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Seismic evaluation of steel structures retrofitted with supplemental elliptical damper

S. A. Mohebi [1], S. M. Zahrai [2]*, R. Raoufi [1]

[1] Department of Civil Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran.
[2] School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran.

ABSTRACT: In the recent past, the application of various types of passive dampers (e.g., yielding metallic dampers) has become a common practice for improving seismic performance of the under-construction buildings and rehabilitation of existing constructions. In this study, a new elliptical metallic damper was introduced to improve the seismic behavior of existing steel structures. Among other parameters, geometrical characteristics are known to affect the seismic performance of the constructions rehabilitated with the proposed elliptical damper. Accordingly, the performance of the proposed damper was investigated through accurate numerical studies on various types of dampers considering various damper dimensions, ellipse major and minor axes length-to-plate thickness ratios, and placements of elliptical shear diaphragm. To study the proposed elliptical damper in terms of its effect on the seismic behavior of rehabilitated buildings, three benchmark structures with 3, 9, and 20 stories were used. Further, far-field and near-field earthquake records were used to undertake nonlinear dynamic analyses. In this work, the proposed elliptical damper was verified by the Abaqus finite-element software, and nonlinear time-history analyses were conducted in the SAP2000 software to check for seismic performance of rehabilitated structural frames with the considered damper. Results of the nonlinear dynamic analyses indicated the appropriate performance of the proposed elliptical damper in terms of reducing the seismic responses of the rehabilitated structures and suitable behavior of the proposed elliptical damper in dissipating the imposed earthquake energy to the structures. Based on these results, upon rehabilitation with the proposed damper, the 3-, 9-, and 20-story structures exhibited smaller maximum lateral roof displacements by 66, 64, and 31%, respectively..

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1- Introduction

Passive structural control systems represent one of the best approaches to establish safety and improving seismic performance of a building. The application of energy dissipation systems is very efficient for this purpose, as is recently regarded by researchers and structural design engineers. With no need to any external source of energy or complex mechanical and/or electronic systems, passive control systems offer easy-to-implement and economically efficient solutions, making them classified as one of the top instruments for reducing adverse impacts of dynamic forces on structures. Yielding metallic dampers are among the most common passive energy dissipation systems, which have long been a hot topic to researchers in the field of structural control because of their simple design, easy construction, stable behavior against lateral loads applied to the structure, and tolerance to environmental factors. Being displacement-dependent dampers in nature, the yielding metallic dampers can desirably dissipate the input energy to the structure due to their robust yielding character and the inelastic behavior of the metals.

Maleki and Bagheri [2 ,1] studied the behavior of hallow and concrete-filled steel pipes to investigate their applicability as a seismic hysteresis damper under shear stress. Analytical results showed that the stiffness and strength of the pipe dampers increase linearly and nonlinearly with the pipe length and thickness, respectively, and decrease with the pipe diameter nonlinearly.

Cheraghi and Zahrai presented a composite system of two independent passive control instruments with different strength and stiffness levels. This yielding damper was made up of multiple coaxial steel pipes of various diameters. The obtained hysteresis curves showed that the proposed damper behaved at multiple levels, therefore dissipating energy at different seismic levels [3]. In another piece of work, Zahrai and Cheraghi tested a multi-level pipe damper. Application of this multi-level system in steel structures showed that the seismic demand of the rehabilitated structures decreases with the help of these dampers [4].

*Corresponding author's email: mzahrai@ut.ac.ir

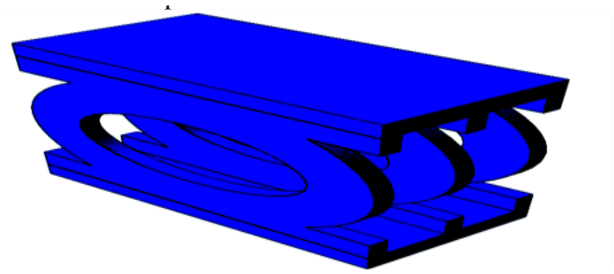

Fig. 1. Demonstration of the proposed elliptical damper.

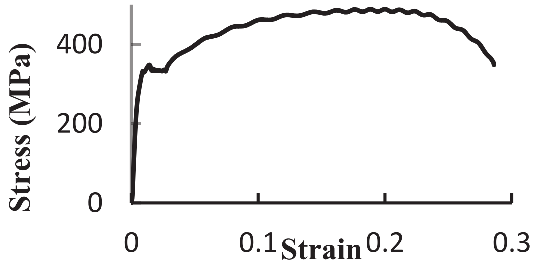

Fig. 2. Stress–strain curve of used steel

In the present work, numerical analyses were conducted in Abaqus, and ranges were proposed for effective geometrical parameters of the yielding damper to ensure the formation of plastic hinge in the proposed elliptical damper. In addition, given the selected elliptical geometry of the proposed damper, various axis lengths (within the proposed ranges for the geometrical parameters) were considered to provide the designer with more options for seismic retrofit, as compared to other types of dampers.

To investigate the seismic behavior of the 3-, 9-, and 20-story benchmark frames, dynamic analyses were performed under far- and near-field earthquake records in different areas with different seismicity levels before and after rehabilitating the frames with the proposed elliptical yielding damper. The analyses were based on lateral roof displacement, inter-story drift, and energy dissipation capacity.

An elliptical yielding damper is composed of vertical and horizontal steel plates. The vertical plates of the proposed damper, which includes elliptical rings, yield under the effect of the lateral displacements due to the formation of plastic hinges, thereby dissipating the induced earthquake energy. The horizontal plates on the top and base of the damper, however, serve as support to the middle part (vertical plates) of the damper, not to mention their role in connecting the damper to the beam and bracing system, as observed in Fig. 1. A major advantage of elliptical dampers compared to circular plates is the variable nature of the ellipse axis lengths, which provides the structural designer with more options compared to the case with circular dampers.

2- Methodology and Analysis

Firstly, the model of the proposed elliptical damper was verified in the Abaqus finite-element software by comparing the numerical results to the experimental data published by Ebadi *et al.* [5], with the results successfully verifying the modeling output of the Abaqus software. The stress-strain curve of the steel material used in the modeling of the proposed elliptical damper was obtained by performing tensile tests on standard samples of the steel plate experimentally (Fig. 2).

In this research, the elliptical rings of the yielding damper with different thicknesses were modeled in the Abaqus software. In this research, seismic assessment of the structures equipped with the proposed yielding dampers was performed on the three benchmark structures presented by Ohtori *et al.* with 3, 9, and 20 stories *[6]*. Using the link element in the SAP2000 software, characteristics of the proposed elliptical damper were applied to the structural frames, and the output hysteresis curve from the SAP2000 software for the Wen nonlinear element was compared to the curves obtained from the Abaqus software. The comparison indicated that the two software tools exhibited very close results, as observed in Fig. 3.

In this paper, optimal lateral stiffness distribution over structure height was adopted to achieve uniform relative displacement at stories. Then, nonlinear time-history analysis was performed to study the effect of the applied retrofit by the proposed elliptical damper on the structures in the SAP2000 software. The earthquake records used in the study by Ohtari *et al.* include near- and far-field accelerograms.

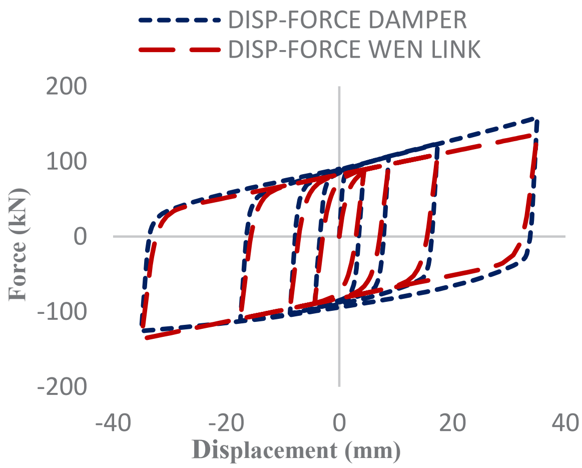

Fig. 3. Comparison of hysteresis curves from the Abaqus and SAP2000 software

3- Conclusion

Results of this research can be classified under two broad categories. In the first category, 16 elliptical rings were modeled in the Abaqus finite-element software and subjected to accurate numerical modeling. Outputs showed that horizontal placement of the elliptical rings (HED) with a longer width improved the damper performance in terms of lateral stiffness, yield strength, and energy dissipation capacity. In the second category, the characteristics obtained from the finite-element method, including effective stiffness and yield strength, were declared in the SAP2000 software by means of the Wen nonlinear link element. Subsequently, the 3-, 9-, and 20-story structures were compared before and after rehabilitation with the proposed elliptical damper based on nonlinear analysis under near- and far-field earthquake records.

Results showed that, on average, the use of the proposed elliptical damper reduced maximum inter-story drift of the 3-, 9-, and 20-story structures by 71, 78, and 51%, respectively, while decreasing the maximum lateral roof displacement by 66, 64, and 31%, respectively, dissipating 62, 63, and 84% of the input energy to the structure.

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