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Multi-objective seismic design method for ensuring beam-hinging mechanism in steel frames

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ABSTRACT

Previous research efforts have shown that the column-beam flexural strength ratios of joints in moment resisting steel frames should be higher than 1.0 or even 2.0 for a beam-hinging collapse mechanism. However, it has been pointed out that, in order to prevent a weak story mechanism in a structure, it is not practical to use a specific single value as a limit for the column-beam flexural strength ratio for all joints of a structure. Therefore, an optimal design technique is needed to determine the column-beam flexural strength ratios for joints in a structure. In this paper, a multi-objective seismic design method for ensuring beam-hinging mechanism in steel moment resisting frame structures is presented and applied to optimal seismic design of well-known steel moment frames. In addition to the constraint for ensuring beam-hinging mechanism, the relationship between the structural cost and the energy dissipation capacity of structures is provided by considering the two conflicting objective functions. In order to select the best design among the candidate designs, as a guide for structural engineers, a simple rule is presented in the form of dissipated energy density defined by the ratio of the energy dissipation capacity to the structural weight.

1. Introduction

Seismic design criteria currently used in several countries such as KBC 2005 [1] and ANSI/AISC 341-05 [2] allow the plastic deformation of structures caused by seismic loads. Seismic designs enable plastic behavior to dissipate seismic energy and use relatively smaller seismic loads since a structure designed to maintain its elastic state during an earthquake is far from being optimum or efficient design. Moreover, for a severe earthquake, ductile behavior of a structure can reduce the repair cost and human injuries by preventing a sudden collapse of the structure.

A moment resisting frame is a simple seismic-resistant system consisting only of beams and columns with rigid beam-to-column joints that secure flexural rigidity. It features advantages such as excellent ductility and variety of architectural planning and, thus, is being widely used in several countries. As it has rigid beam-to-column joints, a moment frame experiences lateral deformations through flexural behavior of columns and beams when an earthquake occurs. Due to such behavioral characteristics, flexural rigidity and strength of members are important factors in determining the overall behavior of a frame structure [3].

Depending on the design of flexural rigidity and strength of the member, damage to the structure can be alleviated by forming plastic hinges only at beams as illustrated in Fig. 1(a), or plastic hinges can be formed at the both ends of all columns supporting a specific story which induces a sudden failure as described in Fig. 1(b). Dooley and Bracci [4], Medina and Krawinkler [5], and Nakashima and Sawaizumi [6] discuss why the column-beam flexural strength ratios of joints should be higher than 1.0 or even 2.0 for a beam-hinging collapse mechanism. In ANSI/AISC 341-05 [2], the strong column-weak beam condition is specified to reduce the possibility of column failures that lead to a sudden collapse of the overall structure. However, Kuntz and Browning [7] pointed out that, in order to prevent a weak story mechanism in a structure, it is not practical to use a specific single value as a limit for the column-beam flexural strength ratio for all joints of a structure. Consequently, an optimal design technique is needed to determine the column-beam flexural strength ratios for joints in a structure.

Also, Moghaddam et al. [8] and Xu et al. [9] showed that an even distribution of inter-story drifts can enhance ductility of a structure and reduce seismic damage. For such reasons, several researchers have proposed techniques that can evenly distribute the inter-story drifts of a structure caused by an earthquake as given in Fig. 1(a). Leelataviwat et al. [10] proposed a new design technique that can evenly distribute the inter-story drifts by dissipating the seismic energy through the plastic-hinge collapse mechanism of beams. Xu et al. [9] suggested a performance-based optimization seismic design technique that minimizes the coefficient of variation of inter-story drifts and the weight of a structure using an optimality criteria-based algorithm. However, design alternatives obtained from the methods for minimizing the magnitudes or variations of inter-story drifts cannot guarantee to improve the initial stiffness and the energy dissipation capacity of a structure.

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