Experimental Study on Durability of Sliding Bearings under Long Duration Dynamic Loading

Ryuichi KOUSAKA [1] Hironori HAMAZAKI[2], Nobuo MUROTA[3], and Mineo TAKAYAMA[4]

[1] *Engineer, Dept. of Structural Engineering, Azusa Sekkei Co. Ltd ,Tokyo, Japan*
Email:kousaka299@azusasekkei.co.jp
[2]*Engineer, Dept. of Seismic Isolation Engineering , Bridgestone Co., Kanagawa, Japan*
Email:hamazaki.hironori@bridgestone.co.jp
[3]*Engineer, Dept. of Seismic Isolation Engineering , Bridgestone Co., Kanagawa, Japan*
Email: murota-n@bridgestone.co.jp
[4]*Professor, Dept. of Architecture, Fukuoka University, Fukuoka, Japan*
Email: mineot@fukuoka-u.ac.jp

ABSTRACT :

In this study, durability of sliding bearing (SB) for seismic isolation was investigated by repeated dynamic loading. Two types of SB-system were subjected to the testing, namely high-friction (HF) type with friction coefficient of 0.13, and low –friction (LF) type with 0.015, respectively. During the loading, the stainless plate is mounted on an heat-insulation plate to prevent heat transfer to the testing machine. The friction coefficient of HF type decreased according to the temperature increasing. However, even after large cumulative sliding displacement, the PTFE still maintained proper characteristics. On the other hand, in the case of the LF type with PTFE-coated mating plate, until firs half of the test, the friction coefficient maintained stable regardless to the temperature increasing, then gradually the coefficient increased mainly because of the pealing of PTFE-coating of the stainless plate. When using LF type SB, this phenomenon should be considered in design of isolation system. The study verified stable characteristics of both SB systems under long duration dynamic loading.

KEYWORDS: Base Isolation, Sliding Bearing, PTFE, Repeated Loading Test, Durability, Heat

1. INTRODUCTION

In Japan, base isolation has been applied to the buildings which require high seismic performance, such as hospitals, public buildings, and important facilities in the business area.
Base-isolated structure tends to be built in the metropolitan area on the large soft plain[1)], such as Tokyo, Nagoya, and Osaka area. When earthquake occurs in those areas, period and duration time of the seismic wave tends to be longer[2)]. In this case, base-isolated structure will be vibrated in large amplitude for many cycles, and the isolation devices require enough durability to the large cumulative deformation without damage.
Sliding bearing (SB) has gained popularity as a seismic-isolation device in this decade. Seismic-isolation with SB effectively achieves longer period, especially for low- and mid-rise structures, has an energy-dissipation capability by its friction-force characteristics, and large displacement capability without stability problem. As the energy-dissipation is obtained by the heat generation between Poly-Tetra-Fluoro-Ethylene (PTFE) and stainless steel plate, or stainless plate coated with PTFE, the durability of the PTFE to the heat is important.In this study, focusing of the SB system, durability was experimentally evaluated by repeated dynamic loading for large number of cycles, and the relationship between temperature of sliding face, number of cycles, and friction characteristics was investigated. SB-system, as shown in Figure 1, consists of PTFE plate, either directly bonded to rubber layer or connected to the flange plate which is bonded to rubber layer with bolts, and laminated rubber bearing, which consist of multi-layered thin rubber sheets and steel plates, and mating plate[3)]. The mating plate, generally made of stainless steel plate, either with or without PTFE-coating, is connected to the back plate. The effect of heat generated during sliding at boundary of stainless plate and PTFE is very important to the durability of SB-system. There were a few studies regarding heat generation problem during sliding.

However, according to the survey of author, those tests were conducted without considering any heat-transfer to the testing machine.
As the actual SB is installed on the base made of mortar or concrete, the boundary is considered to be heat-insulated condition. Therefore, there is a possibility that the effect of heat was underestimated in those tests. In these backgrounds, we conducted the durability test with the boundary conditions heat-insulated with a plate made of special heat-insulation material, inserted between the stainless plate and PTFE of the SB.

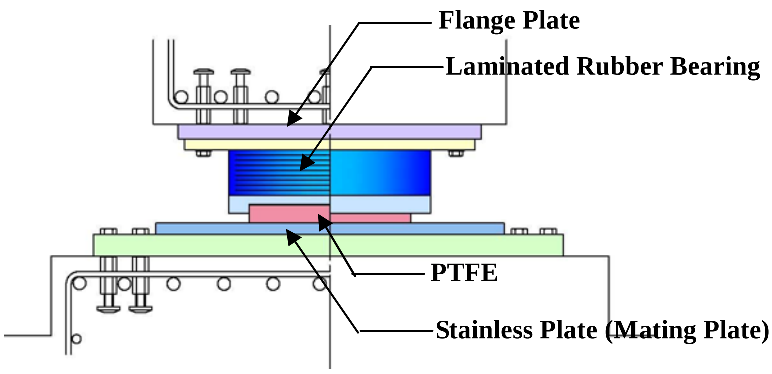


Figure 1 Schematic View of SB-system

2. TEST SPECIMENS AND CONDITIONS

Characteristics of test specimens are shown in Table 1. Two types of SB-system were subjected to the testing, namely high-friction (HF) type with nominal friction coefficient of 0.13, and low–friction (LF) type[4)] with 0.015, respectively. The HF-type is one of conventional material which has been widely used as bridge bearings, and, also has been applied to base isolation devices. Because of its high-friction characteristics, this type has been expected as a damping element as well as load-sustaining device when used for building isolation. On the other hand, LF-type has become popular in this decade. Low friction coefficient enables longer period-shifting which will realize reduction of response acceleration. Therefore, LF-type is especially applied in isolation for high-rise building which usually require longer period-shifting than conventional building, in Japan. Testing machine has capability of 10MN in vertical load (compression), +/-2MN in horizontal load with strokes of +/-200mm. Horizontal frequency of 0.33Hz can be achieved for +/-200mm in cyclic loading. Photo 1 shows the installation of the SB to the test machine attached with thermo-couples for measurement of temperature.

Table 1 Characteristics of Test Specimens

		HF-type =0.13	**LF-type =0.015**
Bearing	Bearing Dia.	225mm	225mm
	Shear Modulus	1.2MPa	0.4MPa
	Rubber Layers	2.8mm×10lys.	1.8mm×6lys.
	PTFE Dia.	160mm	202mm
	Nominal Comp. Stress	10MPa	18MPa
Stainless Plate	Plan Dim.	300mm×500mm	
	Material	SUS304 (JIS G 4303)	SUS304 coated by PTFE

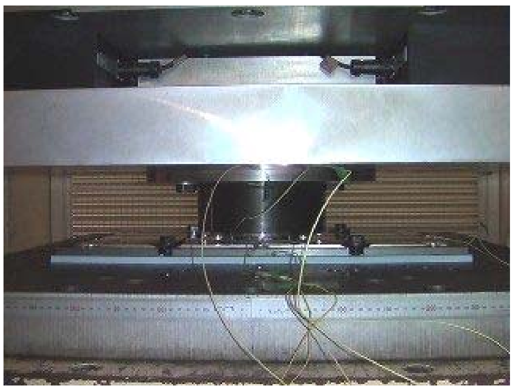
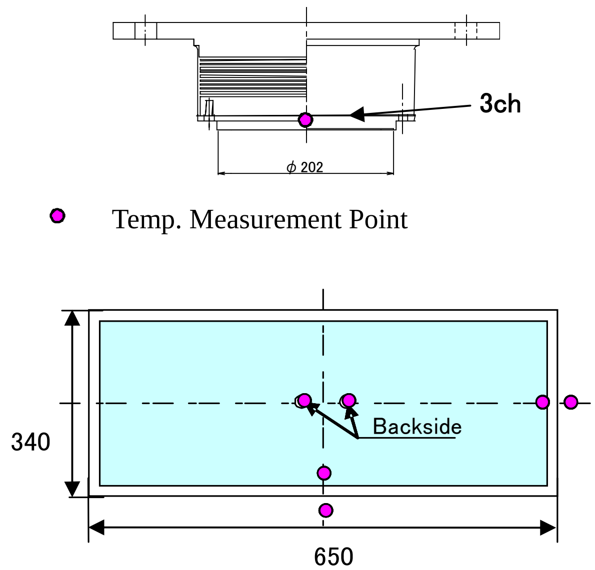


Figure 2 shows the position of temperature measurement on the test specimen. Thermo-couples were installed one point just behind the sliding plate, and 8 points on/behind the stainless plate. Test conditions are shown in Table 2. Compressive stress in Table 2 was defined by the surface area of PTFE, which corresponds to the nominal stress provided by manufacturer[4]. The compressive stresses for HF-type and LF-type were 10MPa and 18MPa, respectively. Test-①, and -② are basic sliding tests, and the results were set as initial property.



1ch : Displacement (for synchronizing)
2ch : Atmosphere Temperature
3ch : PTFE Plate – Backside
4ch : Stainless Plate – Back, Right
5ch : Stainless Plate – Back, Left
6ch : Stainless Plate – Surface, Transverse Dir.
7ch : Test Machine Bed Surface-close to 6ch
8ch : Stainless Plate – Surface, Longitudinal Dir.
9ch : Test Machine Bed Surface-close to 8ch
10ch : Flange Surface of Bearing

Stainless Plate

Figure 2 Temperature Measurement Point

Test-③ is set as the first repeated loading test supposing usual duration-time earthquake motion, followed by Test-④ for investigation of the effect of the Test-③ to the basic friction property. Test-③' was the same loading pattern of Test-③, without heat-insulation plate for reference. And the Test-⑤ is the repeated loading supposing earthquake in long-duration time, which is the focus of this study. The cumulative displacement reaches to around 300m (in HF-type) to 400m (in LF-type), 7.5 times longer than Test -③. Again, basic sliding test, Test-⑥, and -⑦ follow Test-⑤. Both tests are conducted after 24 hours of Test-⑤ in order to evaluate the friction characteristics after recovery to room temperature and the results are compared with Test-①, and -②. Amount of the cumulative displacement was set as having margins for 2 to 5 times of the actual earthquake duration. For example, SANNOMARU earthquake, which is one of representative artificial earthquakes that includes long period waves in Japan, has cumulative displacement of 20m[5].

Table 2 Test Conditions

Test Specimen	Test No.	Comp. stress (MPa)	Loading Velocity (mm/sec)	Freq. (Hz)	Amp. ± (mm)	Number of Cycles	Cumulative Displacement (m)
HF-type (=0.13)	1-①	10 (201kN)	100	0.16	100	3	1.20 (1.16)
	1-②		200	0.32			
	1-③		350	0.40	140	72	40.32
	1-③'		350	0.40	140	72	40.32
	1-④		100	0.16	100	3	1.20
	1-⑤		350	0.40	140	540	302.40
	1-⑥		100	0.16	100	3	1.20
	1-⑦		100	0.16			

(continued Table 2)

LF-type (=0.015)	2-①	18 (576kN)	100	0.16	100	3	1.20
	2-②		200	0.32			
	2-③		350	0.40	140	72	40.32
	2-④		100	0.16	100	3	1.20
	2-⑤		350	0.40	140	692	387.52
	2-⑥		100	0.16	100	3	1.20
	2-⑦		100	0.16			

3. TEST RESULS

3.1 HF-type SB

Figure 3 shows the force-displacement curve of the Test 1-①. The friction coefficient at the 3rd loop was calculated as 0.122, which was -6.6% of the nominal value 0.13. Figures 4 and 5 show the curves of Test 1-⑤, comparing the results from 1 to 100 cycles and that from 255 to 540 cycles respectively. Obviously, it was observed that the friction force decreases as number of cycles increases. Figure 6 shows relationship of the change of friction coefficient and the cumulative number of cycles (in logarithmic scale) in each case. At the 540th cycle, the coefficient decreased as almost 40% of the initial value. The difference between with/without insulation plate is not obvious. Figure 7 shows the change of the temperature at each measurement point. At the center of the stainless plate (Ch.4, and 5), the temperature rapidly increased up to 250 degree, then finally reached to 300 degree in Celsius. The temperature at the back of PTFE (Ch.3) reached only to 150 degree, because of the heat-insulation characteristic of PTFE-material, On the other hand, after loading completion, the temperature went down faster in stainless plate than in PTFE. The friction coefficient after Test 1-⑤ was perfectly recovered to that of initial state. Figure 8 shows the force-displacement curve of the Test 1-⑦, which shows stable characteristics as same as that of Test 1-①.

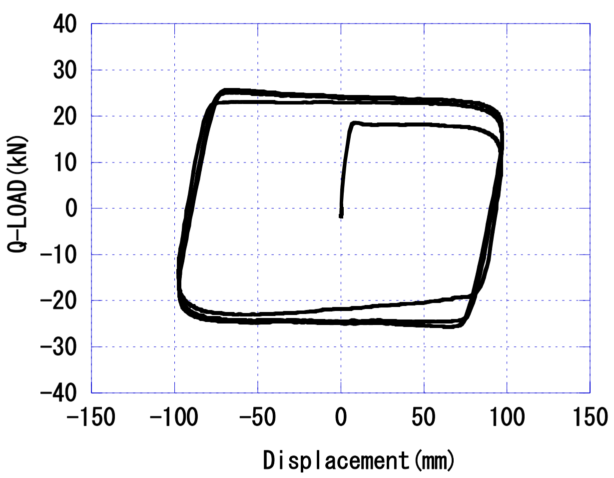


Figure 3 Force-Displacement Curve of Test 1-①: Initial State

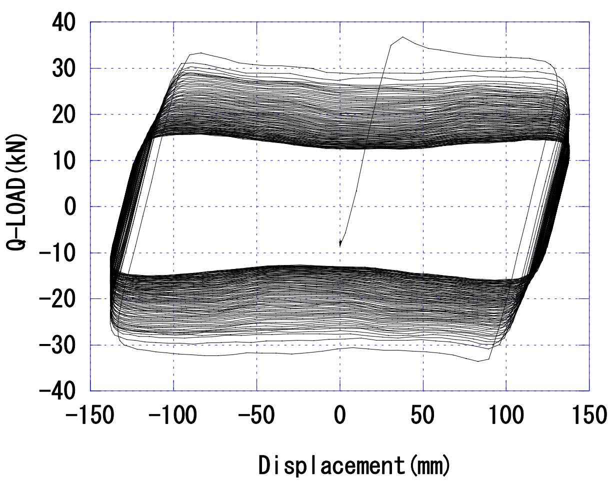


Figure 4 Force-Displacement Curve of Test 1-⑤: From 1 to 100 Cycles

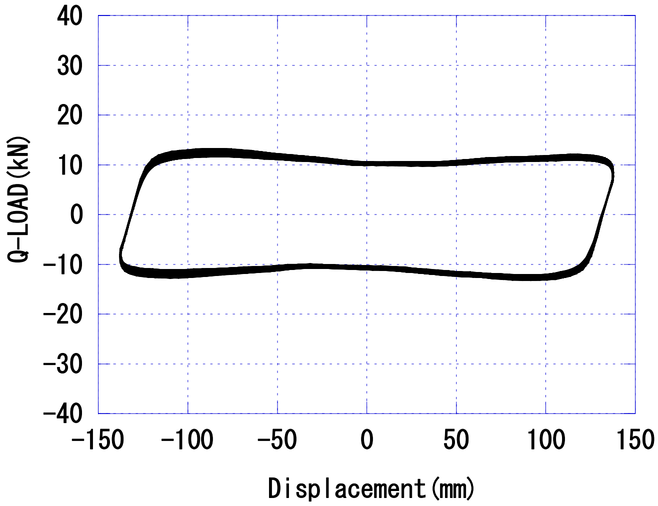


Figure 5 Force-Displacement Curve of Test 1-⑤: from 255 to 540 Cycles

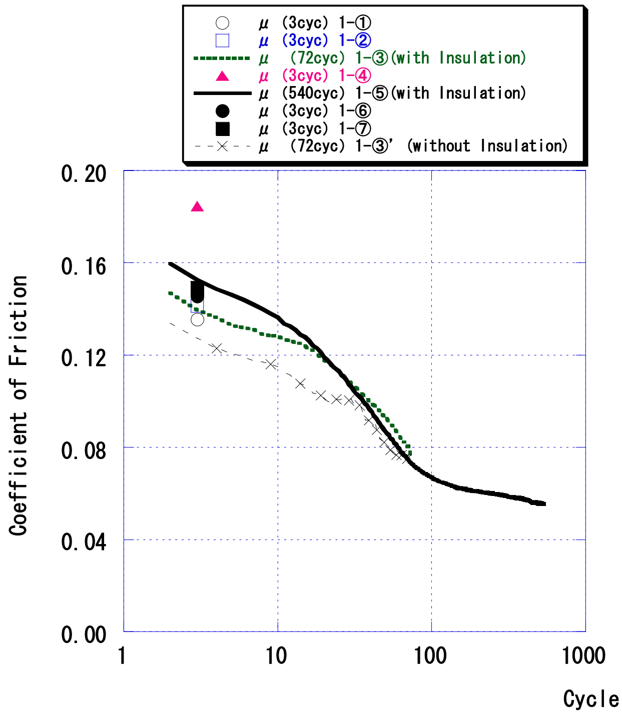


Figure 6 Relationship between Friction Coefficient and Cumulative Number of Loading Cycles of HF-type

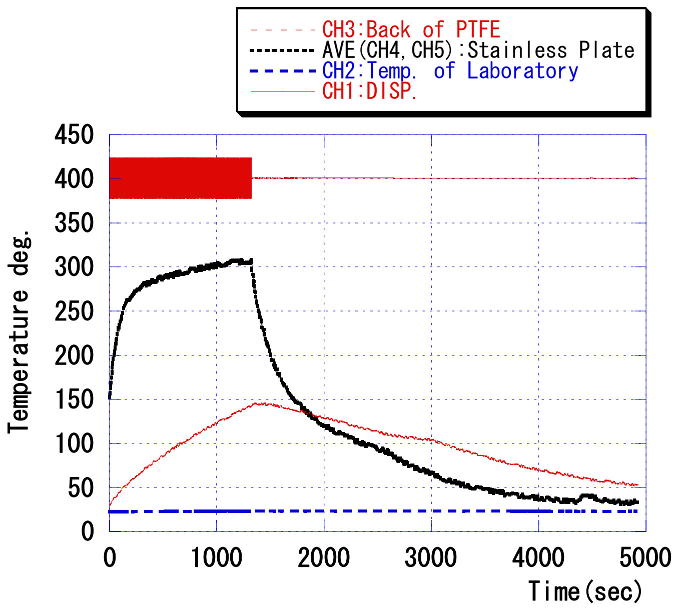


Figure 7 Time History of Temperature-Change at Each Measurement Point:: Test 1-

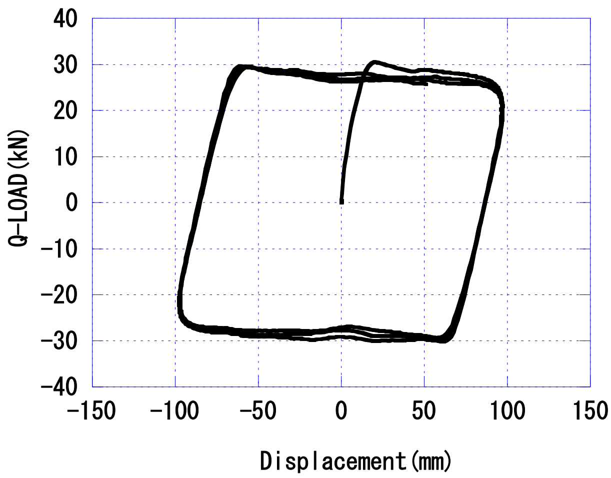


Figure 8 Force-Displacement Curve of Test 1-⑦: After Completion of All Tests

3.2 LF-type SB

Figure 9 shows the force-displacement curve of first loading test, Test 2-①. The measured friction coefficient at 3rd cycle was 0.013, -8.0% of the nominal value of 0.015. The static maximum friction coefficient was almost 3 times of the dynamic coefficient, whereas the difference of static- and dynamic- was very small in HF-type. Figures 10 and 11 show the curves of Test 2-⑤, comparing the results from 1 to 100 cycles and that from 509 to 692 cycles respectively. The friction force at the first 100-cycle set is quite stable, and the change of friction coefficient was small. However, the friction force at the last 100-cycle set (Figure 11) was increased for around 5 times of the first set, and it was quite opposite tendency in HF- and LF-type. Figure 12 shows relationship of the change of friction coefficient and the cumulative number of cycles (in logarithmic scale) in each case. The results indicate that the friction coefficient gradually start increasing after around 150 cycles, and finally the friction coefficient reached to two times of the value at 3rd cycle. The friction coefficients measured in Test 2-⑥, and 2-⑦ were around 0.095, which was about 7.3 times of the initial value. Figure 13 shows the change of temperature at each measurement point. Compared with HF-type, increase curve of temperature at stainless plate is complicated. The temperature increase was slower than HF-type until around 200degree at stainless plate, then the curve of temperature changed the slope and sharply increased up to 300 degree. Figure 14 shows the relationship of the temperature at the stainless plate and friction coefficient of LF-, and HF-type. Friction coefficient of HF-type decreases as temperature increase. However in LF-type, the change of friction coefficient was almost flat until 100th cycle, then suddenly coefficient increased as temperature increase. After testing, it was observed that the PTFE-coat on the stainless plate was almost peeled, and skin of stainless surface was exposed as shown in Photo 2. It is assumed that the damage of PTFE-coat changed the tendency of temperature increase as well as friction coefficient.

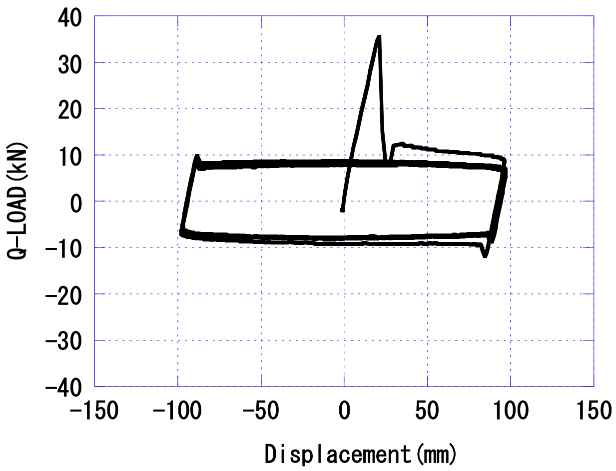


Figure 9 Force-Displacement Curve of Test 2-①: Initial State

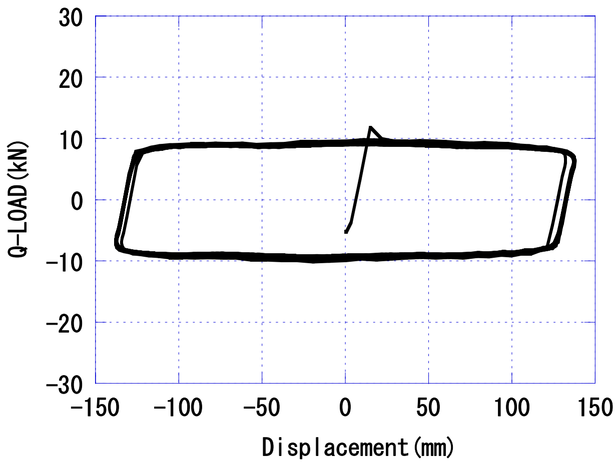


Figure 10 Force-Displacement Curve of Test 2-⑤: From 1 to 100 Cycles

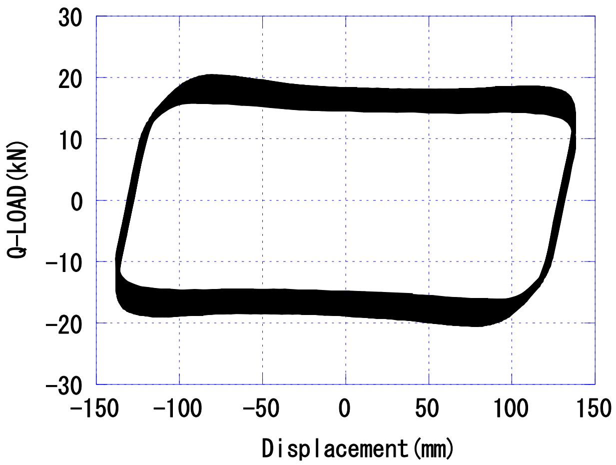


Figure 11 Force-Displacement Curve of Test 2-⑤: from 509 to 692 Cycles

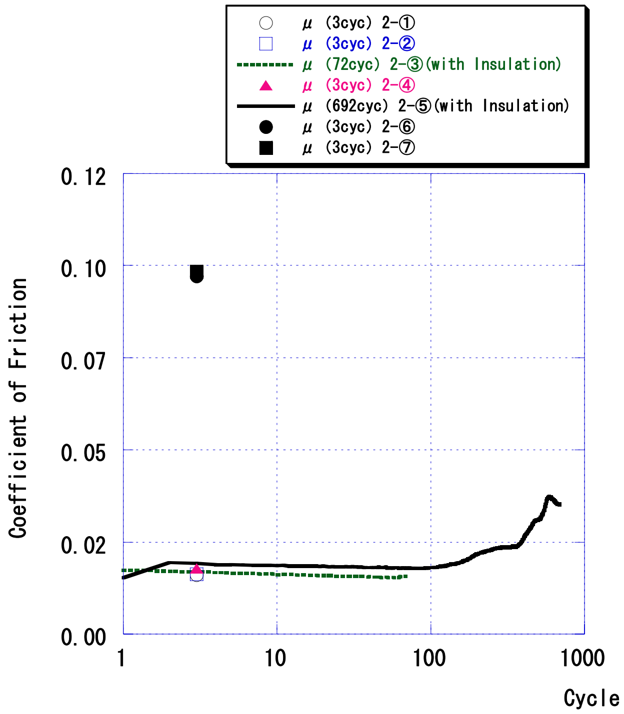


Figure 12 Relationship between Friction Coefficient and Cumulative Number of Loading Cycles of LF-type

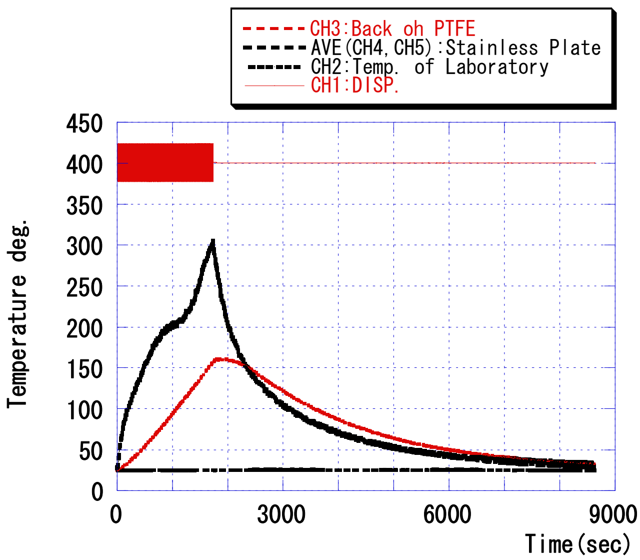
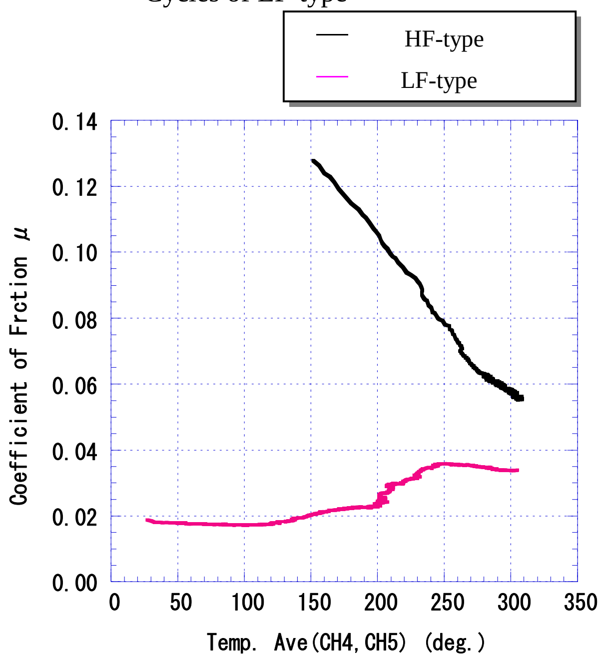


Figure 13 Time History of Temperature-Change at Each Measurement Point: Test 2-



低摩擦と高摩擦の弾性スベリ支承の比較

Figure 14 Relationship Between Friction Coefficient and Temperature at Stainless Plate: Test 2-

Photo 2 Surface of PTFE-Coated Stainless Plate after Testing (PTFE-Coat was peeled by friction)

4. CONCLUSIONS

An experimental study on durability of sliding bearing under long duration dynamic loading was conducted. The cumulative sliding displacement of the whole test was over 300m, by assuming long duration earthquake motion recently expected to happen in Japan. Two types of sliding bearing systems, high-, and low- friction type (HF-type, and LF-type, respectively) were subjected to the testing. Friction coefficient of HF-type decrease as the temperature at sliding surface increase. When the surface temperature cooled downed to the room temperature, the friction characteristics was recovered. In the case of LF-type, until 100th cycle, the change of friction coefficient was small. However, after 100th cycle, friction coefficient started to increase, and finally it reached to twice of the initial value. Even after cooling-down to the room temperature, the coefficient increased to the level of 7.5 times of the initial value. It was observed after testing that the PTFE-coat of the stainless plate at the sling surface was completely peeled, and the skin of the stainless was exposed.
Although the friction characteristics of LF-type system drastically changed after PTFE-coat of the plate damaged, the high durability during repeated loading for long duration time was verified. It was very significant findings that the friction coefficient of HF-type perfectly recovered and still applicable even after 300m cumulative dynamic sliding. Also, the friction coefficient of LF-type was maintained in the small variation from the initial characteristics until half of the total time duration. It was suggested to the structural engineer when designing base isolation system with sliding bearings for long duration time earthquake, that;

- When using HF-type as friction damping element, decrease of friction coefficient according to the sliding displacement should be properly considered in the design.
- When using LF-type as main devices, proper margin for repeated loading should be taken into account.

5. REFERENCES

1) Architectural Institute of Japan, Japan Society of Civil Engineers (2006), Long-Period Ground Motions Due to the Deep Type Huge Earthquake and Joint Proposal Concerning Engineering Works and Architectural Structure (in Japanese)
2) Architectural Institute of Japan Special Committee for Correspondence to Huge Disaster such as Tokai Earthquakes (2005), Long-Period Ground Motions Forecast at Huge Earthquake and the Anti-Seismic Engineering Problem (in Japanese)
3) Akio SUZUKI et al. (2004), An Investigation Report of the Characteristic of Sliding Bearings for Base-Isolated Building, *Journal of Architecture and Building Science*, No.19, pp49-54 (in Japanese)
4) Bridgestone Co. Technical Report (2006), *Bridgestone Elastomeric Sliding Bearing*, Doc.No. BSESB06X1 (in Japanese)
5) Miyuki KAIHOTSU, Kenichirou KIKUCHI, Ryuichi KOUSAKA, and Norio ABEKI (2006) , Fundamental Properties About Seismic Required Performance of Sliding Bearings (Part-1), and (Part-2), *Summaries of Technical Papers of Annual Meeting AIJ B-2, Structures II*, vol2006 pp541-542, pp543-544 (in Japanese)