Optimal distribution of connections with dampers to improve the performance of steel moment frames

Amir Mohammad Rabbani[1], Seyed Mehdi Zahrai[*2]

1- MSc Student, School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran.

2- Professor, Faculty of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran.

Abstract

To reduce the seismic response of steel frames, energy dissipating devices can be placed at connections. These connections can be modeled as a rotational spring and damper in parallel. In this paper, an attempt is made to estimate the best distribution of the connections, by time-history analysis and optimization operation. Although in the previous studies, these connections were distributed uniformly, in this research the combination of these connections in moment frames is proposed. Two 9 and 20-story frames with sections and dimensions based on SAC benchmark structures are studied. The seismic performance of optimized structures with connections equipped with dampers and rigid connections is evaluated and compared to that of the moment frame with uniformly placement of such connections. It is observed that the performance of hybrid structures, despite having fewer dampers in connections, is much better than the structure with uniform distribution of this type of connection. On the other hand, linear and nonlinear behavior of elements and connections in structure is developed. Also, in optimal conditions, 62 and 68% of the connections in linear and 58 and 61% in nonlinear behavior have been equipped with dampers respectively for 9 and 20-story structures.

Keywords

Semi-rigid connections, Rigid connections, Viscoelastic dampers, Optimum distribution, Particle Swarm algorithm

[*] Corresponding Author: Email: mzahrai@ut.ac.ir

Introduction

Different types of connections have been proposed and tested during recent years to reduce damage and structural response against earthquakes or other distractive natural disasters. Although the prequalified beam-to-column connections in codes are considered useful tools for decreasing damage in structural elements and having an appropriate behavior against cyclic loads, connections with high ductility and desirable strength are usually hard to achieve. Therefore, many researchers worked on some beam-to-column connections which are equipped with different types of dampers (connection dampers). Fig. (1a) illustrates elastomeric bolted connections by two elastomeric pads and a shear pin that is proposed by Hsu and Faftis [1].

Some others just placed viscoelastic materials between the angle and beam flanges as revealed in Fig. (1b). Many studies in this context can be listed in references [2, 3]. However the combination of different types of connections, especially for semi-rigid and rigid connections, is suggested as an efficient approach to reduce structural response [4]. One of the important challenges is to find the best position for distributing connections equipped with dampers on the structure. To address this problem, optimization algorithms can be utilized.

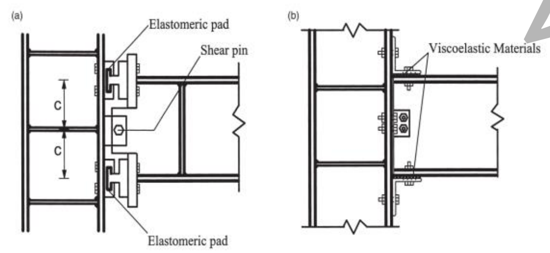

Figure 1) Beam-to-column connection with energy dissipation devices a) Elastomeric pad b) Viscoelastic material [5]

To investigate the performance of the hybrid structures whose connections are rigid and equipped with dampers, this paper employed an optimization algorithm (Particle swarm optimization, PSO) to find the best position for the connection dampers and their optimum properties to reduce structural response. The objective function is considered as a combination of the base shear of the structure and the maximum displacement of the roof. Two 9 and 20-story frames with sections and dimensions based on SAC benchmark structures are studied. The performance of structures compared to each other under three conditions with linear and nonlinear behavior: the first type is a structure with rigid connections. The second type is a structure with a distribution of connection dampers and rigid connections, and the third one is a structure in that whole connections are equipped with dampers. The results showed that the second one outperforms other types of structure in terms of the objective function.

Methodology

Numerical model

The structures that are used in this paper, were designed by Brendo and Johnson [6] for the second phase of the SAC project. Beam and column elements and support conditions are considered as main models, but the connections are designed in this work. Linear and nonlinear behavior of elements and connections are developed. The connection behavior is modeled by a Kelvin-Voigt element, consisting of a rotational spring and a dashpot connected in parallel. Initial stiffness is derived using Eq 1. To introduce the nonlinear behavior of the connection, the suggested bilinear model in [4] is employed and the plastic stiffness is considered as a ratio of initial stiffness. Beams with connection dampers modeled as illustrated in Fig 2.

$$K = \frac{3EI}{L}\frac{\nu}{1-\nu} \qquad (1)$$

Where E, I, and L are the elasticity modulus, moment of inertia, and length of the beam. ν represents the fixity of connection at the end of the beam which can be in the range of zero (for pin connections) to one (for rigid connections).

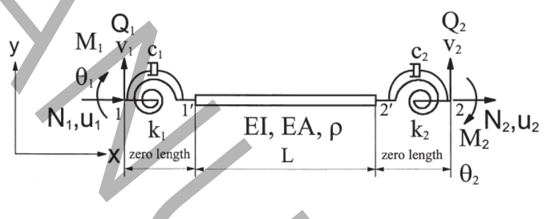

Figure 2 Beam element with rotational spring and damper at its end [5]

PSO algorithm

Particle swarm optimization inspired by the communicational movement of birds is one of the popular and well-known metaheuristic optimization algorithms which was first introduced by Kennedy and Eberhart [7]. The implementation of the PSO algorithm is simple. In the first step, the objective function should be defined. The algorithm uses the particles to move in the search space and investigate the best solution. Each particle remembers its best experience and cooperates with the others to find the best experience in society. The new location of each particle is determined by a velocity term that represents the attraction of global and its own best.

Objective function

Although for considering the structural response, features such as input energy or acceleration of each story can be utilized, in this paper two response characteristics including base shear and maximum displacement of the roof were employed to consider the influence of both criteria of strength and ductility. The objective function is defined as follows:

$$\frac{V}{V_1} + \frac{D}{D_1} \qquad (2)$$

Here V_1 and D_1 represent base shear and maximum displacement of the roof in a structure with rigid connections, respectively. V and D denote base shear and maximum displacement of the roof in a structure with optimal connection in terms of position and its properties.

Earthquake records

Three records utilized for analysis in this work, are selected among far-field records that are introduced in FEMA-P695 [8]. The used records are listed as follows: the Landers 1992, Northridge 1994, and Kobe 1995 earthquakes.

Conclusion

In this paper, responses of two 9 and 20-story hybrid structures under earthquake were investigated. Also, the PSO algorithm was employed to optimize the location, stiffness, and damper damping coefficient of connections equipped with dampers in each structure. The performance of hybrid structures with connection dampers and rigid connections was compared to those of structures having rigid connections and uniform distribution of connection dampers individually. The results explain as follows:

1. It was observed that the best fixity factor in connection for each structure is the less one that is considered. In this study, the less initial stiffness for connections leads to a better response.

2. In the average of three earthquake records, about 62 and 58 percent of beams in 9-story and 68 and 61 percent of beams in 20-story structure were equipped with connection dampers in two linear and nonlinear cases respectively during optimization operations while the other beams had rigid connections. Consequently, the number of beams whose connections were equipped with dampers was not significantly altered by changes in the height and spans of structures. Also considering the nonlinear behavior of elements in analysis leads to decreasing number of beams equipped with connection dampers that reduce the construction costs.

3. With the optimal distribution of connection dampers, damper damping coefficient, and fixity factor for the seismic responses, including maximum lateral displacement of roof and base shear which were investigated in this study, could considerably reduce to a level smaller than those of the frame with rigid connections and uniform distribution of optimal connection dampers.

4. For any distribution of connection dampers in the structures, there is an optimum damper damping coefficient which reduces the structural response.

5. Taking into account uncertainty in seismic records, a specific pattern in structures for the distribution of connection dampers could not be found.

References

[1] S.-Y. Hsu, A. Fafitis, Seismic analysis design of frames with viscoelastic connections, Journal of structural engineering, 118(9) (1992) 2459-2474.
[2] A. Banisheikholeslami, F. Behnamfar, M. Ghandil, A beam-to-column connection with visco-elastic and hysteretic dampers for seismic damage control, Journal of Constructional Steel Research, 117 (2016) 185-195.
[3] M. Saeidzadeh, M.R. Chenaghlou, A.A. Hamed, Experimental and numerical study on the performance of a novel self-centering beam-column connection equipped with friction dampers, Journal of Building Engineering, 52 (2022) 104338.
[4] M. Bayat, S.M. Zahrai, Seismic performance of mid-rise steel frames with semi-rigid connections having different moment capacity, Steel Compos. Struct, 25(1) (2017) 1-17.
[5] Y.L. Xu, W. Zhang, Modal analysis and seismic response of steel frames with connection dampers, Engineering structures, 23(4) (2001) 385-396.
[6] A. Gupta, Seismic demands for performance evaluation of steel moment resisting frame structures, Stanford University, 1999.
[7] R. Eberhart, J. Kennedy, A new optimizer using particle swarm theory, in: MHS'95. Proceedings of the sixth international symposium on micro machine and human science, Ieee, 1995, pp. 39-43.
[8] A.T. Council, Quantification of building seismic performance factors, US Department of Homeland Security, FEMA, 2009.