STRUCTURAL BEHAVIOUR OF 5000 kN DAMPER

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ABSTRACT
This work presents a study on parameters that govern the structural behaviour a high capacity damper with 5000 kN capacity. The damper is based on a rotational friction concept that was developed by the first author. The device is designed to dissipate seismic input energy and protect buildings, especially large and tall buildings from structural and non-structural damage during moderate and severe earthquakes.
The damper has been tested intensively at the Technical University of Denmark. The test proved that the damper is able to achieve the design capacity of 5000 kN.
A computational model based on the finite element software ABAQUS was developed to explain some small differences from the idealized elasto-plastic behaviour of the damper. The comparison of results obtained from the experimental and numerical models shows very good agreement.
The large capacity devices are not difficult to implement in structures and they are economic devices due to material availability.
So far several models of Damptech rotational friction dampers have been installed in 20 projects in Japan and in other countries around the world.

Keywords: vibration control, experimental testing, passive control, retrofit, friction damper.

1. INTRODUCTION

Due to its proven efficiency, the concept of seismic protection based on supplemental damping is gaining momentum within the engineering community worldwide. Friction dampers are often employed in passive response control systems because of their high-energy dissipation potential at relatively low cost and they are easy to install and maintain.
Several models of Damptech rotational friction dampers have been installed in 20 projects in Japan and in other countries around the world (Mualla, Nielsen 2000-2008)
This paper presents the results from the testing of a rotational friction damping device which was conducted at the testing facilities at the Technical University of Denmark.
The main goal of the test was to see if the damper was able to reach the 5000 kN capacity that it was designed for, as a damper based on this concept had never been constructed with such a high capacity.
The damper was able to reach the 5000 kN capacity, but some differences from the perfectly elasto-plastic behaviour were seen. This led to the development of a numerical model of the damper using the finite element software ABAQUS, to explain and find a solution to the differences from the perfectly elasto-plastic behaviour.

2. DAMPER DESCRIPTION

2.1. Main components

The damper consists primarily of several layers of steel plates with 25 mm thickness. The main parts of the damper are 8 long plates and 20 short plates see Fig.1.

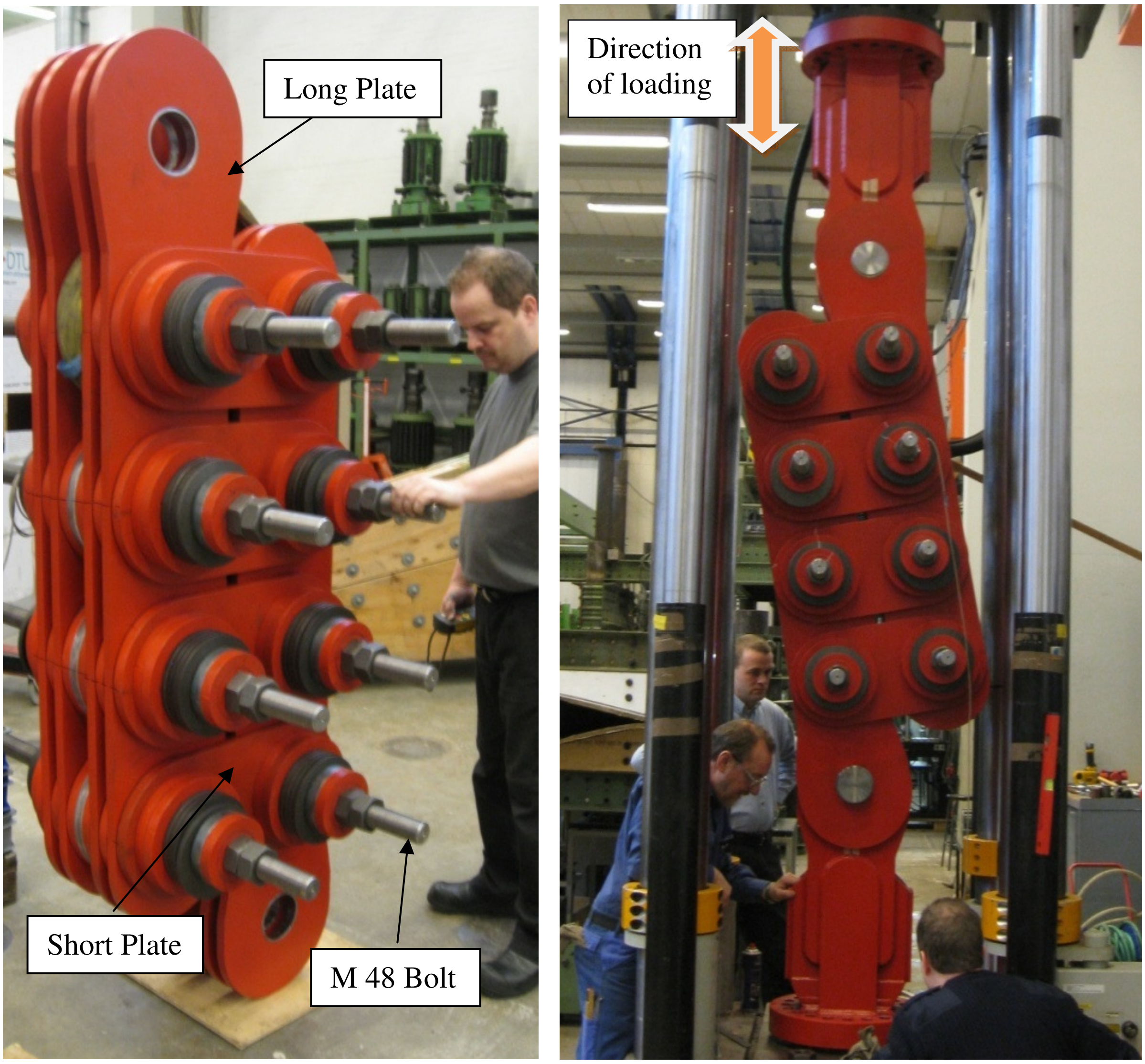

Figure 1. Left: 5000 kN damper. Right: 5000 kN damper installed in the testing machine.

The long and short plates are joined together by a special high strength M48 bolt in each of the eight friction joints. Several layers of high tech special circular friction pads are placed between the adjacent long and short plates in each joint adding up to a total of 64 friction pads, see Fig.2.
The circular friction pads are placed in between steel plates in order to have dry friction lubrication in the unit, ensuring a stable friction force and reducing noise of the movements.

2.2 Basic concept of the damper

The damper is based on rotational friction concept. At zero displacement the short plates are perpendicular to the long plates (Fig.3: Middle).When the damper is displaced in the loading direction the short plates rotate around the bolts and thus allowing the lengthening or shortening of the unidirectional damper (Fig.3: Left and Right).
The bolts are however clamped with large forces up to 700 kN which results in large compression forces in the friction pads and the steel plates. Due to the high friction between the friction pads and the steel plates a large force F, which is proportional to the clamping forces of the bolts, is required to displace the damper considerably.
When the force F is small the damper respone is elastic which means that the displacement of the damper is small and no energy is dissipated by the damper. When the force F reaches 5000 kN the shortplates start to slide and the damper response is plastic and the energy dissipation W_d of the damper is equal to the force multiplied with the displacement Δu ($W_d = F\,\Delta u$).

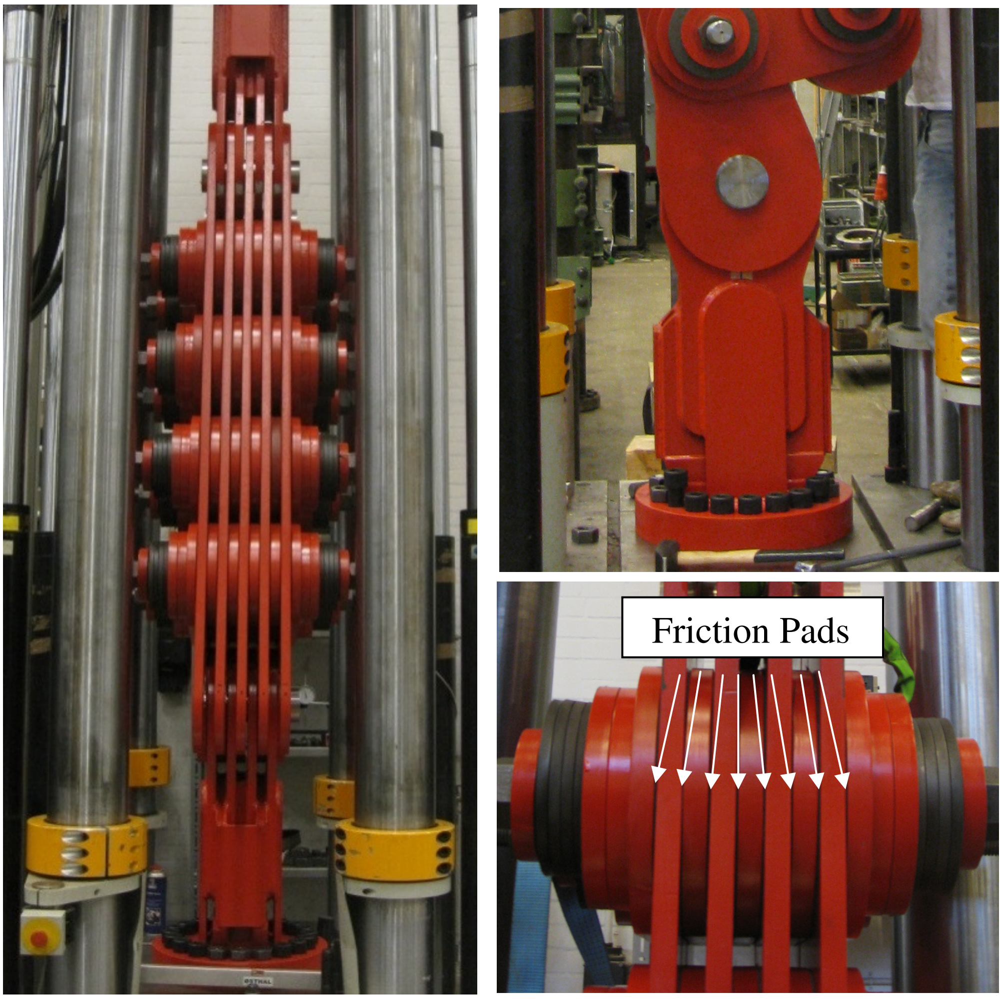

Figure 2. Left: side view of 5000 kN damper. Top Right: Connectors connecting the damper to the testing machine. Bottom right: Friction pads between steel plates.

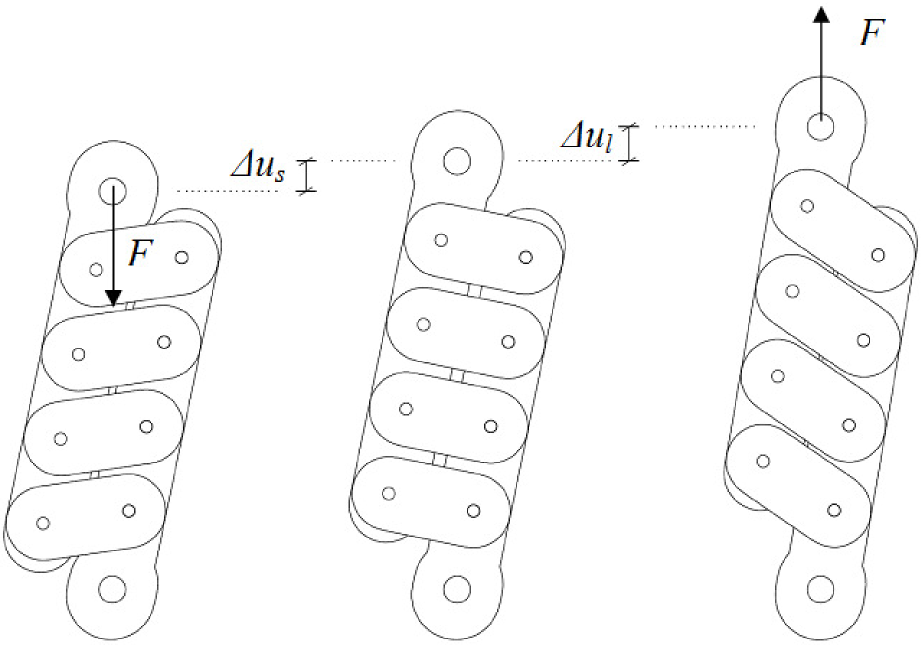

Figure 3. Left: Damper shortened with displacement Δu_s. Middle: Damper in initial position. Right: Damper lengthened with displacement Δu_l

2.3 Basic concept of damper in frame structure

The damper can be installed into a frame structures in different ways e.g, with two dampers and two diagonal bracings as in Fig.4.

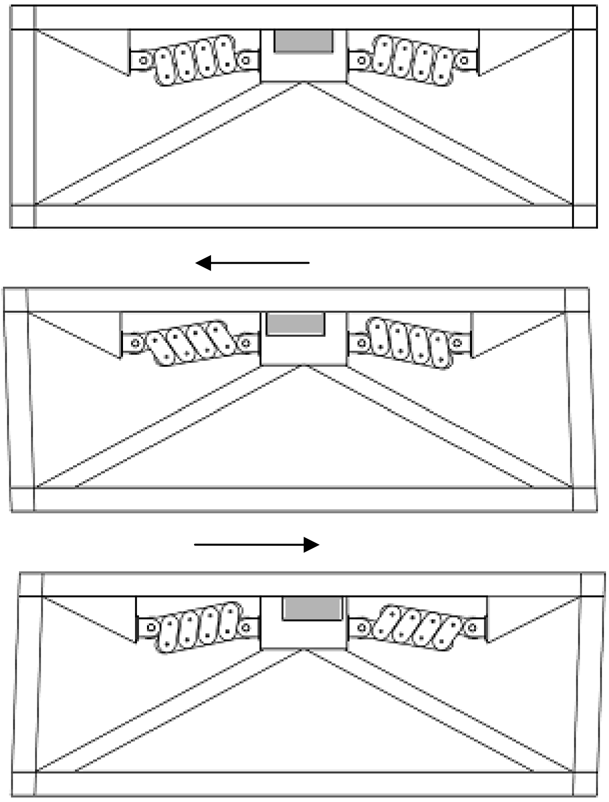

Figure 4. Top: Damper installed with diagonal bracings in frame structure in initial position. Middle: Frame structure moved to the left. Bottom: Frame structure moved to the right.

When a lateral external force excites a frame structure with a large force, the top of the frame structure starts to displace horizontally due to this force. 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 frame structure is moved to the left the left damper is lengthened while the right damper is shortened and both dampers dissipate energy. Similarly when the frame structure is moved to the right the right damper is lengthened while the left damper is shortened and the dampers dissipate energy see Fig. 4.
During an earthquake a frame structure in a building as the one in Fig.4 will be moved from left to right repeatedly and thus dissipating energy as the dampers are lengthened and shortened.

As it is shown, the damper is simple in its components which make it easy to assemble and very flexible in arrangement. An example of this can be seen in Fig.5, where dampers with 4 friction joints are used instead of dampers with 8 friction joints which effectively halves the capacity of the dampers. Dampers based on the rotational friction concept can be arranged in many configurations in bracing systems, as well as in many types of bracing systems.

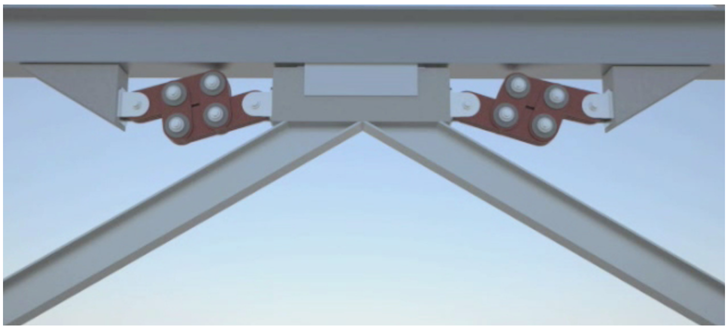

Figure 5. Dampers with 4 friction joints installed in frame structure.

3. EXPERIMENTAL TEST SETUP

The damper was tested at Technical University of Denmark's testing facilities. The 5000 kN Instron machine is one of only a very few in Europe which can perform static and dynamic test with 5000 kN capacity. The damper was connected to two connectors with two M110 pins. The bottom connector was fixed while the top connector was connected to an actuator which was able to displace the damper with an amplitude up to 50 mm in vertical direction.
The 8 bolts were prestressed with a hydralic jack with the desired force and the nuts were thigthened subsequently. Strain gauges were installed in one of the bolts which made it possible to check the force level in the bolt and thus controling that the desired force level had been reached.

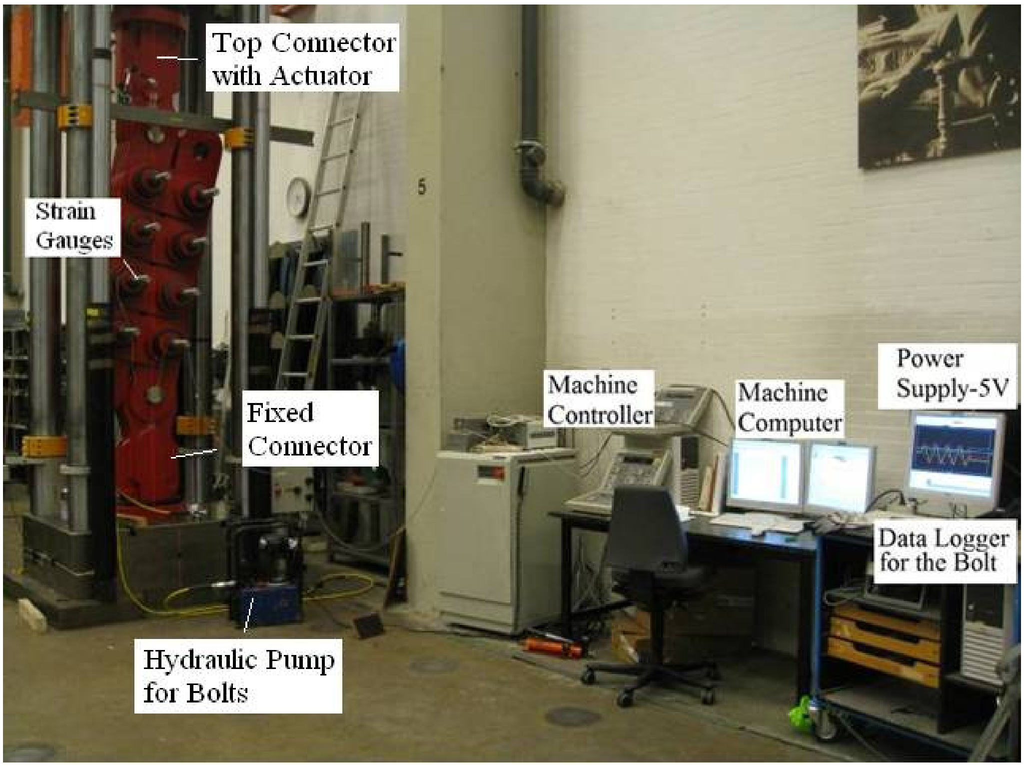

Figure 6. Test setup of 5000 kN damper

The test was displacement controlled and the forces required to displace the damper were recorded by the machine controller and saved in the machine computer.

4.TEST RESULTS

4.1. Hysteresis loop

The damper was tested with amplitudes of 30 and 45 mm displacement and the damper reached the capacity of the testing machine of 5200 kN.
The hysteresis loop of the damper for 30 and 45 mm amplitude was very stable and can be seen in the Fig.7 below

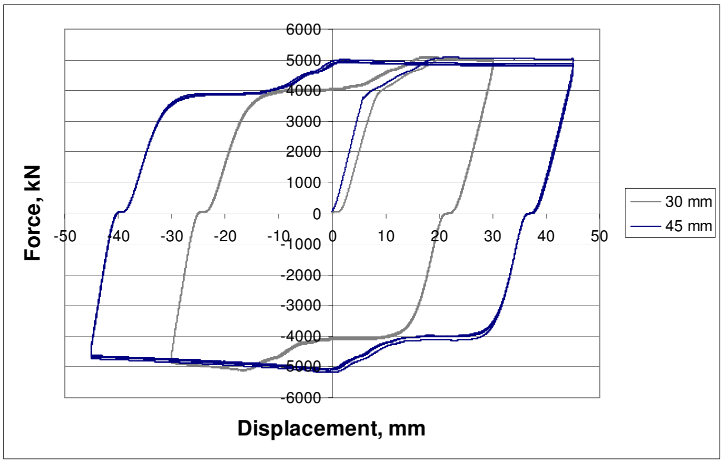

Figure 7. Hysteresis loops for 30 and 45 mm amplitude

The behaviour is nearly linear elastic, perfectly plastic, but some differences are seen. The initial plastic behaviour starts when the force reaches around 4000 kN, but after around 20 mm displacement there is a hardening behaviour in the damper until the force level reaches about 5000 kN. After this point the force level remains approximately constant. This pattern is repeated when the load direction is changed and leads to a slightly lower energy dissipation than the ideal elasto-plastic behaviour.
Ideally there should be elastic behaviour in the damper until the force reached 5000 kN and there should be plastic behaviour hereafter as seen in Fig.8.

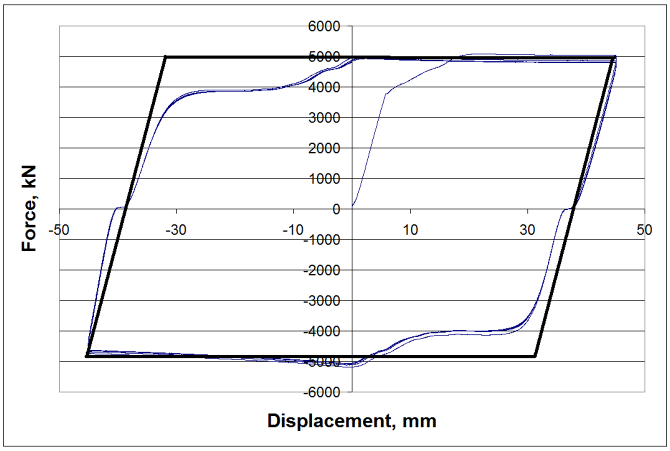

Figure 8. Hysteresis loop for 45 mm amplitude compared to ideal elasto-plastic behaviour

4.2. Frequency

The tests were performed with a frequency of 0.005 Hz as the large forces exeeded the 5000 kN limit of the testing machine. However experimental results such as Mualla (2000a, 2000b) from tests of other rotational friction damper models have shown that the damper performances of such devices are independent of the frequency.

5. COMPARISON OF EXPERIMENTAL & NUMERICAL MODELS

To establish all the important parameters regarding the hysteresis loop of the damper a computational model of the damper was made in the finite element program ABAQUS.

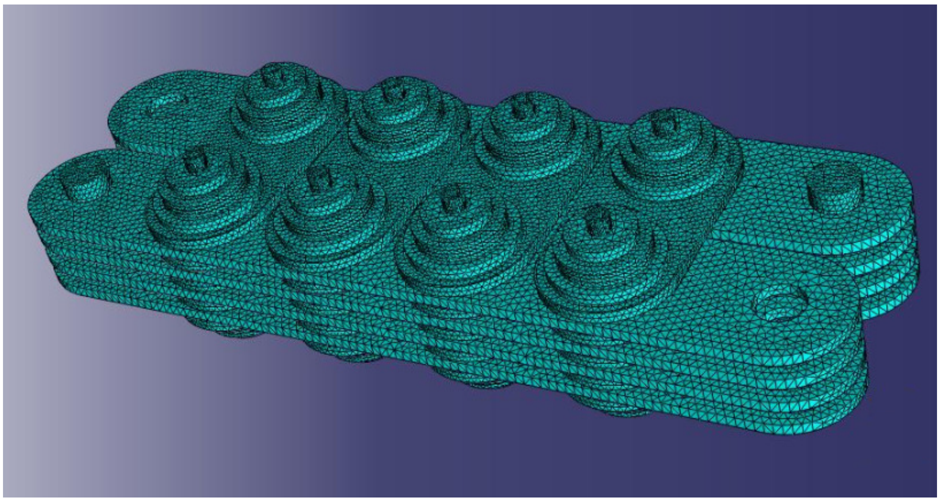

Figure 9: ABAQUS model of 5000 kN damper

Observations from the tests have suggested that some 2 mm tolerances between the M48 bolts and the steel plates could be the reason for the differences from the ideal elasto-plastic behaviour of the damper. In addition to the rotational sliding of the friction pads when the damper was displaced as in Fig.3 a small unidirectional sliding of the friction pads was observed which was possible due to the 2 mm tolerances between the bolts and the bolt holes.
To confirm that this was the reason for the differences the model was run with varying tolerances between the bolts and the bolt holes.

As can be seen in Fig.10 the model showed a clear correlation between the hysteresis loop and the size of the tolerances, as the damper behaviour gets closer to ideal elasto-plastic behaviour when the tolerances decrease.
Furthermore the differences from perfect elasto-plastic behaviour for the hysteresis loop of the model with 2.0 mm tolerances in Fig.10 and the hysteresis loop of real damper in Fig.7 are very similar.

In reality it is, of course, impossible to assemble the damper without any tolerances between the bolt and the bolt holes, but it should be possible to assemble the damper with tolerances of about 0.5 mm and thus getting a damper with practically perfect elasto-plastic behaviour.

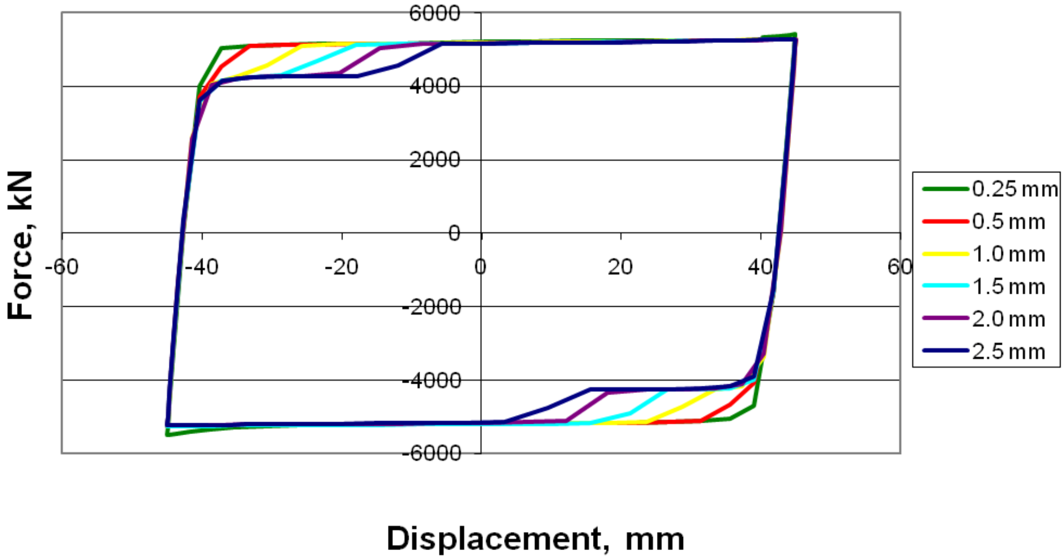

Figure 10. Hysteresis loops of damper model for 45 mm amplitude with varying tolerances between bolts and bolt holes.

6.CONCLUSION

The experimental results confirm that the damper was able to reach beyond the 5000 kN that it had been designed for and that the hysteresis loop was stable.
The hysteresis loop of the damper had a slight difference from the idealized elasto-plastic behaviour as there was a hardening behaviour following the initial plastic behaviour.
Observations from the tests suggested that the 2 mm tolerances between the M 48 bolts and the bolt holes were the reason for the differences, as these tolerances made a small uni-directional sliding off the friction pads possible.
The computational model of the damper confirmed that the tolerances were the reason for the differences, as the hysteresis loop of the damper converged towards an ideal elasto-plastic behaviour when the tolerances converged towards zero.
Friction dampers are often employed in passive response control systems because of their high-energy dissipation potential at relatively low cost and they are easy to install and maintain.
Due to its proven efficiency, the concept of seismic protection based on supplemental damping is gaining momentum within the engineering community worldwide.
Several models of Damptech rotational friction dampers have been installed in 20 projects in Japan and in other countries around the world.

References

Mualla, I.H. 2000a. Experimental Evaluation of a New Friction Damper Device, 12th World Conference on Earthquake Engineering, Auckland, New Zealand.
Mualla, I.H. 2000b. Parameters Influencing the Behavior of a New Friction Damper Device.
SPIE's 7th International Symposium on Smart Structures & Materials, SS2000, CA, USA, 2000.
Mualla, I.H., Nielsen, L.O., Belev, B., Liao, W.I., Loh, C.H., Agrawal, A. 2002. Performance of Friction-Damped Frame Structure: Shaking Table Testing and Numerical Simulations. 7th U.S. National Conference on Earthquake Engineering, Boston, USA.
Nielsen LO, Mualla IH. (2004). Seismic Isolation with a Friction Damping System for Asymmetric Structures, 4th European Workshop on the Seismic Behavior of Irregular and Complex Structures, Thessaloniki, Greece.
Nielsen LO, Mualla IH, Iwai Y. (2004). Seismic Isolation with a new Friction-Viscoelastic Damping System, 13th World Conference on Earthquake Engineering, Vancouver, Canada.
Leif O. Nielsen, Imad H. Mualla, Yuuichi Iwai and Tadashi Nagase, Seismic Isolation Systems Based on Frictional Visco-Elastic Dampers., The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.