Large Capacity Dampers for Buildings and Structures

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SUMMARY
This paper presents a study on the behavior of high capacity friction dampers that are installed in Japan's tallest building. The dampers are based on a rotational friction concept that was developed by the first author.

The dampers were developed as a part of the Abenobashi Terminal building project, as Japan's tallest building with 300 m high located in Osaka, Japan. The capacity of the dampers that were developed for this special project is in the range of 1500 – 5000 kN.

An extensive full scale testing program was conducted in Denmark and Japan. It was part of collaboration between DAMPTECH of Denmark and Kawkin Core-Tech Co., Ltd. of Japan.

The dampers are designed to dissipate seismic input energy (mechanical energy) into heat (thermal energy) and thus protecting buildings from structural and non-structural damage from dynamic loads induced by earthquakes and wind loads from typhoons.

The damper tests showed that the dampers have a very stable performance and are able to reach their high respective capacities. Implementation of the large capacity devices in structures is not difficult and they are economic devices due to material availability.

Several models of the rotational friction dampers have been installed in 20 projects in Japan and in other countries around the world.

Keywords: vibration control, friction dampers, experimental testing, tall buildings, damping.

1. INTRODUCTION

This paper presents the results from tests of several rotational friction damping devices with capacity in the range of 1500-5000 kN.
The goal of the tests was to confirm that the high capacity dampers were able to perform satisfactory. Furthermore the performance of the dampers depending on parameters like frequency of loading, displacement amplitude, numbers of loading cycles and clamping force of the bolts were examined.

2. DAMPER DESCRIPTION

2.1. Main components

The dampers are based on a rotational friction concept developed by the first author. They consist of several layers of long and short steel plates that are bolted together with a high capacity bolt in each friction joint, see Fig 1. In between all the steel plates circular friction pads are placed.

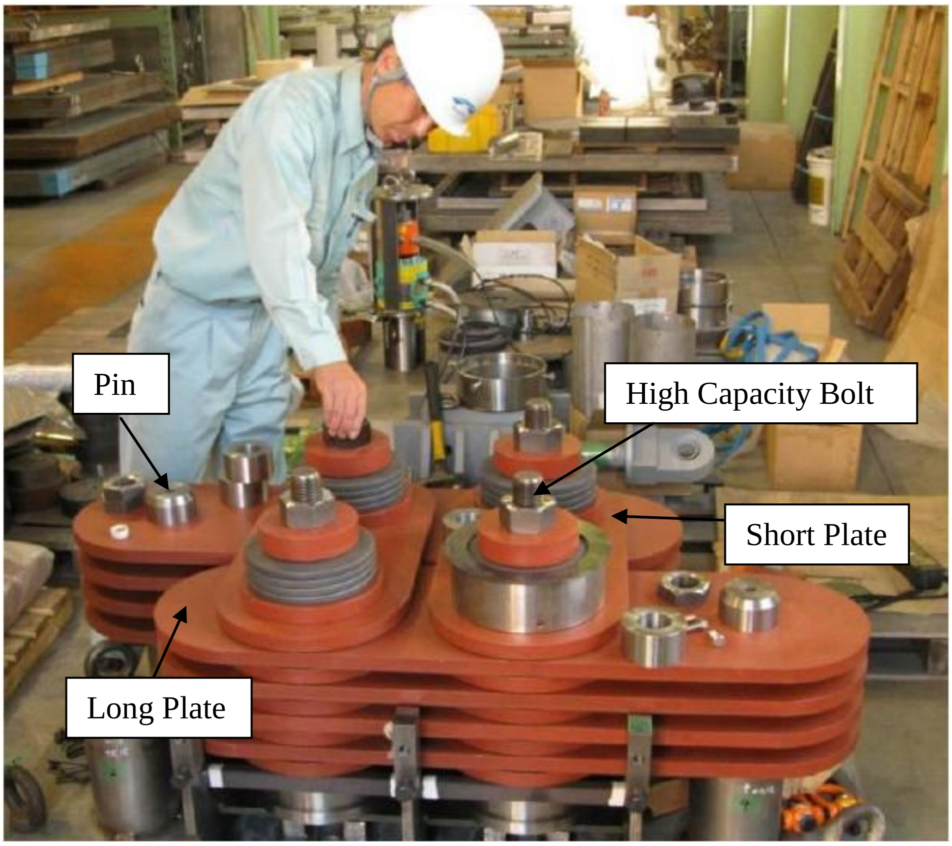

Figure 1: 2250 kN damper assembly

The 5000 kN dampers are very similar to the 1500-2250 kN dampers except the number of friction joints is doubled which results in a longer damper with 8 friction joints.

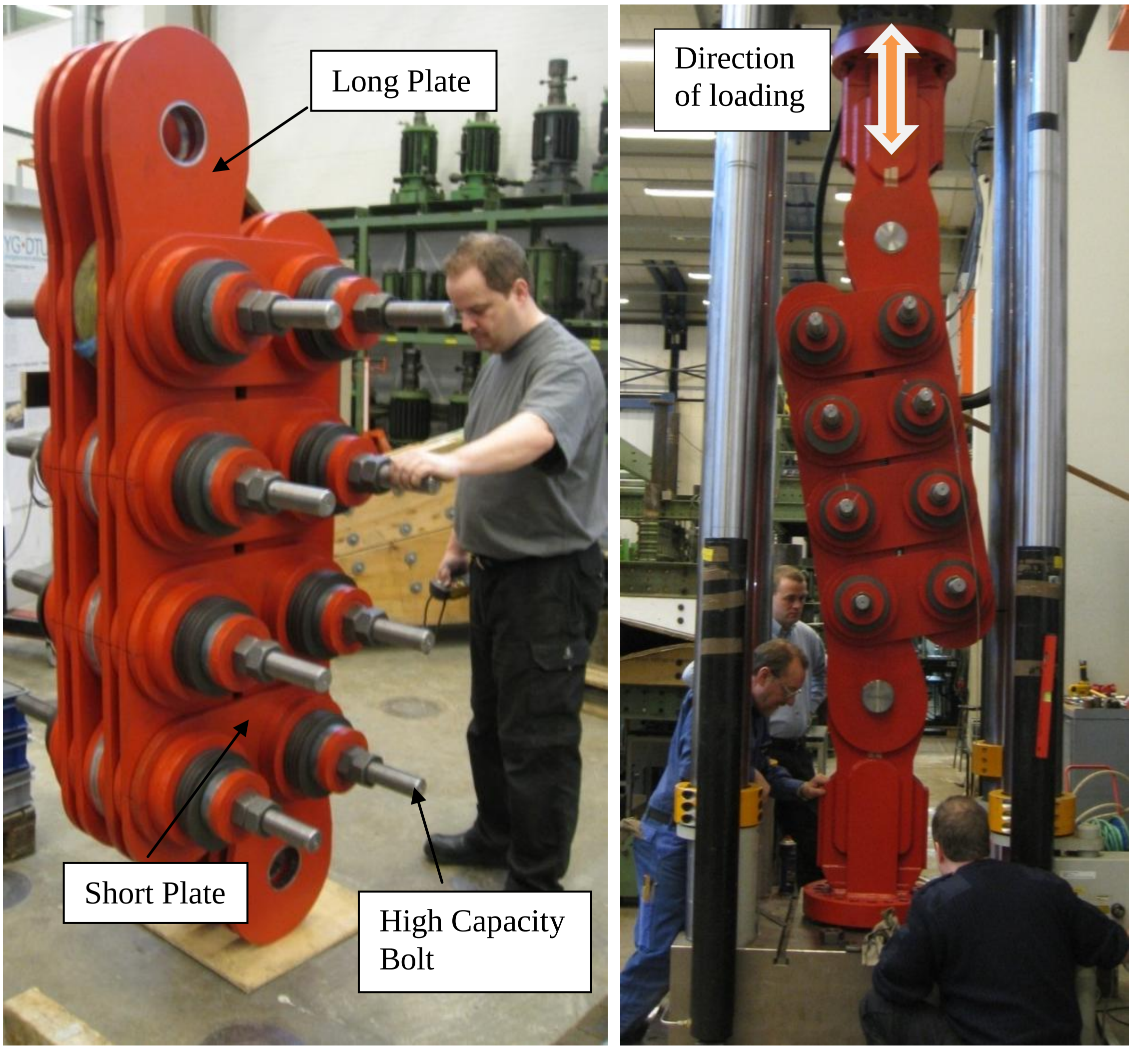

Figure 2. Left: 5000 kN damper. Right: 5000 kN damper installed in the Instron dynamic testing machine

2.2 Basic concept of the damper

When the damper is in the initial position the short plates are perpendicular to the long plates. If the damper is loaded with forces equal to the slip capacity of the damper the short plates start to rotate around the bolts and the damper starts to slide. The deformation mechanisim depends on the loading direction if the damper is in compression (Fig.3: middle) or in tension (Fig.3: Right).
The magnitude of the damper slip capacity depends on the friction forces in the friction joints and is proportional to the clamping force of the bolts.
When the damper is loaded with a force F_{slip} which is eqaul to the damper slip capacity and displaced a distance Δu then the total work done by the damper is $W_d = F_{slip}\,\Delta u$.

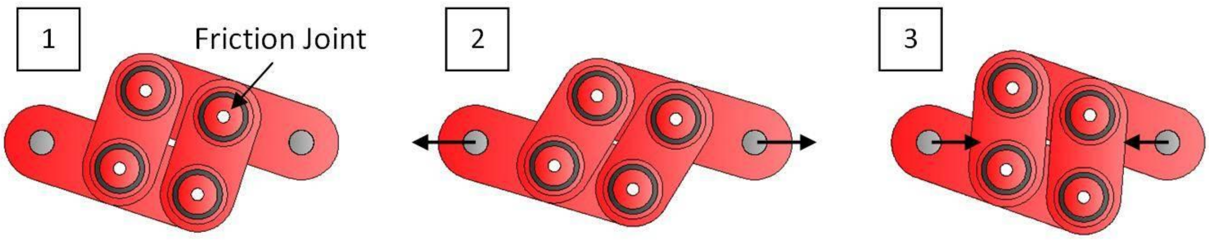

Figure 3. 1: Initial position. 2: Dampers in tension. 3: Dampers in compression

2.3 Basic concept of damper in frame structure

The dampers are flexible and can be used for many building configurations. One such example is frame structures with two diagonal bracings as shown in Fig. 4 and Fig.5.

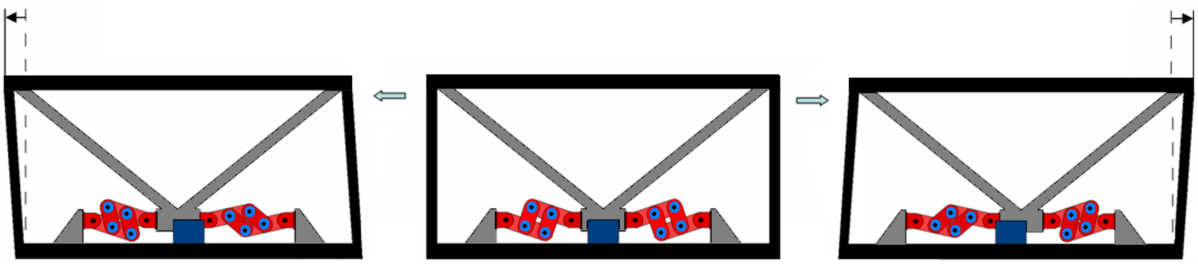

Figure 4. Left: Frame structure moved to the left. Middle: Frame structure in initial position. Right: Frame structure moved to the right

In the case of a moderate or large seismic event the top story of a frame structure starts to displace horizontally relatively to the story below. The bracing system and the frictional forces developed between the frictional surfaces of steel plates and friction pad materials will resist the horizontal motion. When the top of the frame structure is moved to the left the left damper is compressed while the right damper is tensioned and both dampers dissipate energy. Similarly when the top of the frame structure is displaced to the right the right damper is compressed while the left damper is tensioned and the dampers dissipate energy see Fig. 4.

During an earthquake the top story of a frame structure in a building as the one in Fig. 4 will be moved from left to right repeatedly while the dampers are dissipating the kinetic energy from the earthquake into heat, effectively lowering the response of the structure from the earthquake.

Figure 5. 2250 kN Dampers installed in the building

Figure 6. Abenobashi Terminal Building

3. EXPERIMENTAL TEST PROGRAM

A series of tests on dampers in the range 1500 kN to 5000 kN have been performed in Denmark and Japan.

3.1. 5000 kN Damper Tests

The 5000 kN damper was tested in the testing facilities of the Technical University of Denmark. For the tests a 5000 kN Instron machine capable of performing dynamic tests up to 50 mm displacement amplitude was used, see Fig. 7.
The damper was connected to two connectors with two large pins. The bottom connector was fixed while the top connector was connected to the actuator on the top.

Strain gauges were installed in one of the bolts which made it possible to monitor the force level in the bolt and thus controling that the desired force level had been reached.

All tests were displacement controlled and the forces required to displace the damper were recorded by the machine controller and saved in the machine computer.

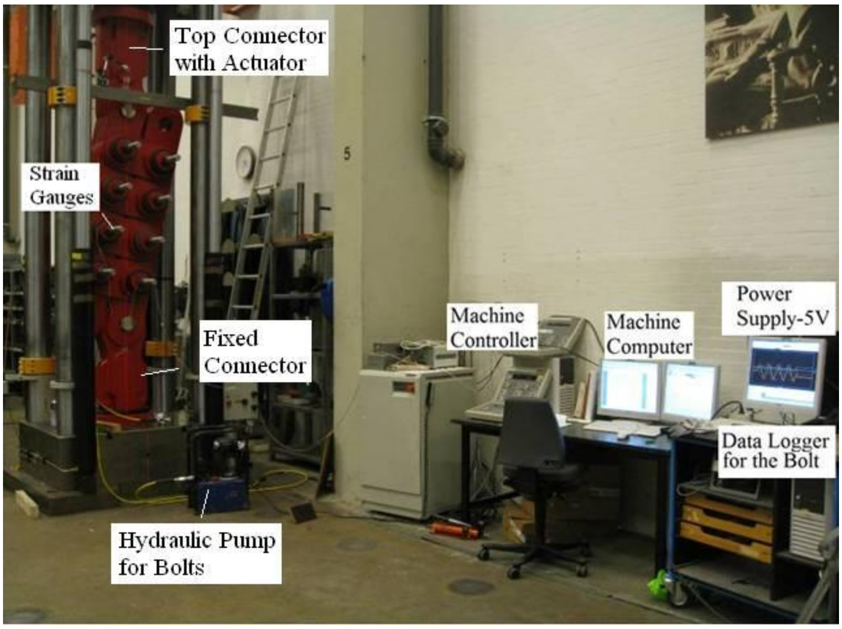

Figure 7. Test setup of the 5000 kN damper in Denmark

3.2. 1500-2250 kN Damper Tests

The test for the KDR1500 was performed with a 3 MN dynamic servo testing machine at Kawakin Testing Facilities in Japan, see Fig.8.

Figure 8. Test setup of 1500 kN damper at Kawakin Testing Facilities in Japan

4.TEST RESULTS

4.1. Test results of 5000 kN damper

The 5000 kN damper was tested up to the limit of the testing machine. The hysteresis loops of dampers with 30 and 45 mm displacement, which were stable for repeating cycles, can be seen in Fig.9. The damper was designed to be able to reach more than the 5200 kN capacity but it was not possible to verify this due to the limitations of the testing machine.

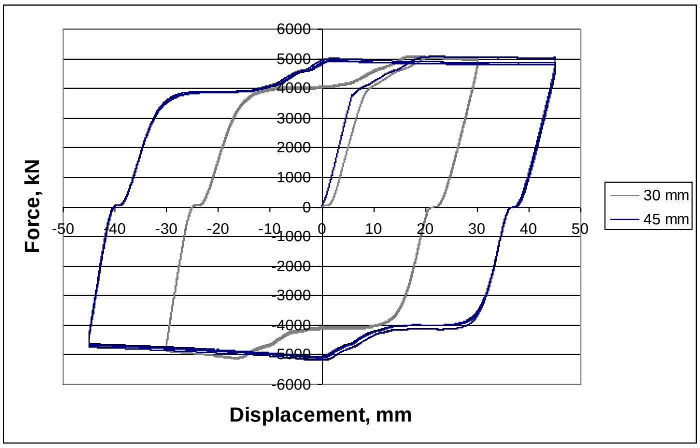

Figure 9. Hysteresis loops for 30 and 45 mm displacement amplitude

The damper behaviour is nearly elasto-plastic but there are some deviations. Most notably after the initial elastic behaviour there is an initial damper slip force of about 4000 kN which is less than expected. After around 20 mm of plastic behaviour the force starts to rise and the damper reaches the full damper slip force of 5000 kN.

This pattern is repeated when the load direction is changed and results in a slightly lower energy dissipation than the ideal elasto-plastic behaviour as the area of the hysteresis loop is slightly reduced.

If the damper behaviour was ideally elasto-plastic there would be elastic behaviour in the damper until the force reached 5000 kN and then followed by plastic behaviour hereafter as seen in Fig.10.

In the given example with 45 mm amplitude in Fig.10 the area of the hysteresis loop of the damper is reduced by 5% compared to the area of the ideal elasto-plastic hysteresis loop.

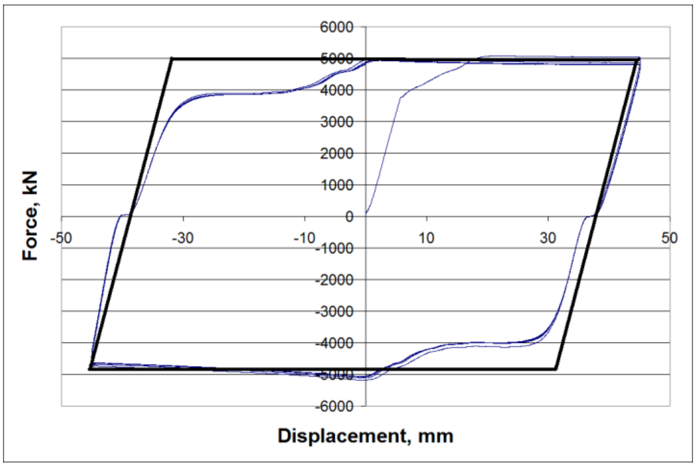

Figure 10. Hysteresis loop of 5000 kN damper for 45 mm amplitude compared to ideal elasto-plastic behaviour

4.2. Test results of 1500-2250 kN damper

A number of experiments for 1500-2250 kN dampers have been conducted at Kawakin testing facilities in Japan as described in the following. The Parameters examined are velocity dependence, amplitude dependence, bolt force relaxation and shape of the hysteresis loop.

The hysteresis loop of 2250 kN damper can be seen in Fig. 11.

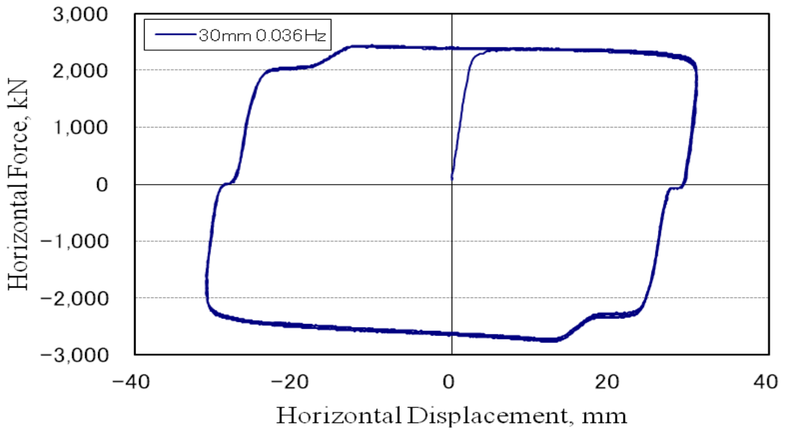

Figure 11. Hysteresis loop of 2250 kN damper

The hysteresis loops of 1500 kN damper with an amplitude of 40 mm is shown in Figure 12.

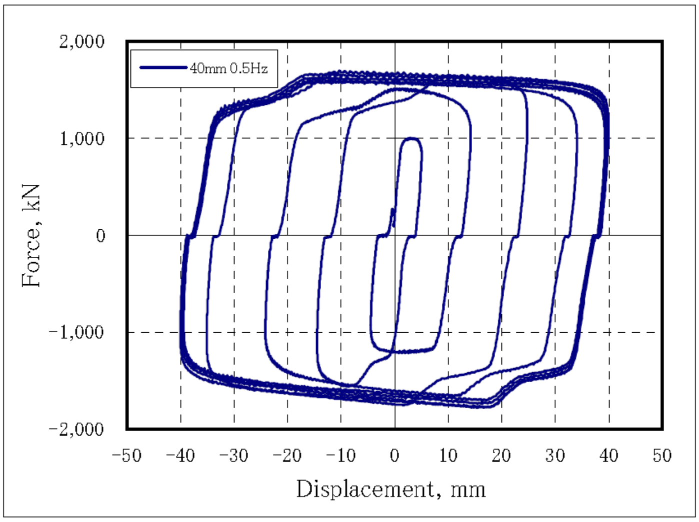

Figure 12. 1500 kN damper hysteresis loop

The damper slip force for varying velocity is shown in Figure 13. The tests were conducted with an amplitude of 20 mm and varying velocity/frequency. The damper slip force is not sensitive to varying velocity/frequency and remains almost constant in the tested velocity range.

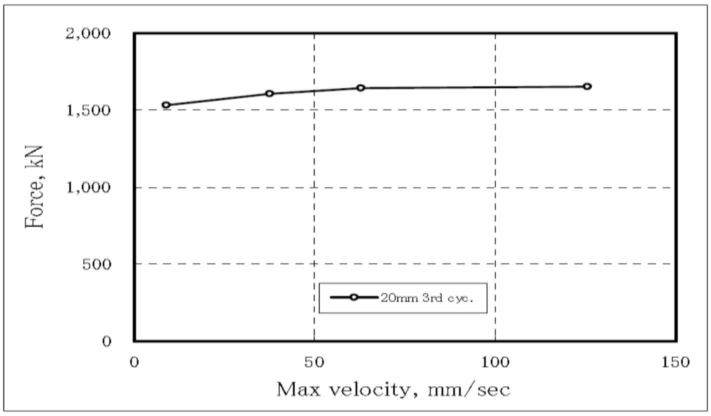

Figure 13. Velocity dependency

The test result of a large displacement test (with 110 mm amplitude) and the theoretical
values are shown in Figure 14. The damper slip force for large amplitudes is close to the theoretical values.

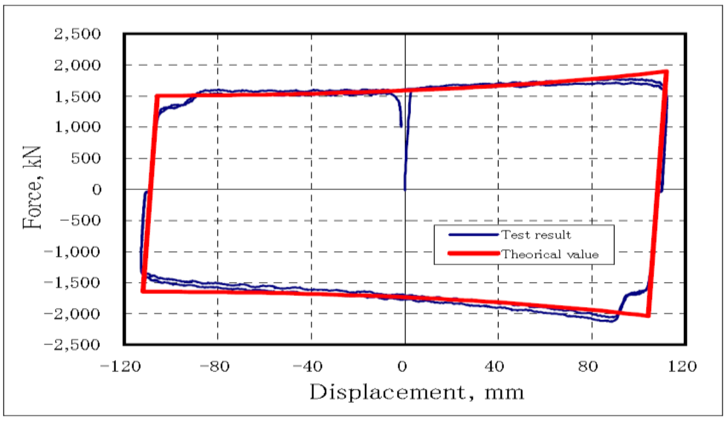

Figure 14. Large displacement test

5. CONCLUSION

A number of experiments with rotational friction dampers in the range of 1500 – 5000 kN have been conducted at the Technical University of Denmark and at Kawakin testing facilities in Japan.
The experimental results indicate very stable behaviour of the dampers in relation to earthquake and extreme wind loads.
The devices are easy to implement in structures and they are economic devices due to material availability.
The dampers have been installed in Abenobashi Terminal building project, the tallest building in Japan.
Several models of Damptech rotational friction dampers have been installed in 20 projects in Japan and in other countries around the world.

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