Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(2) (2021) 159-162
DOI: 10.22060/ceej.2021.16557.6267

Numerical study of arch corner brace segments in simple steel frames to provide seismic resisting system

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ABSTRACT: Braced and rigid frames are the most typical systems that are used to resist lateral loads. Typical braced frames, in comparison with rigid frames, have higher stiffness they have low ductility. On the other hand, rigid frames have high ductility but due to their low lateral stiffness, they maintain large displacements throughout the earthquake, which is not favorable. Furthermore, in rigid frames, the beam to column connection is a critical area that often experiences damage during the earthquake. In this research, the objective is to create a lateral load-carrying system and improve the seismic performance of steel frames using the placement of arch segments cut of steel plates at the corner of simple steel frames and they are yielding. Due to the eccentricity, these components are subjected to an interaction of axial and flexural forces and like yielding dampers absorb the major part of the input energy. In this study, first, the hysteresis curve of arch segments made by ST37 steel was achieved using finite element software, ABAQUS. Then this damper was modeled in SAP software to create the same hysteresis curve. Then, 3, 6, and 9-story bare rigid frames and simple frames with arch segments were modeled and subjected to time-history analysis of 12 different earthquakes. Based on achieved results, maximum roof displacement and maximum story drifts of frames, in simple frames with arch segments compared to bare rigid frames in average reduced 22 and 8%, respectively. Also in simple frames with arch segments on average 46% of input energy was absorbed by arch segments that indicate the relatively good performance of this system.

Review History:

Received: 6/15/2019
Revised: 8/9/2020
Accepted: 11/13/2019
Available Online: 1/29/2021

Keywords:

Lateral load-carrying system
arch segments
rigid frame
time-history analysis
energy dissipation

1. INTRODUCTION

In recent years, due to the need for high-performance structures, vibration control of the structure has been considered by researchers. Metallic dampers are among the passive control devices whose mechanism is based on plastic deformations of steel [1] and due to their low cost and high reliability, they have been studied by many researchers. These types of dampers act like fuses, meaning they absorb input energy and prevent damage to the main members of the structure. The original idea of using yielding metal dampers in the structure was proposed in 1972 by Kelly et al. [2] and in 1974 by Skinner et al. [3].

Rigid frames are among the common lateral resisting systems which have high ductility. On the other hand, concentrically braced frames have good lateral stiffness, but due to the brace buckling, they have low ductility and energy dissipation capacity.

As mentioned earlier, one of the main problems of the bracing system was the brace buckling. Another approach suggested by the researchers to solve this problem was the use of crescent-shaped braces. In 2009, Trombetti et al. [4] introduced a new hysteretic member called the crescent-shaped brace. In 2015, Palermo et al. [5] studied the crescent members alone and then conducted comprehensive experimental research in this regard [6]. In 2017, Kammouh et al. [7] also evaluated the performance of crescent members and their application in multi-story structures with shear performance. The idea of using metal handles in the corners of the frame and between the beams and columns [8] was introduced after the 1994 earthquake to repair rigid steel frames.

In 2017, Hsu and Halim [9] proposed the use of curved dampers. The curved dampers are cut from steel plates. This type of damper, as in Fig. 1., due to the presence of eccentricity, yields axial and flexural forces and dissipates the incoming energy. They used this damper in the corners of the frame with semi-rigid joints as depicted in Fig. 1., and showed through numerical and experimental study that the stiffness, strength, performance, and energy dissipation of these frames are significantly improved.

In this research, for the first time, the idea of using arch-shaped corner brace segments in frames with simple joints is investigated and the performance of the proposed system compared to conventional rigid frames is evaluated using time-history analysis in multi-story frames. For this purpose,

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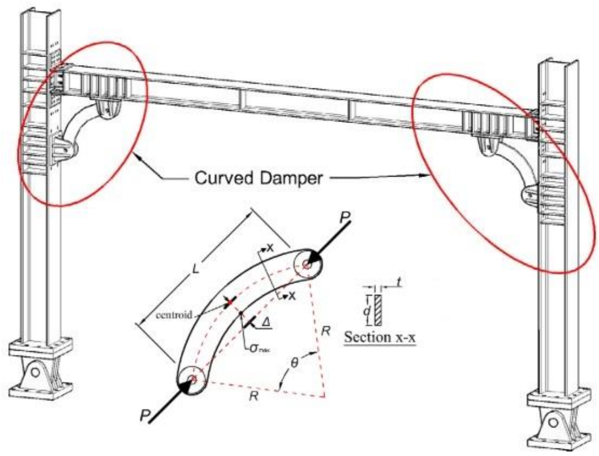

Fig. 1. Application of curved dampers in frames with semi-rigid joints [9]

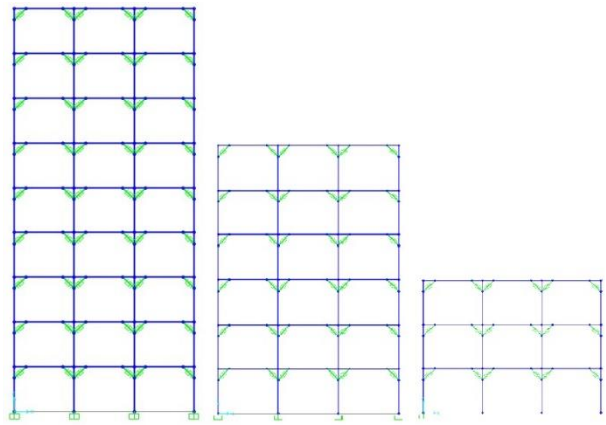

Fig. 2. Modeling for simple frames with arch corner brace members

first, the hysteresis curve of the arch segment is obtained using ABAQUS [10] finite element software and then these parts are modeled in SAP software using the curve obtained from ABAQUS software. Finally, multi-story rigid frames and simple frames with arch segments are modeled in SAP [11] software and subjected to time-history dynamic analysis.

2. ARCH SEGMENTS MODELING AND VALIDATION

To start modeling, the first arch segment was modeled in ABAQUS finite element software. The "solid-3D" element was used to model this member and was subjected to quasi-static analysis. o validate the results obtained from ABAQUS software, the arch segment hysteresis curve in the experimental work of Hsu and Halim [12] was obtained using the software and compared to the experimental curve. The arch member was then modeled alone using nonlinear links in SAP software. The results obtained from ABAQUS software were used for modeling. Cyclic curves were extracted for each of the links. The model whose results most closely resembled the ABAQUS model, the "Wen" model, the selected for the rest of the study.

3. MODELING AND ANALYSIS OF FRAMES IN SAP SOFTWARE

In the continuation of this study, rigid frames and simple frames with arch segments are modeled in SAP software. The modeled frames have 3, 6 and 9 stories with a height of 3 meters and 3 spans of 4 meters. For this purpose, first the rigid frames are modeled and according to the 2800 standard and assuming the type III soil and the zone with very high relative seismic risk, the initial sections for use in the frames are obtained by determining the seismic forces by the statically equivalent method. Then, each frame is modeled with simple joints and arch segments as in shown in Figure 2. In modeling of the frames, plastic joints were used by ASCE 41-13 [13] for beams and columns. The six frames are then studied using time-history analysis with 12 different earthquake records. In the time-history analysis used, to consider the nonlinear behavior of the defined plastic joints, the direct integration solution method is used.

After analysis, roof displacement, relative story displacement percentage, energy applied to the frame, and energy dissipated by arch segments are extracted for all six frames under different earthquakes, and in the case of a single rigid frame and simple frame with arch segments, are compared.

4. CONCLUSIONS

Rigid frames have high ductility but due to low lateral stiffness during large earthquakes show large displacements that are not desirable. Also, in rigid frames, the beam-to-column connection area is a critical area that often fails when lateral loads are applied. In this paper, the performance of steel frames is improved by the yielding of arch-shaped corner brace members cut from steel plates. For this purpose, first, the hysteresis curve of the desired arch member with ST37 steel was obtained using ABAQUS finite element software and then this member was modeled in SAP software by matching the obtained hysteresis curve. Then, the 3, 6, and 9-story rigid frames and the corresponding simple frames with the arch members were modeled and subjected to dynamic analysis using the time history of different earthquakes.

Based on the obtained results, the simple frame with arch segments has a more desirable seismic performance than the rigid frame alone. In this study, the parameters of maximum roof displacement, maximum relative story displacement percentage, and input energy and energy dissipation rate by arch segments were investigated. According to the obtained results, the maximum displacement of the roof and the relative displacement of the stories were reduced by 22 and 8% on average in the simple frames with arch segments compared to the single rigid frames, respectively. The results also showed that in simple frames with arch segments, on average 46% of the input energy is dissipated by arch members.

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HOW TO CITE THIS ARTICLE

N. Abbasmaram, S.M. Zahrai, Numerical study of arch corner brace segments in simple steel frames to provide seismic resisting system, Amirkabir J. Civil Eng., 53(2) (2021) 159-162.

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