Vibration Evaluation of Cable Penetration Sealing System for Earthquake Resistant by Dynamic Structural Testing System

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ABSTRACT

In Japan, common cable Penetration Sealing Systems (PSS) consist of calcium-silicate board, mineral wool and fire resistant putty. However such systems can not perform adequate earthquake resistance since these products are developed with the intention of providing fire resistance only. Calcium - silicate board is brittle and fire resistant putty has low adhesive strength - both materials are unsatisfactory for surviving earthquakes. Several new types of cable PSS use a flexible board, composite board (steel plate + ceramic mat) and adhesive putty. These systems are expected to show good earthquake resistance because they absorb vibration energy due to good elastic properties. In order to evaluate and compare the earthquake resistance of various cable PSS, full scale vibration tests and fire simulation tests were performed.. The vibration tests used dynamic structural testing equipment; which utilized a 3-axes shaking table. Fire tests were conducted after vibration tests by immersing the samples into a large scale furnace.

NOMENCLATURE

F_{max}	Given maximum external force to PSS (kg)
A_{max}	Maximum acceleration generated on penetration item(gal)
m	Mass of penetration item(cable and cable tray)(g)
G	Gravity acceleration (m/s^2)
gal	acceleration(cm/s^2)
kine	velocity(cm/s)

INTRODUCTION

The cable PSS fire performance (fire rating) has been determined by the Building Center of Japan (BCJ). The BCJ is associated with the Ministry of Construction and gives a fire rating appraisal to every PSS.
In order to acquire an appraisals for a PSS, the system must demonstrate fire prevention performance in a fire test simulation. The fire prevention performance is determined upon exposure to the conditions stated in the JIS A 1304 standard. The PSS performance, as determined by the BCJ bylaws, are the following;

(1) The temperature of the cable jacket in contact with the atmosphere on the unexposed side shall not be more than 340° C. for the rating period.
(2) The temperature of the other fire stop element surfaces, including the floor or wall, on the unexposed side shall not be more than 260° C. for the rating period.
(3) The PSS shall not permit abundant smoke from the elements on the unexposed side during the rating period, nor abundant passage of smoke through the opening.
(4) During the fire simulation, changes regarded as harmful for fire resistance (such as deformation, destruction, falling off etc.) shall not occur.
(5) Upon completion of the fire test, flames shall not be present on the unexposed side of the PSS for 10 minutes.

As stated above, cable PSS have been tested only with regard to fire prevention performance; the earthquake resistance has not been considered. As a result of the Osaka-Kobe earthquake, which occurred on January 17,1995, many PSS suffered damage such as cracking, falling apart, and detachment to the walls and floors. The damage was especially great for PSS which used calcium-silicate board as shown in Fig.1 and 2. This is very significant to note because it is very common for fires to occur as a result of an earthquake.

Putty which treated the lower part of the cable and sealing putty for board joints completely dropped

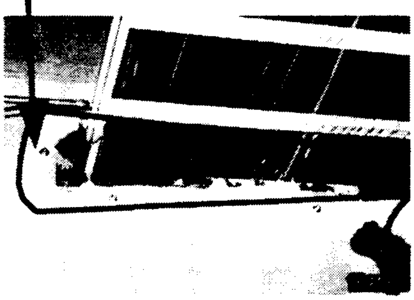

Fig.1 Wall Damage Example(1)
(Calcium-silicate board PSS)

Similar to (1), the putty dropped off. The boards were cracked in few places, and spots which had been lifted can also be seen.

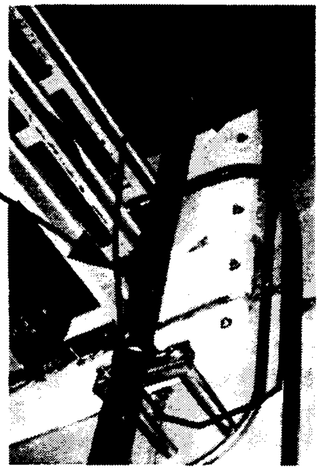

Fig.2 Wall Damage Example(2)
(Calcium-silicate board PSS)

Another important finding is that there was not even one damage report of a 3M applied PSS in the field. the difference in the amount of damage is likely due to the different characteristics of each material. In order to confirm this, a bending test and an impact test for various fire resistant compartment boards and for various fire resistant putties were conducted. In both the bending tests and impact tests, the 3M board deflected and absorbed the stress without cracking. However, the calcium-silicate board cracked or broke apart in each case. In the adhesion force test, the 3M putty showed high performance like an acrylic adhesive, but the other putty performances were very weak. These results suggest superiority of the earthquake resistance of the 3M materials. Although it can be assumed from these tests that the earthquake resistance of the 3M PSS is superior, it must be demonstrated by further testing. It is very important to conduct vibration testing to a model of an actual PSS. Since such an evaluation had not been done so far, this is the reason for the present study.

In this study, the earthquake resistance was evaluated and compared for several typical cable PSS. Full scale vibration tests were performed using dynamic structural testing equipment on a 3-axes shaking table. Fire tests were then conducted after the vibration tests in order to determine the fire ratings in accordance with the bylaw of BCJ.

EXPERIMENTS

Selected Cable PSS

There are over 20 companies which supply cable PSS in Japan. Over 300 PSS have been released to the market. Five PSS, including two 3M systems, were selected as representative from this list of 300. A drawing and description of each system, and materials used to compose the system, are shown in the following figures.

No.1 Sumitomo 3M rubber sheet system (BCJ-BOSAI-1022)(Fig.3)

This system is comprised of intumescent rubber sheet(FS-195) and intumescent putty(CP-25WB). A cable of a size beyond 100mm² (conductor cross section size)must wrap specific length of mat(M20A). The sheet consist of hydrated sodium silicate and chloroprene rubber and covered with aluminum foil both side. It is elastomeric and flexible. It functions as an effective intermittent fire-brake within cable tray runs. The composition of putty is basically same with sheet. It use to seal cracks, voids, or holes against flame, smoke and water penetration. It has elastomeric and adhesive property. This system feature is no fill up need.

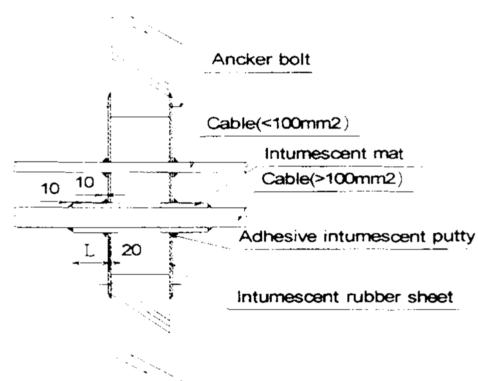

Fig.3 Typical cross section

No.2 Sumitomo 3M composite Sheet system (BCJ-BOSAI-1113) (Fig.4)

This system is comprised of composite intumescent sheet(ST-120), mat(M20A) and putty. A cable of a size beyond 100mm² (conductor cross section size)must wrap specific length of mat. The composite sheet consist of ceramic fiber, vermiculite and binder. It is flexible and bounded on one side to a layer of 0.24mmt galvanized steel. The other side covered with aluminum foil. The mat is without steel. These functions as an effective intermittent fire-brake within cable tray runs. The putty is described in the preceding clause. This system feature is no fill up need also.

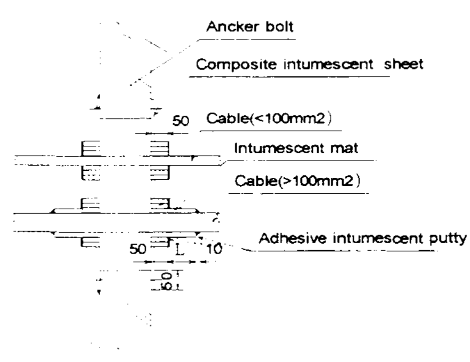

Fig.4 Typical cross section

No.3 Calcium Silicate board one sided system (Fig.5)

This system is comprised of calcium-silicate board and fire resistant putty(TAIKA PLAST-A). A cable of a size beyond 325mm² (conductor cross section size)must paint specific length. The board is popular building material which has noncombustibility. Though it seems hard , it will be broken more than a regular power to be. The putty consist of inorganic materials. It is sticky. So it adhere on a cable only with its stickiness. This system feature is able to assemble from one side.

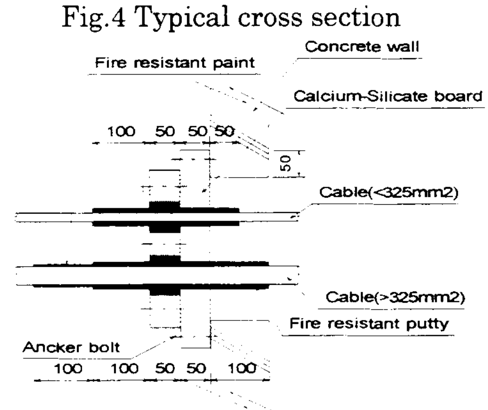

Fig.5 Typical cross section

No.4 Calcium Silicate board both sided system (Fig.6)

This system is comprised of calcium-silicate board, rock wool and fire resistant putty(DANSEAL-P). The board is popular noncombustibility building material. Though it seems hard , it will be broken more than a regular power to be. Inside of wall are filled with rock wool of]high packing density. The putty consist of inorganic materials. It is sticky. So it adhere on a cable only with its stickiness. This system feature is popular as being low-priced.

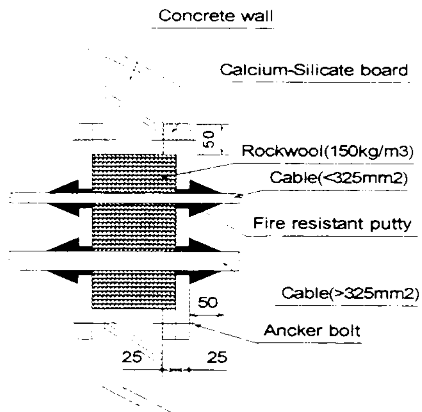

Fig.6 Typical cross section

No.5 Rock-wool board system(Fig.7)

This system is comprised of molded rock wool board and fire resistant putty(FLAME PUTTY). The board comprised of two components. The heart is inorganic rock wool, fire resistive coating(FLAME COAT) on one side which thickness is over 1.5mm. It is amount of flexible. The putty consist of inorganic materials. It is sticky. So it adhere on a cable only with its stickiness.

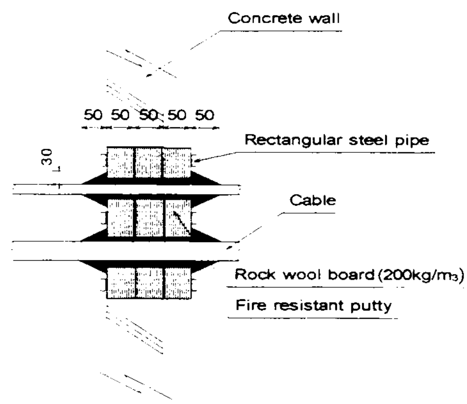

Fig.7 Typical cross section

Concrete

Each test specimen of cable PSS which assembled on simulated wall made by pre-cast reinforced concrete slab, mounted center of frame as shown Fig.8. It made from the ready-mixed concrete, obtained from a local source, was composed of one part Type I Portland cement, 1.8 parts sand, and 3.5 parts Gravelite aggregate, by bulk volume, mixed with proper quantity water.

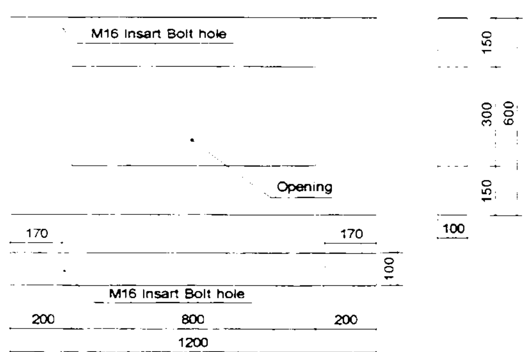

Fig.8 Simulated wall (mm)

Through-Penetrating Items

Every test specimen uses the same through-penetrating items shown in Fig.9. The various cable PSS are then assembled in accordance with the manufacturers' recommendations. The cables were fixed in the cable tray with strings.

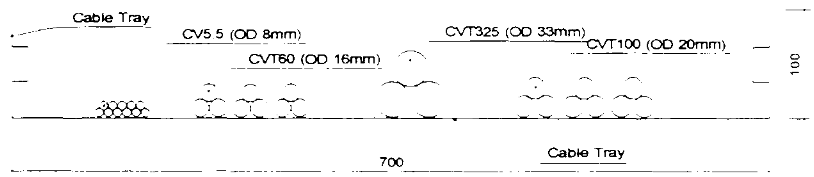

Fig.9 Penetrating Items (mm)

Vibration test setup and method

Full scale vibration tests were performed using dynamic structural testing equipment which is the shaking table can achieve 3-dimensional movement of 6 degrees of freedom in KUMAGAI GUMI Co.,Ltd..

Fig.10 shows the summary of the vibration test system. This vibration test were simulated nature of the ground motion (both horizontal and vertical) by a building structure of wall using I beam steel frame.

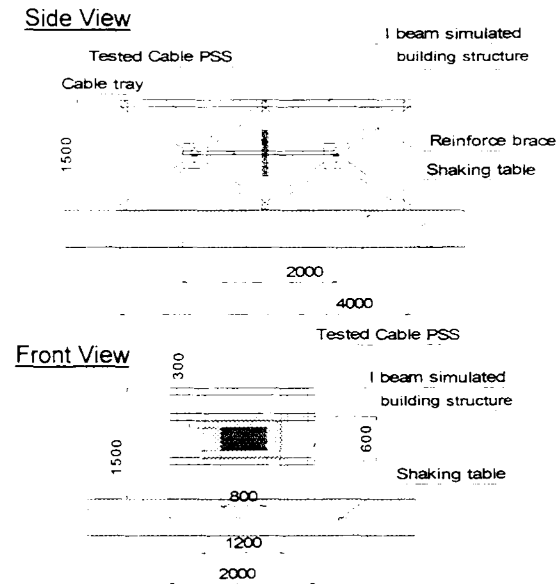

Fig. 10 Summary of the vibration test system

Each test specimen was attached to a test frame. Next, each simulation concrete board was fixed in the frame with high tension bolts and a steel plate. Consequently, the concrete board will always move with the frame. A cable tray was hung from the ceiling with hanger bolts and hanger supports (typical installation method in Japan) as shown in Fig.11 to 13. The cable tray was supported so that it passes through an opening in the simulation frame. The weight of the penetrating items is supported by the frame when no load is on the cable PSS at vertical direction. The purpose of the vibration test is to measure the acceleration at several points on the cable tray and pre-cast reinforced concrete slab for each specimen. The other points were used to measure the shaking table(①) and frame(⑧,⑩).

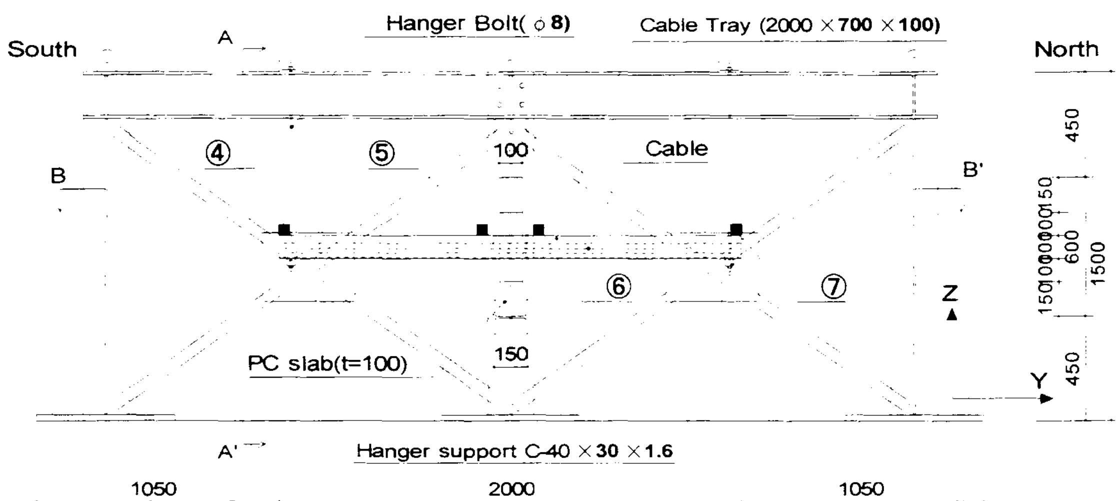

Fig. 11 C-C' cross section of settled test frame

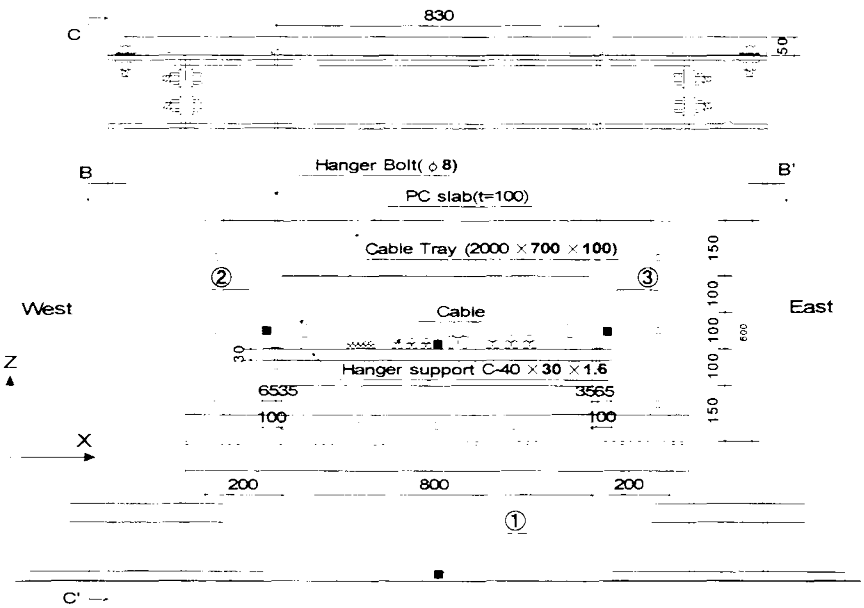

Fig. 12 A-A' cross section of settled test frame

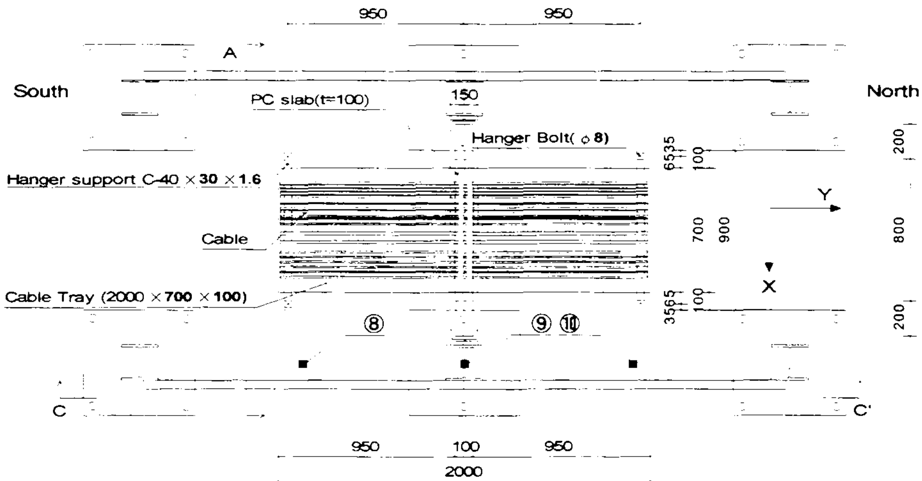

Fig. 13 B-B' cross section of settled test frame

Mounting

The settled frame with test specimen were mounted on the shaking table shown in Fig.14. The mounting method is connections with high tension bolt. The arrow of axes in the figure means a plus direction of input acceleration. For any given ground motion, the magnification depends on the system's natural frequencies of vibration and the mechanisms of damping.

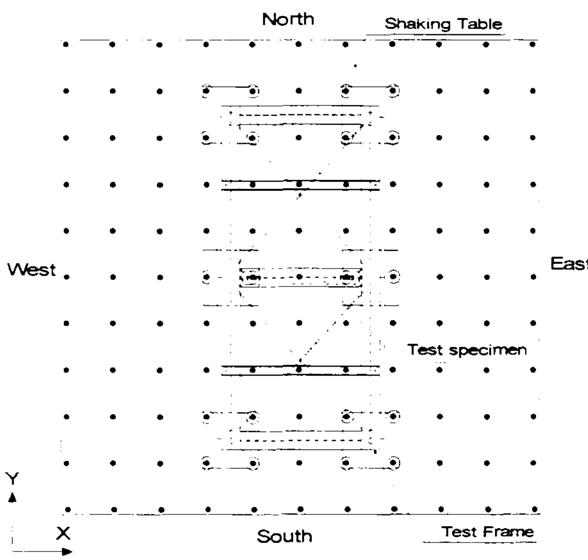

Fig. 14 Frame position on the table

Table 1 shows the wave form and strength of the input waves which were used at this test. The vibration tests were conducted in the order listed in the table (starting from the top). TAFT and KOBE waveforms are reproduced waves that were based on observed measurements taken during actual earthquake events - these display multiple-frequency waveforms. SINE beat is a single axis test and was selected to produce maximum acceleration of this test equipment. After each vibration waveform, observations were made on each specimen to determine if damage or other changes had occurred.

Table 1 Excitation waves used at test

Wave Form	Level / Frequency	Excitation Axis	Maximum Acceleration(gal)	Maximum Velocity(kine)	Excitation Test Specimen
TAFT	Level 1 (25 kine equivalent)	X Y Z	122 257 82	11 25 6	All Specimen
KOBE	Level 1 (25 kine equivalent)	X Y Z	171 227 92	20 25 11	All Specimen
	Level 2 (50 kine equivalent)	X Y Z	171 454 92	20 50 11	All Specimen
SINE Beat	10 Hz	X	750	12	All Specimen
	10 Hz	X	1000	16	All Specimen
	10 Hz	X	1500	24	All Specimen
	10 Hz	X	2000	32	Only No.2
	10 Hz	Y	1000	16	All Specimen

Fire exposure tests setup and method

Upon completion of the vibration testing, every specimen was subjected to a fire test. The fire tests were conducted and the furnace temperatures were controlled in accordance with the standard, Method of Fire Resistance Test for Structural Parts of Building, JIS A 1304. Each specimen was tested verticality on a furnace (to simulate a fire on one side of a wall). The furnace temperatures at the center and ends of the center line of exposed surface of the test specimen were adjusted to follow the standard time-temperature curve as specified in the Standard JIS A 1304. These temperatures were measured by means of six thermocouples symmetrically located on the exposed surface. The four sides of the concrete slab were insulated with ceramic-wool batts.

The temperatures on the surface of firestop elements(9-10), penetrating items(1-8) on the unexposed side of each specimen were measured by thermocouples located as shown in Fig.15. The thermocouples on firestop material were covered with dry ceramic pads.

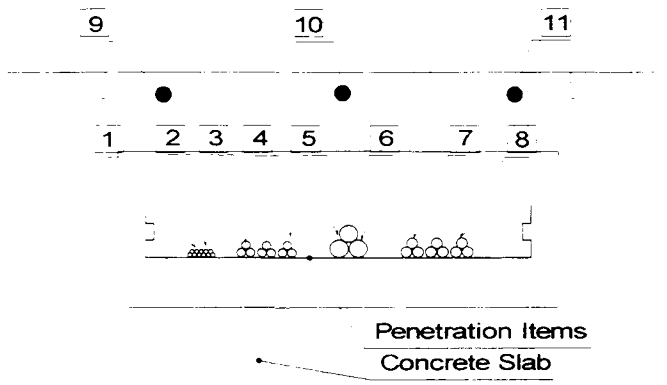

Fig. 15 Thermocouples location

The pressure within the furnace chamber (with respect to atmospheric pressure) was measured near the center of the furnace using a stainless steel pressure probe located approximately 10 cm behind the exposed surface of the concrete wall slab. Throughout each fire test, observations were made regarding the character of the fire and its control, the condition of the exposed and unexposed surfaces of the test specimens, and all developments pertaining to the performance of various fire resistant PSS, with special reference to integrity and flame passage through the PSS. The final judgment(fire rating) was enforced in accordance with the bylaws of BCJ as described previously in this paper.

RESULTS AND DISCUSSION

Vibration test

a) Character and condition of shaking table and frame

For each specimen, the excitation waveform was input exactly as estimated to the shaking table and frame. These are confirmed from measured data by each acceleration gauge. The data(②,③) measured on the concrete slab are almost identical with those measurements taken for the shaking table. For example, the comparison of X-axis data with the Kobe Level 2 of No.3 specimen is shown in Fig.16. These results indicate that the concrete slab moved with the frame as if to form a single rigid body.

Such a behavior would be similar to the basement or the 1st floor of an actual building. Furthermore, the concrete slabs were firmly fixed on the frame and didn't contribute to harmonic or amplified vibration.

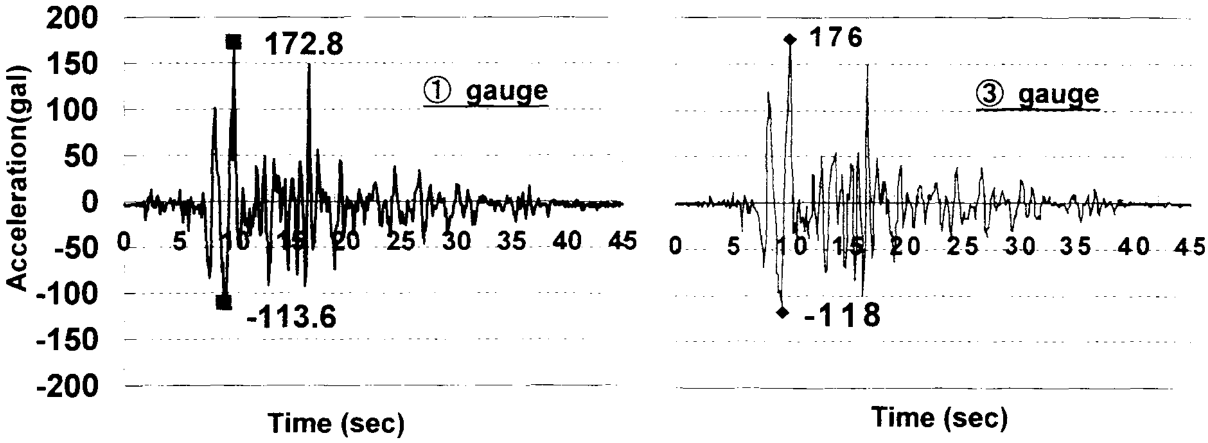

Fig.16 Comparison of X-axis data with ① and ③, Kobe Level 2 of No.3

b) External force to PSS

During excitation to each PSS, the penetration items were measured for acceleration. The external forces were generated to the PSS in all directions. The maximum acceleration of X,Y And Z axis were measured. The Maximum external force can be calculated using the following equation;

$$F_{max} = A_{max} \times m / G$$

where m is 110 (kg), and G is 980 (gal).

For example, if A_{max} of Y-axis is 400(gal), F_{max} of Y-axis should be app. 44.9 (kg).

c) Observations during test

The following observations were made during each vibration test. All referenced dimensions are approximate.

Table 3 External appearance summary

Test Specimen No.	KOBE Level 2	Sine Beat X axis 1000 gal	Sine Beat X axis 1500 gal	Sine Beat X axis 2000 gal
No.1	○	○	○	—
No.2	○	○	○	○
No.3	△	×	×(Fig.17)	—
No.4	○	△	×(Fig.18)	—
No.5	○	○	×(Fig.19)	—

○:No particular problem △:Slight damage ×:Major damage —:Not tested

No.1 Sumitomo 3M rubber sheet system

After 1500 gal excitation, no damage such as cracks and peeling on the fire resistant intumescent board FS-195 and seal putty CP-25WB. During excitation, FS-195 was confirmed to be modified like waves by activating its rubber sheet state characteristic.
At 1500 gal, ④ F_{max} ≒ 660 kg, ⑤ F_{max} ≒ 480 kg.

No.2 Sumitomo 3M composite Sheet system

After 1500 gal excitation, no damage such disengaging and tearing. After 2000 gal excitation, while fine tears in the putty of intumescent mat were seen, no peeling no breaks were confirmed at all. At 2000 gal, ④ F_{max} ≒ 560 kg, ⑤ F_{max} ≒ 360 kg.

No.3 Calcium Silicate board one sided system

The lower board(50mmt) was cracked at the time of 1000 gal excitation, and at 1500 gal, a crack was caused on the left of the upper board. The board was lifted from wall. The putty around tray was also lifted over 10 mm.
Also the putty was peeled off by excitation, causing a space from which light of the opposite side was confirmed to be void.
At 1000 gal, ④ F_{max} ≒ 400 kg, ⑤ F_{max} ≒ 425 kg.

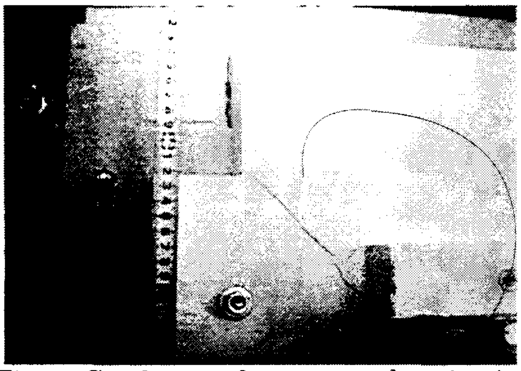
Fig.17 Condition after 1500 gal excitation

No.4 Calcium Silicate board both sided system

At the time of 1000 gal excitation, the board was lifted about 2 mm to the front, and at 1500 gal, as shown Fig.18, the board was further lifted about 10 mm, and the upper and lower boards became loose. An anchor bolt to fix the board can be seen. During vibration, a large amount of internal rock wool was confirmed to have splashed. At 1500 gal, ④ F_{max} ≒ 820 kg, ⑤ F_{max} ≒ 885 kg.

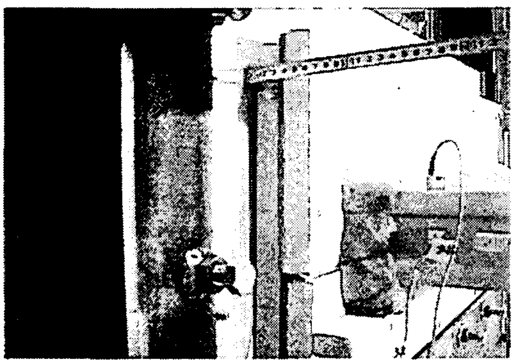
Fig.18 Condition after 1500 gal excitation

No.5 Rock-wool board system

Putty material could not follow cable swing, and as such was cracked around the cables. On the lower part, the partially cracked putty was unable to hold its own weight and dropped off. Putty around cable tray was also cracked by the motion of the tray and the crack width was about 10 mm.

At 1500 gal, ④ F_{max} ≒ 695 kg, ⑤ F_{max} ≒ 900 kg.

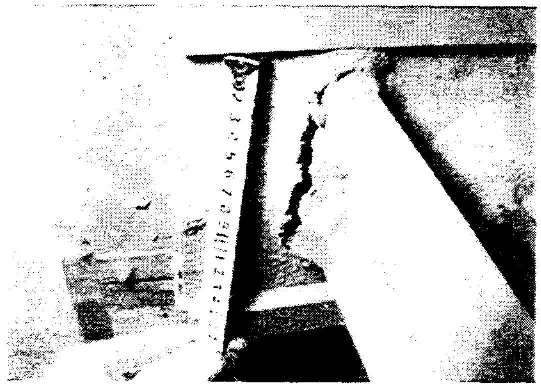
Fig.19 Condition after 1500 gal excitation

Fire exposure tests

a) Character and distribution of fire

For each fire test, the fire was luminous and well-distributed, and the followed the standard time- temperatures curve as outlined in the Standard, JIS A 1304, and as shown in Table 4.

Table 4 Furnace Temperatures

Test Time (min)	Temperature(℃) (JIS A 1304 Curve)	Average Furnace Temperature (℃)				
		No.1	No.2	No.3	No.4	No.5
10	705	650	715	670	680	610
30	840	785	850	790	810	760
60	925	930	910	890	990	890
90	980	960	950	N/D	1010	960
120	1010	1020	1005	N/D	1040	1000

b) Pressure within the furnace chamber

During the first one or two minutes of each fire test, the measured furnace pressure with respect to standard atmospheric pressure was slightly negative to neutral. Thereafter, the measured furnace pressure was positive and remained constant at 0.1mm of water.

c) Temperature rating

For each fire test, the maximum temperatures of the cable jacket and the other fire stop element surfaces are shown in Table 5.

Table 5 Cable jacket and Fire stop elements surface temperatures

Measurement group ( ):limit temperature	Maximum Temperature (℃)				
	No.1	No.2	No.3	No.4	No.5
Cable jacket (340℃)	289	293	N/D	463	306
Elements surface (260℃)	194	204	N/D	168	249

d) Observations during test

The following is a summary of the observations and comments recorded during each fire test. All referenced dimensions are approximate.

No.1 Sumitomo 3M rubber sheet system

time	observations
2	Light smoke coming from the open top of CVT cable.
30	Smoke stopped. Sheet has intumesced little. CVT 100 cable jacket are bulging.
90	Sheet surface has intumesced more.
120	No apparent change.(Fig.19) Furnace fire extinguished.

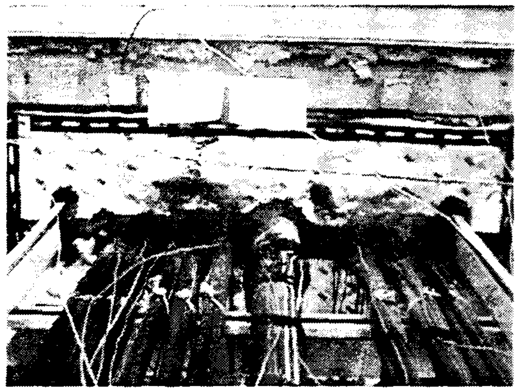

Fig.19 Condition after 120 min fired

No.2 Sumitomo 3M composite Sheet

time	observations
2	Light smoke coming from the open top of CVT cable.
60	Smoke stopped. CVT 100 cable jacket is bulging.
90	CVT 60 cable jacket is bulging.
120	No apparent change.(Fig.20) Furnace fire extinguished.

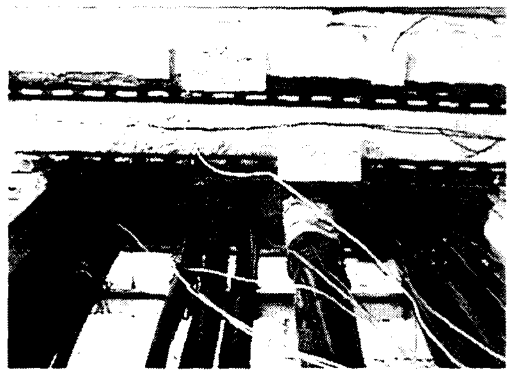

Fig.20 Condition after 120 min fired

No.3 Calcium Silicate board one sided

time	observations
2	Heavy smoke coming from the around the system.
40	Smoke continues.
50	Several crack generated at putty on cable.
60	Flame coming from right side of tray.
95	Fire breaks out on CVT 250. Test stopped.(Fig.21) Furnace fire extinguished.

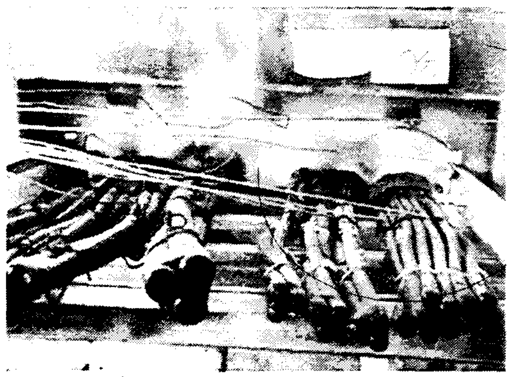

Fig.21 Condition after 95 min fired

No.4 Calcium Silicate board both sided

time	observations
2	Light smoke coming from the open top of CVT cable.
30	Smoke stopped.
50	CVT 325 cable jacket are bulging.
60	CVT 100 & 60 cable jacket are bulging.
90	CVT 325 cable jacket are burst.
120	Emission of light verify in CVT 325 cable.(Fig.22) Furnace fire extinguished.

Fig.22 Condition after 120 min fired

No.5 Rock-wool board system

time	observations
2	Heavy smoke coming from a crack in the putty.
10	Smoke continues to emanate from the crack
50	CVT 325 cable jacket is bulging.
70	CVT 100 & 60 cable jackets are bulging.
90	CVT 325 cable jacket burst.
110	Smoke continues to emanate from the crack and cable damages.
120	Smoke continues.(Fig.23) Furnace fire extinguished.

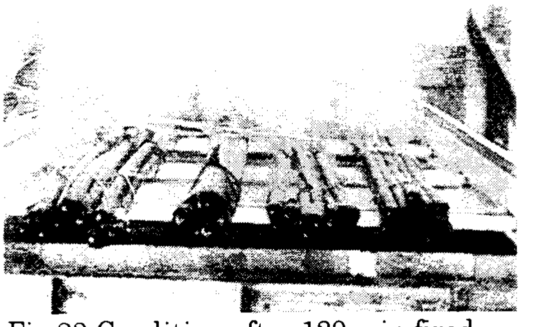
Fig.23 Condition after 120 min fired

CONCLUSION

A ductile possessing flexibility which used 3M PSS had no damage at all even if an excitation acceleration of 1500 gal and 2000 gal were received, but the other PSS with brittle board and putty which had sticky or harden were all confirmed to have had major destruction and injurious damage at1500 gal.
And also based on these initial damages, their own originally fire resistant deteriorated severely. In this study, we are confident that a vibration test quite exactly was able to reproduce an actual earthquake. The main conclusions are
(1)Penetration items amplifying by having excitation and then input external force to PSS . In time of actual earthquake, it is anticipated a large power depends on PSS.
(2)No.1 and 2 PSS which consist flexible board and adhesive putty show good earthquake resistant due to these material have vibration absorbency and strong adhesive. Then these PSS maintained an enough fire-resistant performance even a fire after vibration test.
(3)The other PSS which consist calcium-silicate board and sticky putty are very week against earthquake course board is rigid and brittle, putty have low adhesive property. Then these PSS , a fire-resistant performance remarkably fell at a fire test after vibration test.

ACKNOWLEDGMENTS

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