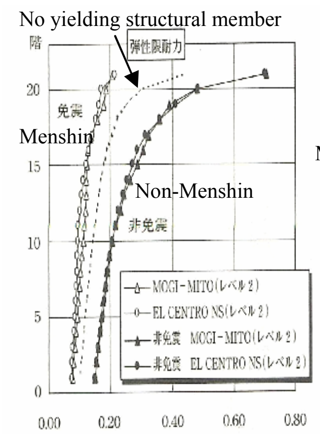


Fig.5.3(a) Shear coefficient

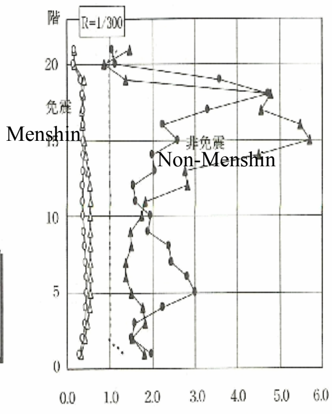


Fig.5.3(b) Drift cm

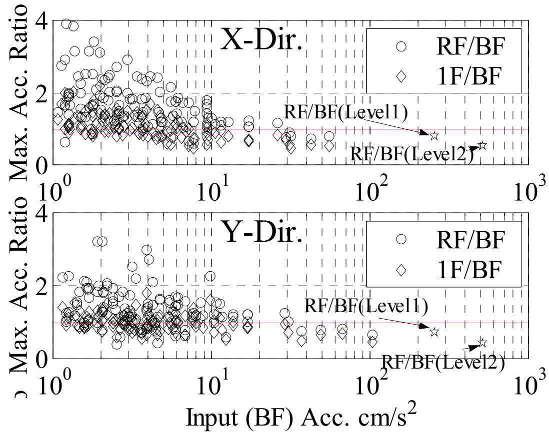


Fig.5.4 Results of earthquake observation

6. Observations of strong motion in Menshin buildings in Japan

After the 1995 Kobe, damaging earthquakes continue to hit Japan about every year. Results seen are as we expected.

6.1 1995 Kobe, 2 buildings[17]

Both are located at 30km from the epicenter of the earthquake. In the Menshin building, accelerations were not multiplied, but in the Non-Menshin building accelerations amplified 4 times to be 1G.

Table6.1 Matsumura Gumi Co. T.R.I Building

Max. Acc.(cm/s^2)		Direction		
Menshin RC3F High-Damped Isolators	Floor	NS	EW	UD
	RFL	198	273	334
	1FL	148	253	266
	Basement	272	265	232
Non-Menshin S3F RFL		965	677	368

Table6.2 The Yusei WEST Building

Max. Acc.(cm/s^2)		Direction		
Menshin SRC6F Natural rubber & Metal Damper	Floor	NS	EW	UD
	RFL	75	103	377
	1FL	57	106	193
	Basement	263	300	213

6.2 **2003 Off-shore Tokachi earthquake, the Hoshigaura Hospital** (Designed by authors) [18]

HRB, σ =5.7N/mm^2, Menshin Period: 2.6second

Fig.6.1(a) Hoshigaura Hospital RC3F

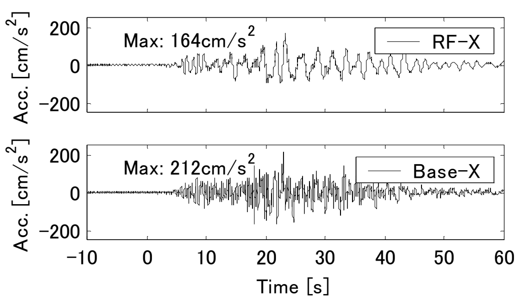


Fig.6.1(b) Observed Accelerations(X Direction)

6.3 2004 Niigata, the Ojiya Hospital[19]

0.8G at the basement became 0.2G on the building.

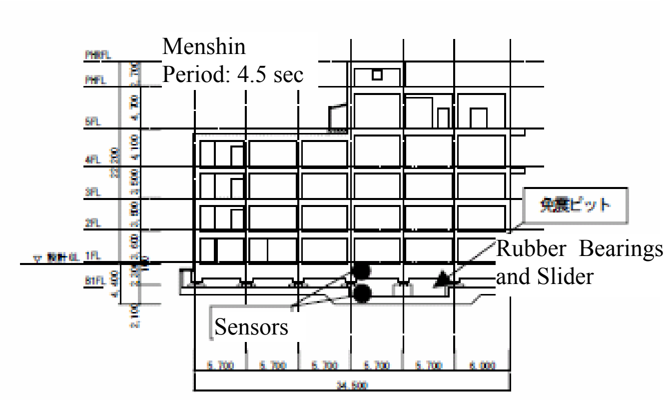


Fig.6.2(a) Elevation of the structure

	Basement	Upper	Ratio
方向	基礎部	免震上部	最大加速度比
NS	740.4	198.0	0.27
EW	807.7	205.2	0.25
UD	487.2	749.4	1.54

(加速度の単位：gal)

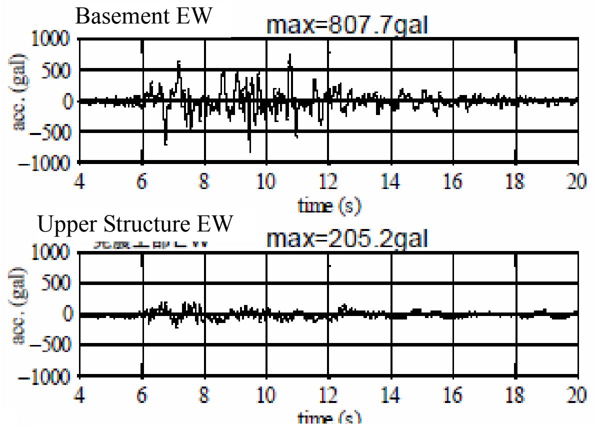


Fig.6.2(b) Observed Accelerations(EW Direction)

7. Conclusion

Just now, it seems that Japan has the most advantage about Menshin technologies. But to our regret, transfer overseas of such technology is negligible when compared to other technologies such as electronics, machinery, automotive, and so on. The authors hope that the Menshin technologies are not only used more in the U.S. but also advanced nations and developing countries – e.g. inland of mainland China, the R.O.C(Taiwan), Southeast Asia, Turkey, West Asia – a single earthquake kills some dozens of thousands of people. Subsidiary, the author expects acquisition of foreign currency for the Japanese welfare as the population will decrease and economy may go recession in Japan.

There is a strong desire to spread the Menshin technologies world wide through collaborative work and competitions between Japan and the U.S.- Like the newest Boeing jet whose 40% of the parts are provided from Japan -, and the author suggests to adapt the word “Menshin” into everyday vocabulary in much the same way as the word “Tsunami” has been taken in.

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