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Study on Beam-to-Column Connection with Viscoelastic Hysteretic Dampers for Seismic Damage Control

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Abstract

Dampers are energy-dissipating devices widely applied for new and existing structures in earthquake prone areas. A new steel beam-to-column connection for seismic energy dissipation is presented in this paper. Dissipation of energy is provided for with the use of visco-elastic material that works in shear and of elasto-plastic steel bolts that act in bending. Through analysis, it is shown that the proposed system produces stable connection superior to the conventional connections. In this study viscoelastic hysteretic dampers are utilized along with steel bars at the beam column junction. Installation and repair of the proposed detail are easy to implement as it consists of placing a viscoelastic damper as a lower pad on the seat angle of the connection and a series of bolts connecting the top flange to the seat angle. Effects of various parameters on the behavior of the proposed connection are studied comprehensively.

Keywords: *Visco-elastic, Hysteretic, Beam-to-column connection, Passive energy dissipation*

1. Introduction

Over the past few decades world has experienced numerous devastating earthquakes, resulting in increased loss of human life due to collapse of buildings and severe structural damages. The traditional approach to design an earthquake resistance building is to provide adequate strength and stiffness against earthquake forces. In recent years, there have been many proposals on how to control the damage of structures in events of large earthquakes. Different procedures including active, passive and combined methods are available for the same purpose. In the active methods it is tried to apply external resisting forces in a direction opposite to the action of the inertial forces at each time step. In contrast, in a passive control the dynamic characteristics of the building including its period and or damping are permanently changed to larger values in order to decrease the potential of large forces from being produced in structural members. Passive control systems usually are of displacement dependent devices including yielding metal dampers, friction dampers, or of velocity dependent components such as visco-elastic or liquid dampers. Dampers are energy-dissipating devices widely applied for new and existing structures in earthquake prone areas. The controlling devices reduce damage significantly by increasing the structural safety, serviceability and prevent the building from collapse during the earthquake. Dampers are effective in reducing drifts while maintaining shear forces at the same level or under certain conditions, less than those of structures without dampers. Using dampers in the structure increased these days due to demand and desire for safer, more reliable and more comfortable buildings. Passive dampers are used recently in many mid and high rise buildings. These dampers will absorb the extra energy from the seismic transient and is attenuated. Such passive dampers also play key role in the implementation of structural rehabilitation which is essential for the realization and promotion of sustainable buildings.

The capacity of a structure or a structural component to dissipate vibration energy is known as damping. The principal mechanism involved in damping is the conversion of instantaneous strain and kinetic energy into heat, which is dissipated into the surrounding environment. Damping increasing reduces structural response (acceleration and displacement). Damping effect at low frequency have no effect on spectrum amount and at high frequency, it has low effect on response acceleration.

Viscous dampers are the simplest earthquake energy dissipation system is implemented in many structures. In this study visco-elastic dampers are utilized along with steel bars at the connection to dissipate earthquake induced energy in a more reliable way. Installation and repair of the proposed damper is easy to implement.

2. Objective

Objective is to study beam-to-column connection with Visco-elastic hysteretic dampers for evaluating the energy

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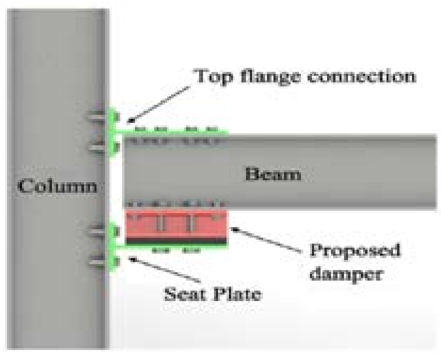
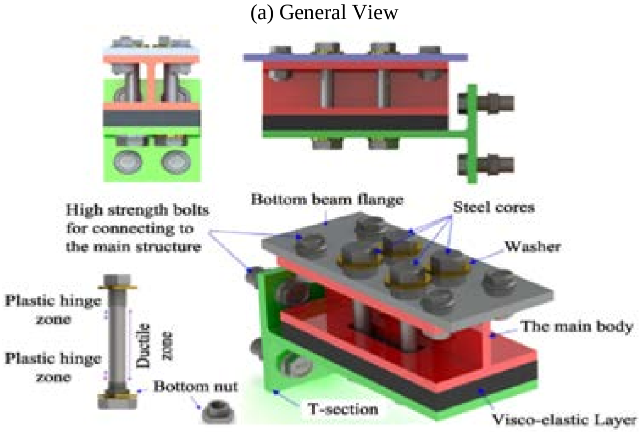
dissipation. The effect of different parameters on the behavior of the proposed damper is also studied.

3. Proposed Connection System

The suggested damper is a combination of viscoelastic and hysteretic dampers. The whole damper is located below the bottom flange of beam and consists of a T-shape seat plate, a layer of special viscoelastic rubber, a supplemental I-beam segment and a number of screws and bolts for connecting different parts. The assembly is shown in Fig. 1.



(a) General View



(b) Close up View

Fig 1. The Suggested Damper

4. Configuration and Properties of the Model

A model of rubber should account both for its hyper elasticity, and for its viscosity. In this study Mooney-Rivilin model is adopted. Steel under cyclic load shows its hardening behavior at the end of yield plateau. It can be modeled as an isotropic, kinematic or combined behavior. Kinematic model stimulate the real behavior of steel under cyclic actions and the same is adopted here. The plan dimension of the rubber layer is 260x180 mm with a reference thickness of 20mm. Values of the parameters in different connection assemblies analyzed are shown in table 1. In this table n, L, D, and t are number of bolts, length of bolt leg, diameter of bolt, and thickness of rubber.

Table 1: Characteristics of the Studied Connection Assemblies (all dimensions in mm)

Assembly name	*Beam section*	*Column section*	*n*	*L*	*D*	*t*	*D/L*
Effect of diameter and height of the bolt core							
DC1	ISMB 200	ISMB 250	8	60	12.5	20	0.21
DC2	ISMB 200	ISMB 250	8	60	15.0	20	0.25
DC3	ISMB 200	ISMB 250	8	60	17.5	20	0.29
DC4	ISMB 200	ISMB 250	8	60	20.0	20	0.33
DC5	ISMB 200	ISMB 250	8	80	22.5	20	0.28
DC6	ISMB 200	ISMB 250	8	80	25.0	20	0.31
Effect of thickness of the rubber layer							
DC7	ISMB 200	ISMB 250	8	80	17.5	22.5	0.22
DC8	ISMB 200	ISMB 250	8	80	17.5	25	0.22
DC9	ISMB 200	ISMB 250	8	80	17.5	27.5	0.22
DC10	ISMB 200	ISMB 250	8	80	17.5	30.0	0.22
Effect of beam and column section							
DC11	ISMB 300	ISMB 250	8	60	20	25	0.25
DC12	ISMB 300	ISMB 250	8	60	20.8	25	0.26
DC13	ISMB 300	ISMB 250	8	80	21.5	25	0.27
DC14	ISMB 300	ISMB 250	8	80	22.9	25	0.28
DC15	ISMB 300	ISMB 250	8	80	23.5	25	0.29

Table 2: T- Section Thickness

Dimensions (mm)	*Top*	*Bottom*
Flange	15	15
Web	12	15

5. Modeling in Ansys

Element type used is SOLID 185, to model the system. CONTA 174 and TARGE 170 are used to create contact element.s

Two types of contacts are present in the damper system. At the interface of different plates, such as the bottom flange of the beam and the top flange of the supplemental I-beam segment, contact condition is introduced at the finite elements nodes. The second type of contact is at the interface of rubber and the steel plates above and below it, and at the screws of the steel cores in the attachment locations. Here, the finite element nodes of the contacting materials are tied to each other.

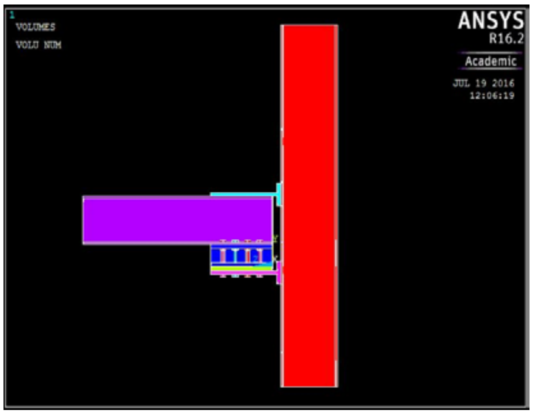


Fig. 2 Model of Connection System

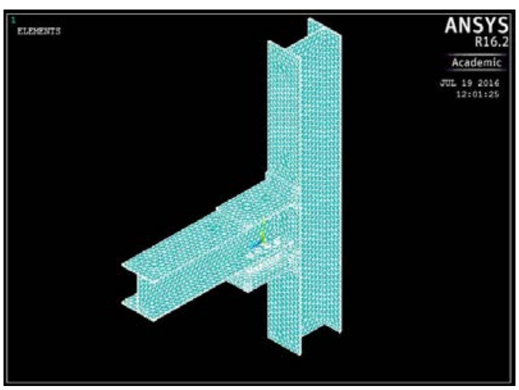


Fig. 3 Isometric View of Model in FEA

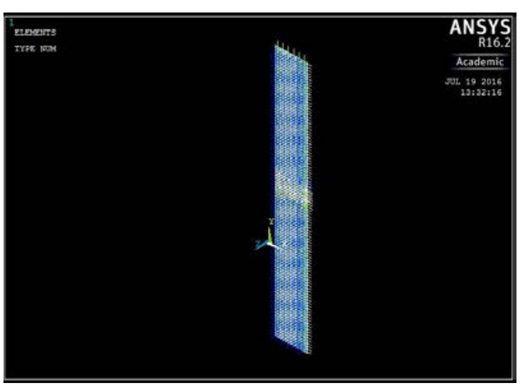


Fig. 4 Contact and Target Pair

A one-sided connection of a beam and column is analyzed with a hinged condition at the column's endpoints and a cantilever condition for the beam. The cyclic rotation of the connection is provided for with applying cyclically increasing vertical displacements at the free end of the beam.

To study the effects of different parameters on the behavior of the proposed damper, 15 analytical dampers were developed for nonlinear finite element analysis. The parameters studied are:

1) Diameter and length of the steel cores;
2) Thickness of rubber layer;
3) Dimensions of beam and column section;

6. Results and Discussions

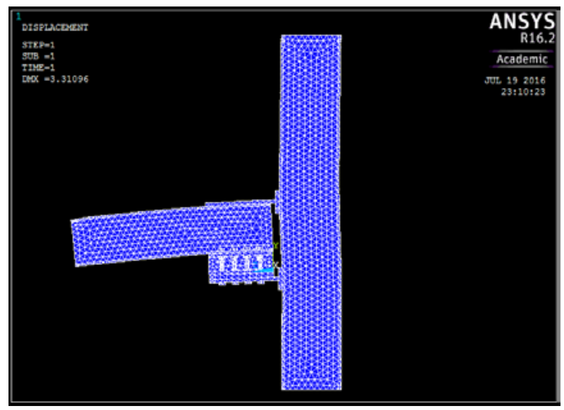


Fig. 5 Resultant Displacement

The von-mises yield criteria predict that yielding will occur whenever the distortion energy in a unit volume equals the distortion energy in the same volume when uniaxially stressed to the yield strength.

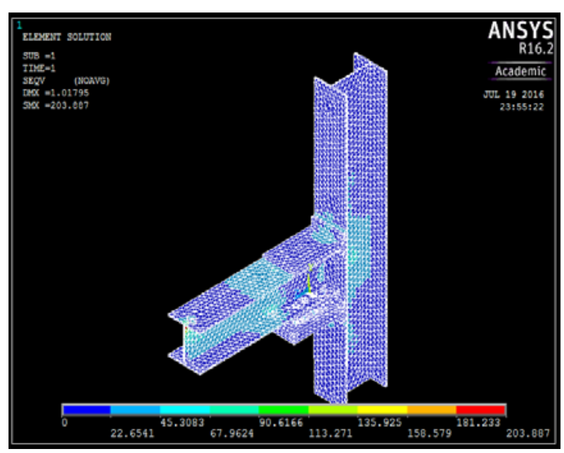


Fig. 6 Contours of Von-mises Stress

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6.1 Parametric Study

1. Effect of diameter and length of bolt core

It is observed that the connection behavior tends to that of the conventional connection for steel cores with larger diameters. At the same time, from a certain diameter upwards, longer steel cores result in yielding of the beam prior to the steel cores that is not desirable. Fig. 7 shows the total dissipated energy. The connections DC3, DC4 and DC5 have behaved better than the others. It means that D/L must be 0.2–0.3, to retain an appropriate energy dissipation capacity in the system.

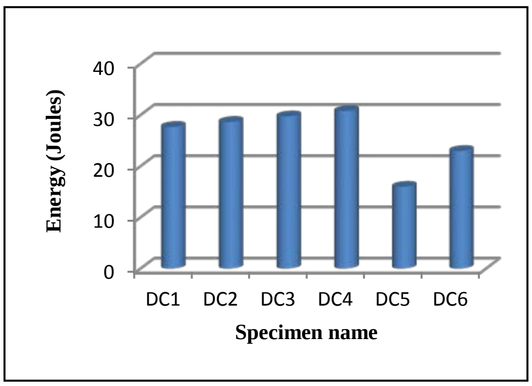

Fig 7. Energy Dissipation of System for Various Diameter and Height of Bolt Cores

2. Effect of the thickness of the rubber layer

For the connections of this section, the thickness of the rubber layer is varied between 22.5 to 30mm with 2.5mm increments. Variation of thickness of the rubber layer did not result in a sensible change in the behavior of the connection. There is no increase in the plastic energy and displacement produced by the connection.

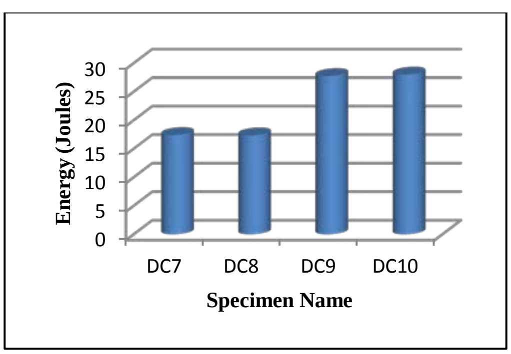

Fig 8. Energy Dissipation for Various Rubber Layer Thicknesses

It is because of reduction of the shear strain in the thicker layers in contrast to increase of dissipated energy due to a larger volume of a thicker rubber. These two opposite effects tend to neutralize each other. Fig 8 shows energy dissipation of the various sections.

3. Effect of the beam section

For evaluating the effect of a larger beam, the beam section was increased to ISMB 300. Five connections with varying bolt diameters, (20mm, 20.8mm, 21.5mm, 22.9mm, and 23.5mm) were designed. Then the total dissipated energy was calculated. The Fig 9 shows energy dissipation of the sections. The displacement is increased with larger beam.

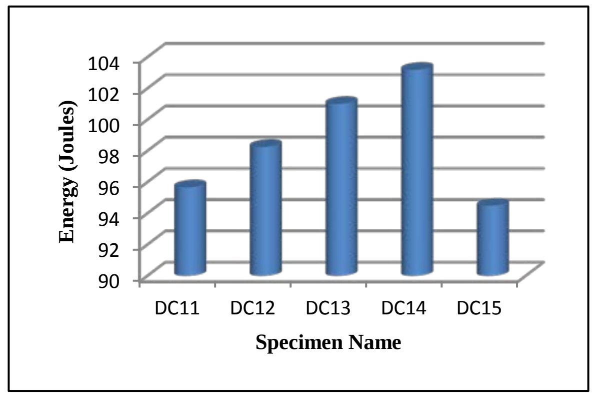

Fig 9. Energy Dissipation for Larger Beam Section

7. Conclusions

A new passive control system consisting of a visco-elastic hysteretic damper to be installed in a moment resisting connection in a steel structure was presented in this paper. It consisted of a number of vertical steel bolt cores for accommodating the hysteretic energy dissipation capacity and a horizontal rubber layer for providing a visco-elastic behavior and a restoring force after a large earthquake. The bolt cores extended between the bottom flange of the beam and a T-section seat through a supplemental I-beam. The energy dissipation capacity of the system was shown to be desirable with implementing a pseudo static test on a connection sample used also for a verification analysis of the analytical model. A comprehensive parametric study on 14 sample connections resulted in recommending suitable ranges of parameters for design purposes of the proposed damper.

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