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DEVELOPMENT OF ADVANCED FRICTION SLIDING DAMPER

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ABSTRACT:

Many vibration control systems have been developed to reduce damage to buildings during earthquakes. We developed a friction sliding damper using high-tension bolts in the latter half of 1990's and applied it to a building. This damper absorbs a building's vibration energy using the frictional energy consumed by a brake pad and a stainless plate fastened with the high-tension bolts. The main application form of this damper has been as a brace, but the number of stud-type application forms is increasing.
In the other side, seismic retrofit is necessary for buildings that don't provide the seismic performance required by the Japanese Building Standards Law. Various technologies have been proposed to improve the seismic performance of such buildings. For example, building strength has been improved by adding braces and walls, building deformation performance has been improved by wrapping carbon fiber around columns, and seismic forces have been reduced by installing new base-isolation systems. However, progress in seismic retrofit has been hampered by problems of loss of building amenity, high cost, and construction difficulty. To solve these problems, a method has been developed of installing stud-type friction sliding dampers outside an existing building.
This paper describes performance confirmation dynamic loading tests that have been performed on full-scale brace-type and stud-type friction sliding damper set in a steel frame, and a dynamic loading experiment result on an R/C frame equipped with friction sliding dampers.

KEYWORDS: friction damper; brake pad; coned disc spring; high-tension bolt; seismic retrofit

1. COMPOSITION AND FEATURE OF DAMPER

This damper was developed as a damping system that inserted it between the brace or the stud and the building. This damper causes a constant frictional force by using the technology of the disk brake. The building's vibration energy is converted into thermal energy by using this frictional force and the building's response is decreased.
It is necessary to select the material that obtains a steady coefficient of friction to keep the frictional force to be constant. Moreover, the pressure of the sliding surfaces should be kept constant. In this damper, a stable frictional force can be achieved by fastening the brake pad and stainless plate through coned disc springs.
Composition of this damper is shown in Figure 1. Application of this damper is shown in photograph 1.

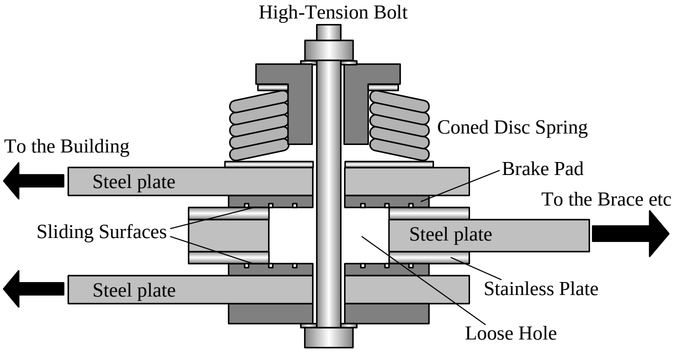


Figure 1 Basic composition of this damper unit

Photograph 1 Application of this damper

2. PERFORMANCE TEST WITH FULL-SCALE BRACE-TYPE AND STUD-TYPE DAMPER

To consider the application form to the building, performance confirmation tests have been performed on full-scale brace-type and stud-type dampers set in a steel frame.

2.1. Performance Tests with Full-Scale Brace-Type and Stud-Type Damper

2.1.1 Outline of Brace-Type Damper

The loading frame for the brace-type damper is shown in Figure 2 and Photograph 2.

The friction damper is composed of the damper units of 12 sets shown in Figure 1. The coned disc spring was 100mm in the diameter, and 13 pieces were used with one damper unit. The pressure of the sliding surface of the damper unit is 83.3kN, and the total pressure of the friction damper part is 1,000kN. There are two sliding surfaces, and the coefficient of friction is about 0.32. Therefore, the frictional force is 640kN. The fastening powers of the high-tension bolts were controlled by confirming the height of the coned disc springs.

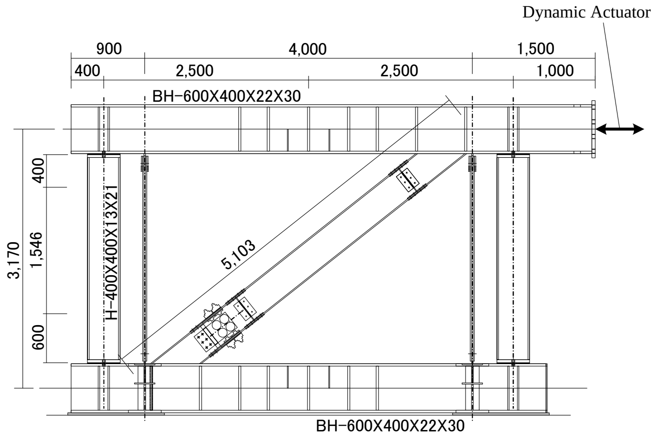
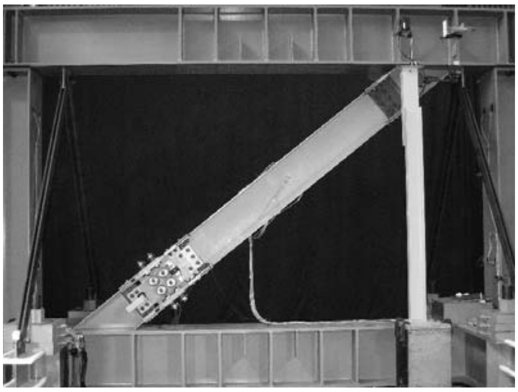


Figure 2 Loading Frame for Brace-Type Damper


Photograph 2 Loading Frame for Brace-Type Damper

2.1.2 Outline of Stud-Type Damper

The loading frame for the stud-type damper is shown in Figure 3 and Photograph 3.

The friction damper is composed of the damper unit of 7 sets shown in Figure 1. Four damper units shown in Figure 3 are not used so that there is a limit in the performance of a dynamic actuator. The coned disc spring was 130mm in the diameter, and 13 pieces were used with one damper unit. The pressure of the sliding surface of the damper unit is 158.1kN, and the total pressure of the friction damper part is 1,107kN. The frictional force is 708kN.

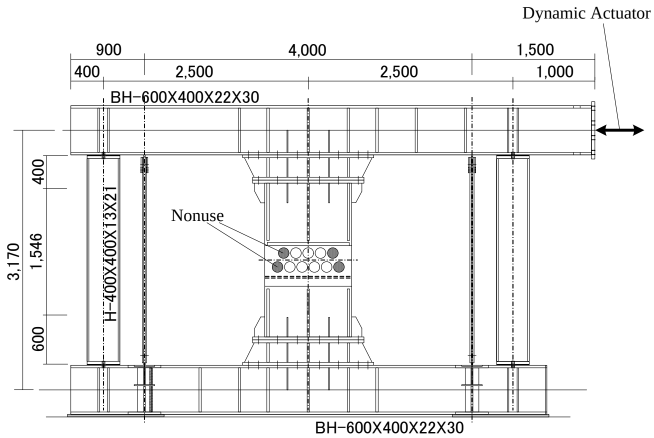
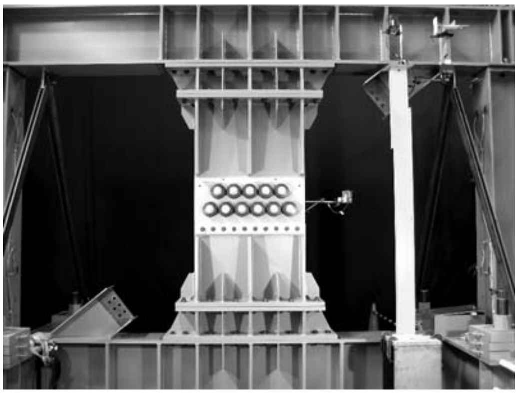


Figure 3 Loading Frame for Stud-Type Damper


Photograph 3 Loading Frame for Stud-Type Damper

2.1.2 Test Cases and Excitation Waves

The loading tests were executed by setting up a dynamic actuator at the position shown in Figure 2 and Figure 3. The test cases are shown in Table 1. The excitation waves are shown in Figure 4.

Table 1 List of Test Cases

Specimen	Case	Wave	Frame Transformation
Brace Type	B-1	Sine Wave	±10mm
	B-2		±20mm
	B-3		±30mm
	B-4		±40mm
	B-5		
	B-6		
Stud Type	S-1	Sine Wave	±10mm
	S-2		±20mm
	S-3		±30mm
	S-4		±40mm
	S-5		
	S-6		

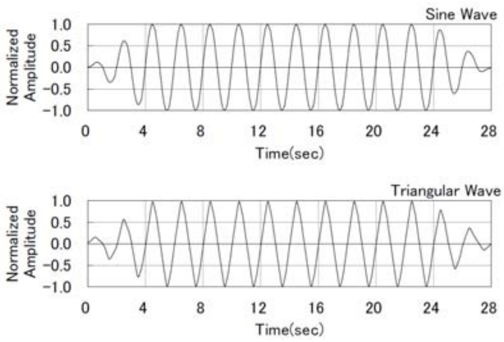


Figure 4 Waves for Excitation Test

2.2. Test Results

2.2.1 Test Results of Brace-Type Damper

The test results are shown in Table 2. The relations between the frictional force and the transformation of the damper part (case B-2 and case B-5) are shown in Figure 5. The relations between the frictional force and the transformation of the damper part showed steady bi-linear type characteristic in all test cases. The coefficients of friction are about 0.29 except case B-1. These test results show that the brace-type damper almost caused the design frictional force. The transformations of the damper are smaller than the transformations of the actuator because of the angle of the brace and the frame elastic deformation.

Table 2 Test Results of Brace-Type Damper

Specimen	Case	Positive Side Frictional Force (kN) Upper: Maximum Value Lower: Minimum Value	Positive Side Coefficient of Friction $\mu(+)$	Negative Side Frictional Force (kN) Upper: Maximum Value Lower: Minimum Value	Negative Side Coefficient of Friction $\mu(-)$	Average Coefficient of Friction $(\mu(+)+\mu(-))/2$
Brace Type	B-1	553	0.251	552	0.254	0.252
		450		463		
	B-2	606	0.288	602	0.288	0.288
		544		548		
	B-3	614	0.300	605	0.296	0.298
		584		580		
	B-4	594	0.291	590	0.290	0.290
		570		568		
	B-5	602	0.282	596	0.282	0.282
		525		532		
	B-6	606	0.284	607	0.287	0.285
		531		539		

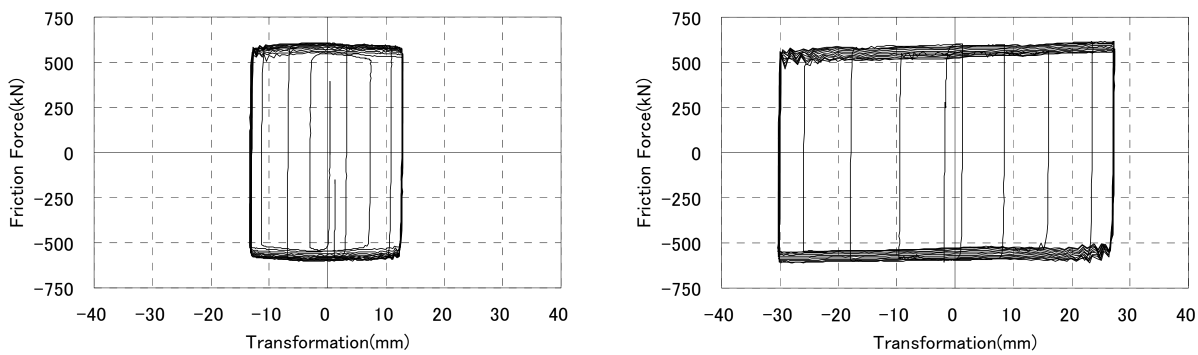


Figure 5 Relations between Frictional Force and Transformation (Brace-Type)

2.2.2 Test Results of Stud-Type Damper

The test results are shown in Table 3. The relations between the frictional force and the transformation of the damper part (case S-2 and case S-5) are shown in Figure 6. The relations between the frictional force and the transformation of the damper part showed steady bi-linear type characteristic in all test cases. The coefficients of friction are about 0.32. These test results show that the stud-type damper almost caused the design frictional force. The transformations of the damper are smaller than the transformations of the actuator because of the stud transformation and the beam transformation.

Table 3 Test Results of Stud-Type Damper

Specimen	Case	Positive Side Frictional Force (kN) Upper: Maximum Value Lower: Minimum Value	Positive Side Coefficient of Friction μ(+)	Negative Side Frictional Force (kN) Upper: Maximum Value Lower: Minimum Value	Negative Side Coefficient of Friction μ(−)	Average Coefficient of Friction (μ(+)+μ(−))／2
Stud Type	S-1	679	0.282	714	0.302	0.292
		569		623		
	S-2	685	0.297	723	0.315	0.306
		631		673		
	S-3	740	0.321	763	0.329	0.325
		682		695		
	S-4	747	0.317	787	0.336	0.327
		657		701		
	S-5	744	0.316	776	0.327	0.321
		654		672		
	S-6	745	0.316	782	0.330	0.323
		656		677		

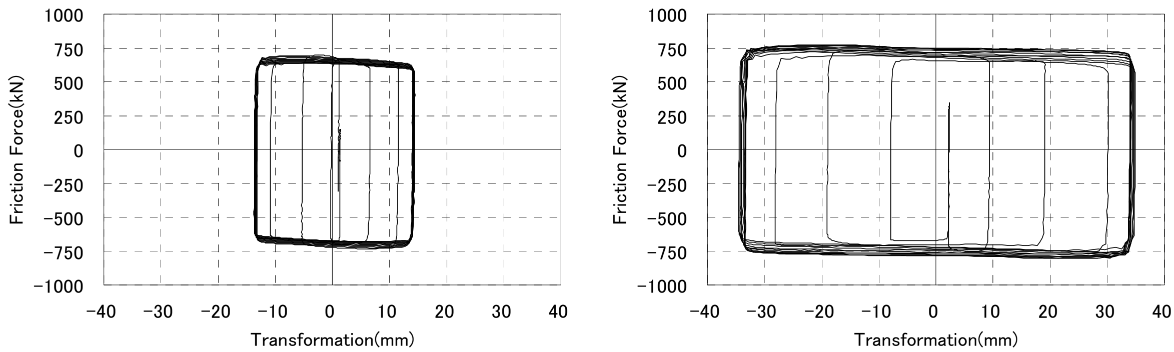


Figure 6 Relations between Frictional Force and Transformation (Stud-Type)

3. PERFORMANCE TEST ON R/C FRAME EQUIPPED WITH STUD-TYPE DAMPER

The effects of seismic retrofit when the stud-type friction damper was installed outside of the R/C frame were confirmed by a dynamic loading experiment.

3.1. Outline of Specimens and Method of Loading Tests

The outline of the specimens is shown in Figure 7. The specimens were made on the scale of 1/3.

The tests were executed in four specimens (R1, R2, R3 and R4) with different length of the steel beam for reinforcement. And, one specimen (N) without reinforcement was tested. As for the hoop reinforcement of the column, SD295A was used. As for others reinforcement, SD345 was used. The steel beam that the stud is welded was connected to the R/C beam that drove the anchor through grout. The compressive strength of concrete is 19.2N/mm^2. The compressive strength of grout is 57.8N/mm^2. The arrangement density of the anchor and the stud is shown in Figure 7. The sliding force of the friction damper is 200kN. The situation of specimen R1 test is shown in photograph 4.

The loading apparatus is shown in Figure 8. The axial force loaded into the column on both sides is 0.2bdFc. The excitation waves are sine waves of 1.0Hz and 0.5Hz. The amplitude was gradually enlarged. The deformation angle are 1/2040, 1/680, 1/340, 1/204, 1/170, 1/136, 1/102, 1/82, 1/68, 1/58, 1/51 and 1/41 radian.

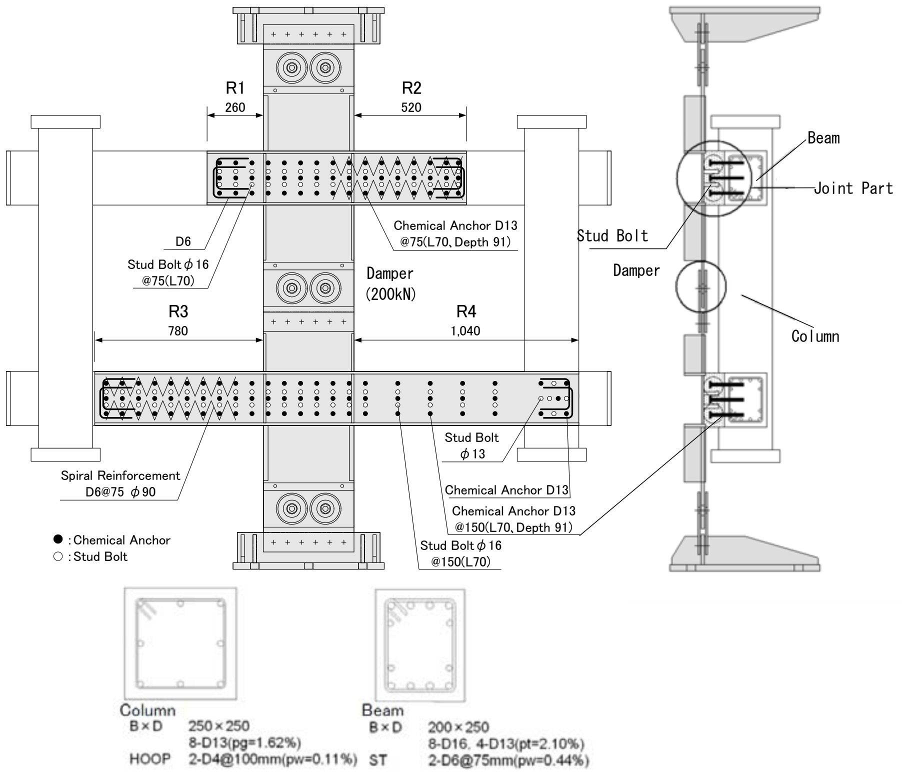
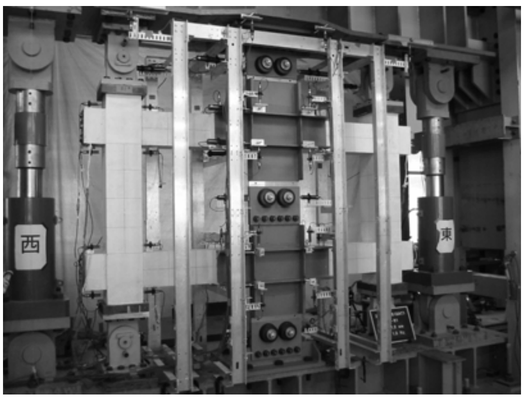


Figure 7 Outlines of Specimens



Photograph 4 Installation of Specimen

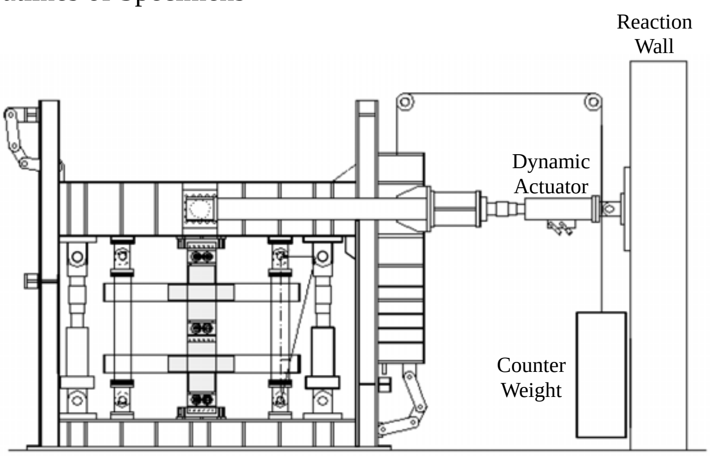


Figure 8 Loading Apparatus

3.2. Test Results

3.2.1 Failure Process

The failure patterns are shown in Figure 9.

In specimen N, the flexural yielding was previously caused at the edge in the beam, the yielding zone extended to the joint part in the column and the beam next, and the joint part failure was caused finally. Therefore, the joint part in the column and the beam was most intensely damaged in all specimens.

In specimen R1 and R2, the shear crack of the beam is previously caused in the part without the steel beam. Next, the shear yielding of the beam was caused, and the yielding in main reinforcement of beam was caused finally. Damage at the edge in the beam was remarkably caused.

In specimen R3 and R4, the flexural crack is previously caused at the edge of the beam near the column. Next, the flexural crack was caused in the column. Afterwards, yielding in main reinforcement in the beam was caused, and the yielding of the shear reinforcement was caused finally. In specimen R4, strength is the highest.

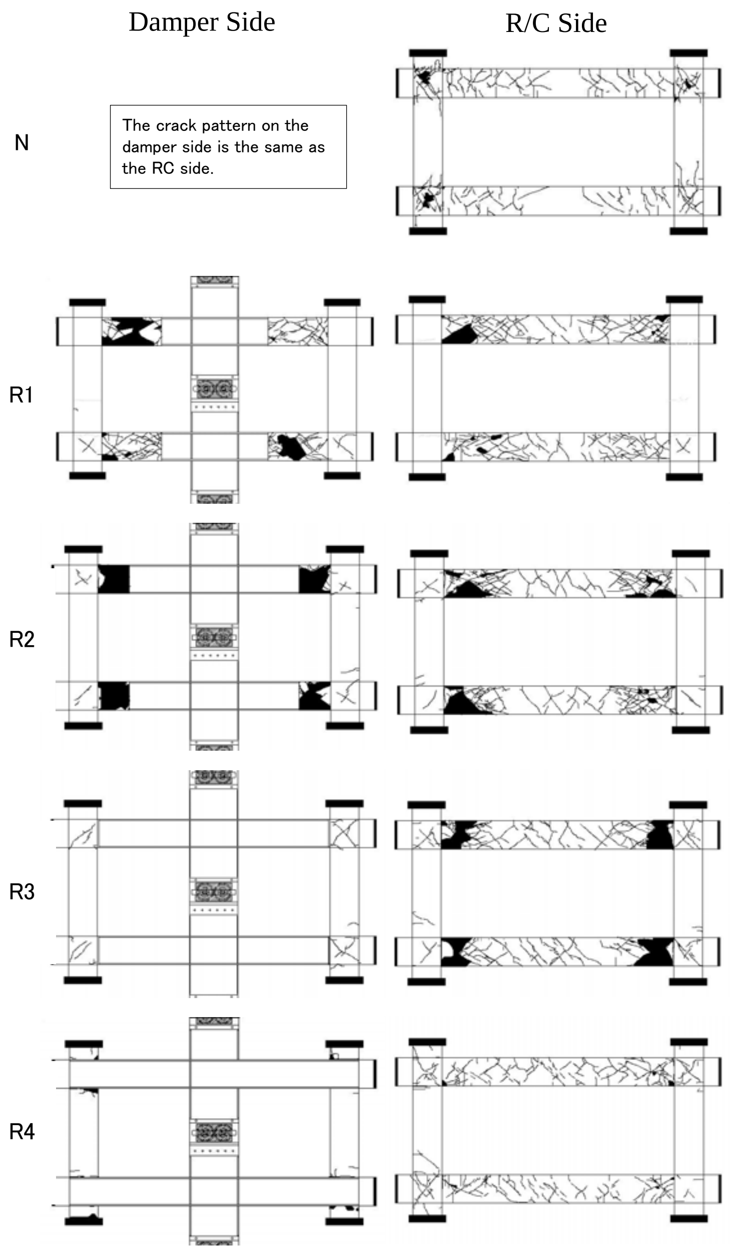


Figure 9 Failure Patterns

3.2.2 Relations between Loading Force and Story Deformation Angle

The relations between the loading force and the story deformation angle are shown in Figure 10.

The hysteresis loop areas of specimen R1 and R2 are smaller than these of specimen R3 and R4. These results were caused due to remarkable damage of the edge of the beam without the steel beam. In specimen R1 and R2, the rotational deformations of the center part of the beam are caused due to the damage of the edge of the beam, therefore, the transformations of the damper become small, and the performances of the damper have decreased.

In specimen R3, the hysteresis loop area is larger than these of specimen R1 and R2. The damper has effectively absorbed energy. However, the hysteresis loop showed the slipping properties a little by the yielding in main reinforcement of the beam.

In specimen R4, the effect of seismic retrofit was the most excellent in all specimens. The decrease in strength was not caused to the end of the loading test, and the loop without the slipping properties was shown. When the deformation angle is 0, loading force exceeds 200kN that is the design frictional force of the damper according to assumption.

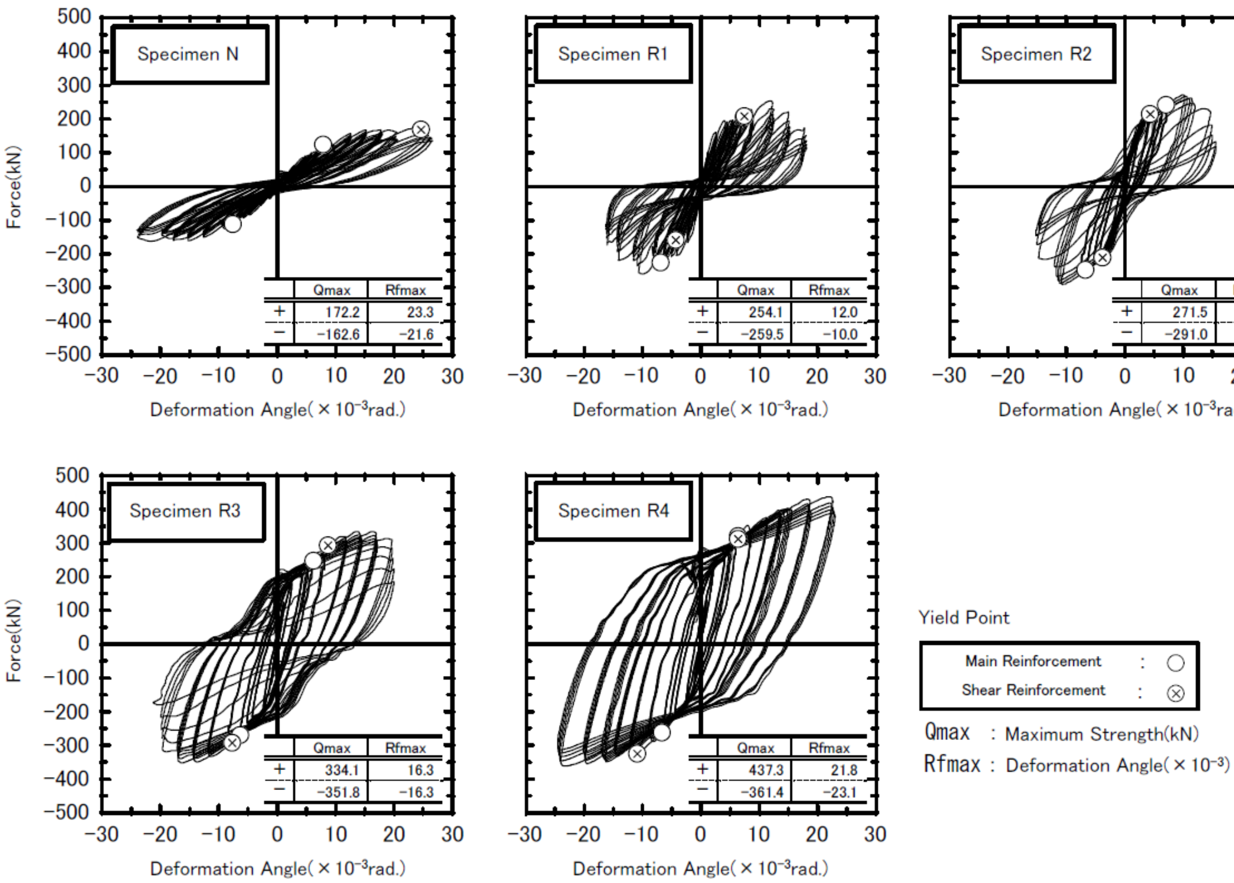


Figure 10 Relations between Loading Force and Story Deformation Angle

4. SUMMARY

To consider the application form to the building, performance confirmation tests have been performed on full-scale brace-type and stud-type dampers set in a steel frame. And the effect of seismic retrofit when the stud-type friction damper was installed outside of the R/C frame was confirmed by a dynamic loading experiment. The following results were obtained by these tests.

(1) The friction sliding damper of the brace-type and the stud-type showed a steady frictional force. The coefficients of frictions are from 0.29 to 0.35 (0.32±10%).

(2) The effect of seismic retrofit can be improved by distributing the steel beam with the stud-type friction damper to the total length of the existing R/C beam.

5. POSTFACE

The tests on the seismic retrofit of the R/C frame were executed by using the subsidy in 2006 of the Ministry of Land, Infrastructure, Transport and Tourism. And it was executed by Professor Kuramoto of the Toyohashi University of Technology (Present Professor of Osaka University) and the member of the Kuramoto laboratory. Moreover, we got valuable guidance and cooperation. We wish to express our gratitude.