EXPERIMENTAL EVALUATION OF NEW FRICTION DAMPER DEVICE

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SUMMARY

A new friction damper device was designed to dissipate and absorb input energy in order to increase building safety. It can be used in retrofitting or in designing of new buildings. The friction damper was tested intensively in order to verify its characteristics and performance. This device consists of several steel plates that rotate against each other in opposite directions, producing friction between its parts. Utilization of this type of geometric deformation of the damper parts of frame displaced laterally, is a way to permit substantial controlled energy dissipation. The interfaces between the inner pieces of the device were faced by use of different materials such as brass or friction pad material. This device is characterized, especially when the friction pad material is used, by a very stable hysteric non-degrading behaviour over many cycles. It is also linearly dependent on displacement amplitude and normal load. Some velocity dependency was observed during tests, due to change of friction coefficient of sliding phase. The damper was implemented in a single story steel frame model. This frame is a 1/3-scale model of typical frame. It is connected to the frame by use of chevron-bracing system and prestressed bars were used instead of structural steel bracing sections. Harmonic loading was used to excite the frame. The response was studied for different values of parameters such as forcing frequencies, displacement amplitude, bolt-clamping force and prestressing bar force. In conclusion, using of supplemental damping provided by this friction damper, dissipate a big amount of kinetic energy in a structure, and thereby eliminate the utilization of structural ductility while the structure remain elastic without damage.

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INTRODUCTION

The buildings normally designed to have some inelastic deformations such as having plastic hinges in beams firstly and then in columns. This idea is good because a lot of input energy is dissipating, which provide the required safety, but the damages and the expenses are high. In order to eliminate and reduce the damages to the structures main elements; beams and columns, special devices installed in selected places to perform some protection to these elements by having some plastic deformation. Passive control devices have been successfully used in structures to reduce their dynamic response when they were subjected to earthquakes or strong wind gusts. Friction devices, as they are part of these dampers, were used because they present high potentially at a low cost, easy to install and maintain. Several friction devices have been tested experimentally, Pall [9], Sumitomo [1], Fitzgerald [5], Constantinou [3], Dorka [4], Grigorian [6], Nims et al [8], and some of these have been used in buildings around the world. Several researchers worked to develop seismic design procedure for these dampers; Cherry [2] have proposed a simple and practical design method that attempts to optimize the slip force in friction damped braced frame structures

The work presented in the present paper is about the development of a new friction damper that can easily manufactured, installed in a short time without a need to qualified staff, and inexpensive. As well as using a material not only to provide a very stable performance over many cycles but also can resist adhesive wear and not damaging the damper plates surfaces so it can be reused again for unlimited times.

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NEW FRICTION DAMPER DEVICE

The novel friction damper consists of 3 steel plates rotating against each other and in between these plates, there are two circular friction pad discs, in order to have dry friction lubrication in the unit, ensuring stable friction force and reducing noise of the movement.

The damper main parts consist of a central plate and two side plates, as shown in Fig.1. The central plate holds and connects the damper device to the girder of frame structure by a hinge, which provided by having a plain bearing, in order not to introduce moment in the girder when this device used in retrofitting of buildings. Also creating such a hinge will increase the amount of relative rotation between the central and side plates, which in return increase the amount of energy dissipation in the system. The two side plates connect the damper to the bracing system and in this work, invert V bracing were used. This bracing consists of pretension bar members in order to avoid compression forces and therefor buckling. The bracing bars are hinged connected at both ends, by having plain bearings, to the damper and to the column base connection.

The reason for using two side plates and not one, was to increase the frictional surface area and to provide the necessary symmetry in to obtain plane behaviour of the device. The bolt connects the three plates of the damper to each other. This adjustable bolt is used to control the normal force applied on the friction pad discs and the steel plates.

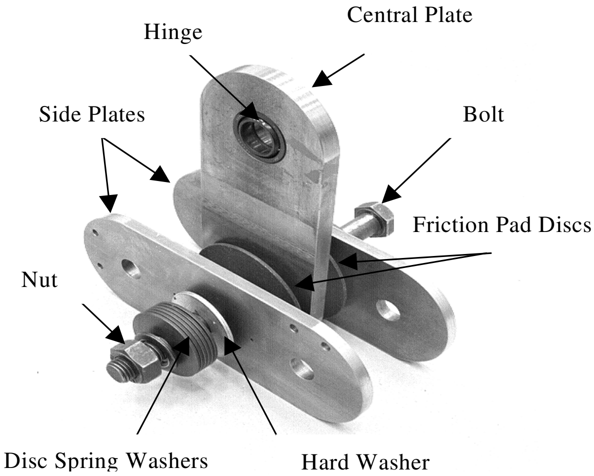

Figure 1: Details of the friction damper device

In order to keep a constant clamping force while the damper functioning, several discs spring washers (Belleville Washers) are used. Hardened washers were placed between these springs and steel plates to prevent any marks on steel plate due to the disc springs when they were in compression. The steel plates used for this damper are of Fe 360.

In order to reflect current fabricating practices and to simulate industry standards, local structural steel fabricators manufactured all of the steel specimens and no special attempt was made to control the flatness or the dimensions of the damper.

MECHANISM OF THE DAMPER

When a horizontal external force excites a frame structure, the girder starts to displace horizontally due to this force. The damper will follow the horizontal motion of the frame because of the hinge connection, which transfer the forces to the damper parts. The bracing system and the frictional forces developed between the frictional surfaces of steel plates and friction pad materials will resist the horizontal motion.

The central plate will start to move horizontally and rotate around the hinge. The clamping force in the bolt, which makes the damper parts stick to each other, and due to this introduces frictional forces. These frictional forces will rotate the side plates within the same amount of rotation and direction as the central plate dose, because they are higher than the applied forces. The damper will continue being in sticking phase until the applied forces in the damper exceed the frictional forces, at this moment, sliding starts and the central plate rotates relatively to the friction pad discs, around the bolt. The side plates also start to slip and rotate but in another direction because of the tensile forces in the bracing. In this sliding phase, the damper will dissipates energy by means of friction between the sliding surfaces. This phase will keep on and later will be changed to the sticking phase when the load reverses its direction.

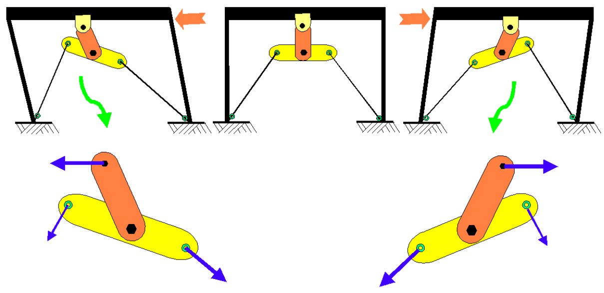

Figure 2: Mechanism of the friction damper device.

This process of moving from phase to phase is repeated upon reversal of the direction of the force application. Fig.2 explains the mechanism of the damper device under an excitation force in different directions.

As it is shown, the damper is very simple in its components which make it easy to assemble and very flexible in arrangement. It can be arranged in many configuration of bracing system, as well as in many types of bracing system. The simplicity of the damper design allows constructing a device with multi units, based on the requirements of the designed friction force and the space limitations. Beside the time required to installe the device within a building is relatively short.

EXPERIMENTAL PROGRAM

In order to verify the frictional component of the proposed friction damper device, a number of qualification tests have been performed in the laboratory to evaluate the theoretical studies of this damper. The experimental program included two phases:

1. Testing the damper device with three different types of friction materials
2. Testing a scale model steel frame with implemented friction damper device.

Testing the damper with different friction materials done with Instron machine to verify the parameters which affect its performance. These include cyclic tests of the damper. From these tests, the proper found material among the other materials, was used in the tests of the scaled frame model incorporating friction damping device, which was performed by a shaker. These experimental studies were carried out in the laboratory of the department of structural Engineering & Materials, Technical University of Denmark. Full details of the experimental program were explained in Mualla [7]
The damper specimen, described above, was placed within an Instron hydraulic testing machine type 8502 as shown in fig. 3. Displacement, forcing frequency and applied force control were possible through a controller unit. The test control was done by the PC running Instron software; “Max 5.2”. All testing was done under displacement and forcing frequency control, the resulting data were transferred to Data Acquisition Board System, which was integrated with system controller and in conjunction with PC.

For immediate visual observation of the results, force – displacement curves were drawn on the PC monitor.
The damper was mounted on the Instron by a frame holder, designed especially for this case. The frame holder was connected rigidly to the machine. The damper was connected to the holder by two small plates fixed rigidly to the holder. Each of these plates was connected to the side plates by a hinge. These two plates were used later to connect the bracing bars to the damper. Inside these plates, ball bearings were fixed in order to reduce friction through the damper activity with scaled frame model.

Figure 3: Setup of the damper tests with Instron machine

The applied load was measured by a dynamometer having two strain gages fixed on it. This dynamometer was connected by a bearing hinge at both ends to prevent any kind of bending. The clamping force in the bolt was measured my two strain gages embedded inside the bolt. The required clamping force could be applied by tighten the bolt head with a spanner and the readings were obtained directly from a multimeter. The displacement measured by a potentiometer with a special setting of using a roller head. This setting of potentiometer was used later to measure the relative rotation between central plate and the side plates through the 2nd phase of the experimental program.

In order to evaluate the damper performance, a series of tens of dynamic cyclic tests were performed with three different types of materials: brass, highly frictional material and friction pad material. Brass was chosen because of it's low cost and widely available commercial material.

In general, the friction damper performance's are affected by certain parameters, these parameters were studied in these tests, and are as follows: frequency dependency, displacement amplitude, bolt clamping force and long running tests.

The damper was tested with displacement amplitudes of 5, 10, 15 and 20 mm with 0.3 Hz forcing frequency. Fig. 4 shows the applied displacement and resulting hysteresis loops of the brass shims. It's clearly shown that, when the amount of the area was increased due to the increase of the displacement, the friction force was almost constant without showing any fluctuation or disturbances.

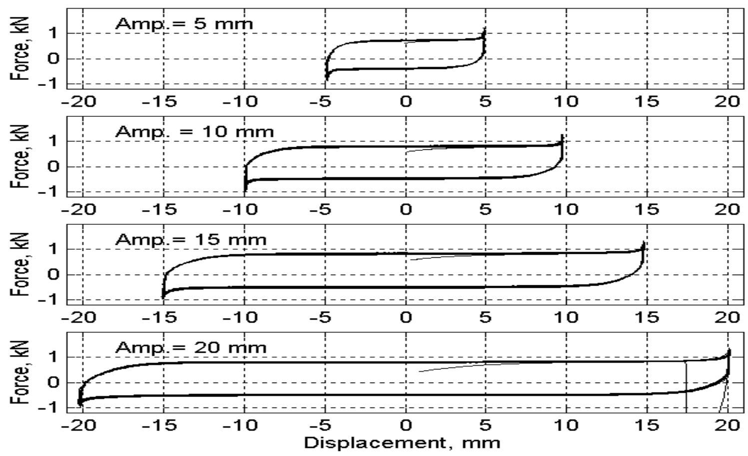

Figure 4: Effect of using different displacement amplitudes on the hysteresis loops of brass shims.

The high forces were observed at the end of each cycle were due to the relative velocity of the plates reaches its minimum value. The visual inspection of the faying surfaces shows scares and adhesive wear between steel and brass.

FRICTION PAD MATERIAL

The performance of the damper can be more improved by using another material having the ability of resisting wear as much as possible as well as performs a stable hysterises for long term of cycles. Such improvement is likely to be achieved by providing a more suitable material combination. An asbest free friction material (Friction Pad Material, FPM) was found after searching for a material with a special requirement. This material is a composite one, with a friction coefficient of 0.35-0.45.

In order to study the damper performance with the friction pad material under long running cyclic test, the damper was subjected to up to 400 cycle with 0.5 Hz frequency and 4 kN clamping force. The results were very encouraging, no fading was noticed, and the noise caused by friction was much less than other materials. FPM tests showed negligible damage to their friction surface and the most important, the steel plates surfaces were free of scars or damages , except that a thin layer of powder film were found on the plate surfaces.

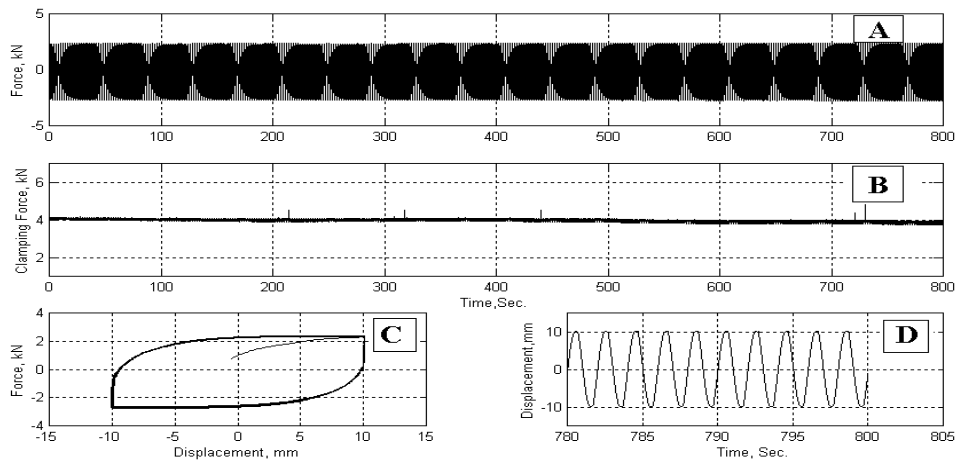

Fig. 5: [A] Force history for 400 cycles, [B] Bolt Clamping Force history [C] Force – Displacement hysterises. [D] Displacement history for the last 10 cycles.

5. SCALED FRAME WITH FRICTION DAMPER

A single story, one bay, steel frame model was built and tested statically and dynamically in order to verify the effectiveness of the friction damper concept experimentally. These tests of the damper device implemented with steel frame were planed to ascertain the damper performance under practical condition prior to interducing it into use of the building. The overall dimensions of the model frame are 1.125 m height and 1.10m span. The frame structure columns are steel stripes of 50x15 mm. The beam is a hallow rectangular steel section of 90x50x5 mm and rigidly connected to the column by all around butt-welding. The structure was fixed rigidly to the massive floor of the laboratory. The ratio of beam moment of inertia (Ib) to column moment of inertia (Icol) was 91.73. The natural frequency of this frame was 6.8 Hz.

The frame girder was excited horizontally with a force, experimentally applied by rigid bar. Force transducer measured the force transferred between the structure and the attached rigid bar. This measured force was continuously stored by the DAP Program. The position of the frame was obtained using potentiometer with a roller head rigidly mounted on external frame holder. The relative rotation between the steel plates was measured by a potentiometer, with a roller head, fixed on side plate. These measurements were divided by the distance between the potentiometer head and the centreline of side plates in order to measure the relative rotation between the rotated plates. The rotation of central plate was measured by another potentiometer, and the readings were divided by the distance between the head and the centre of the hinge that connects the damper to the frame girder.

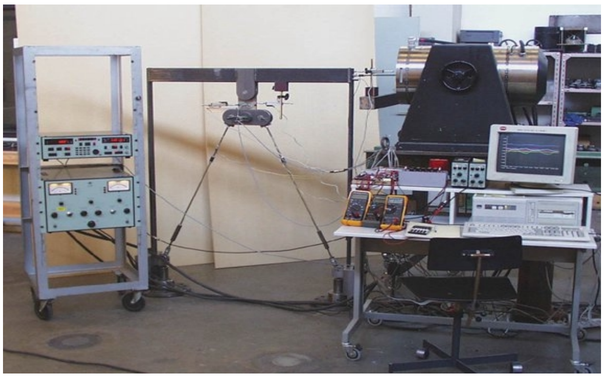

Figure 6: Experimental setup of SDOF with FDD

5.1 FREQUENCY DEPENDENCY

One of the most important parameter in verifying the friction damper devices is the frequency dependency. The frame was tested by 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 Hz forcing frequency with same value for all of the other parameters. The results, which represent moment, M, in the damper and relative rotation between the plates, Theta, show clearly that it is almost independent for this range of frequencies as it is shown in Fig 7, which makes the use of Coulomb law sufficient. Its worth to mention that some dependency was observed in the measuring tests of sliding coefficient of friction when high velocities were applied.

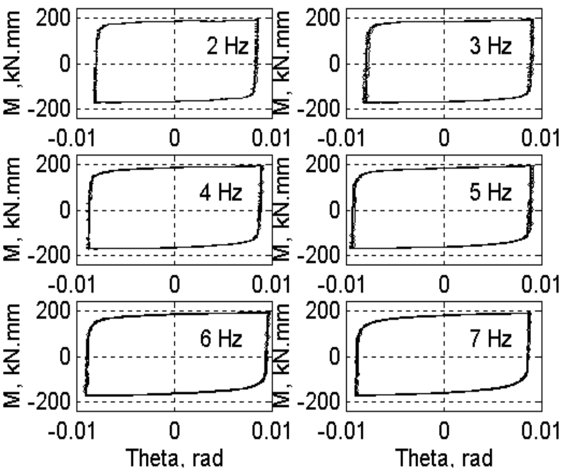

Figure 7: Effect of Different Forcing Frequency 2, 3, 4, 5, 6 and 7 Hz on Moment – Theta relation

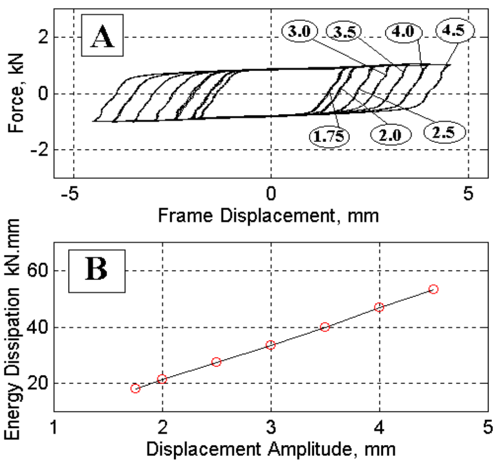

Figure 8: [A] Effect of different displacement amplitude [B]Energy dissipation – displacement relation.

DISPLACEMENT DEPENDENCY

The frame was tested with different displacement amplitudes in order to verify its influence on the damper behaviour. In these tests the frame displacement was controlled with 1.75, 2, 2.5, 3, 3.5, 4 and 4.5 mm as shown in Fig. 8A. The energy dissipation, which is the enclosed area of horizontal force – displacement curve, for each amplitude was, plotted versus frame displacement in Fig. 8B. It's clearly shown that the linearity effect of this parameter, makes the mathematical modelling very simple.

ENERGY DISSIPATION

The performance of the damper can also evaluated by the amount of input energy that can be dissipated. The scaled frame was excited by 3 Hz with amplitude of 0.8 kN. It's clearly seen, from Fig. 9, that the amount of energy dissipated by the friction damper, was about 89 % of the input energy. This high percent proves the efficiency of this type of friction damper devices in absorbing and dissipating the amount of input energy.

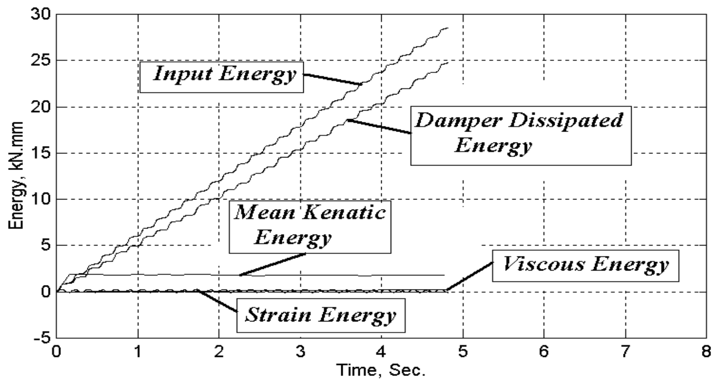

Fig.9: Energy response of the experimental testing of scaled frame with damper device

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CONCLUSIONS

A new friction damper device was proposed to retrofit buildings subjected to dynamic loads. The damper is very easy to manufacture, install, and maintain without a need of qualified staff. It's very economic device. Intensive experimental tests were performed to study its parameters such as, forcing frequencies, displacement amplitude, bolt-clamping force and prestressing bar force. The successful performance of the damper in providing stable hysteresis loops is due to the use of Friction Pad Material which causes no damages to the steel plates beside the very stable performance over many cycles without any degradation in the friction force. Tests showed that the device is a velocity independent for certain range, and linearly displacement dependent, which makes it easy modeling mathematically.

One can conclude that, the use of supplemental damping provided by this friction damper dissipates a big amount of kinetic energy in a structure, and, thereby eliminates the utilization of structural ductility while the structure remains elastic without damage.

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