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Seismic retrofit of special truss moment frames using viscous dampers

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ABSTRACT

The special truss moment frame (STMF) is known to provide higher lateral stiffness with relatively less weight as compared to conventional moment resisting frames. In this study the seismic performance of STMF was investigated by fragility analyses and the results were compared with the performance of special moment resisting frames. Then seismic retrofit scheme was proposed by installing a viscous damper in the special segment to meet enhanced seismic performance objective. The required amount of additional viscous damping was determined based on the nonlinear static procedure provided in the ASCE/SEI 41-10. The analysis results showed that the STMF showed larger stiffness and strength but smaller ductility compared with the moment frames, which resulted in similar seismic fragility in both structures. The seismic performance of STMF with viscous dampers in the special segments turned out to meet the desired target performance, and the effect of adding viscous dampers in the seismic fragility was most significant in the complete damage state.

1. Introduction

The special truss moment frame (STMF) is a seismic load-resisting system that consists of horizontal truss floor beams with specially designed segments that are expected to act as seismic fuses. This framing system is known to provide higher lateral stiffness with relatively less weight as compared to conventional moment resisting frames. Basha and Goel [5] proposed seismic design criteria for the system and carried out experimental study of the STMF system with vierendeel middle segment. They found that the system results in increased economy and inelastic deformation capacity compared with other conventional framing systems. Chao and Goel [6] provided a performance-based plastic design procedure in which the seismic energy demand is balanced with the hysteretic energy dissipation in the special segments. Jordan et al. [13] analyzed STMF systems subjected to seismic load, and proposed modified design procedure for special segments introducing pin connections to the chord members. They found that, compared with conventional STMF systems, significant reduction in axial, shear, and bending moments could be achieved by introducing pin connections. Chao and Goel [6] employed the plastic design method to design chord members in the special segment. They also presented a direct performance-based plastic design method based on an energy concept and plastic design method which requires no iterative evaluation. The procedure begins by selecting a desired yield mechanism for the structure, and the design base shear and lateral forces are determined from spectral energy for a given hazard level. Then the frame members are designed by following the plastic design method. Pekcan et al. [18] proposed a special truss moment frame (STMF) with a buckling restrained brace in a special segment combined with introduction of pin connections at the ends of chord members. The proposed system was

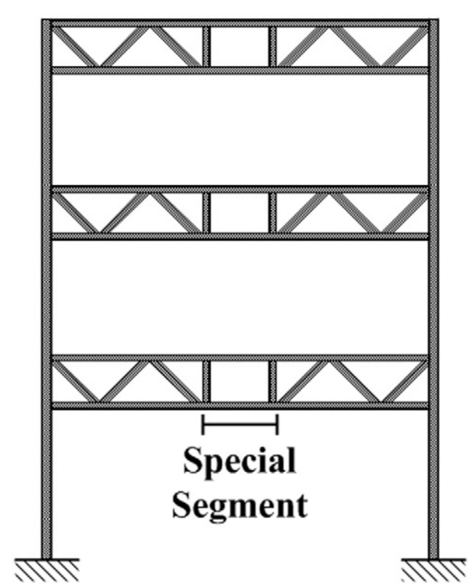

Fig. 1. Typical configuration of a STMF.

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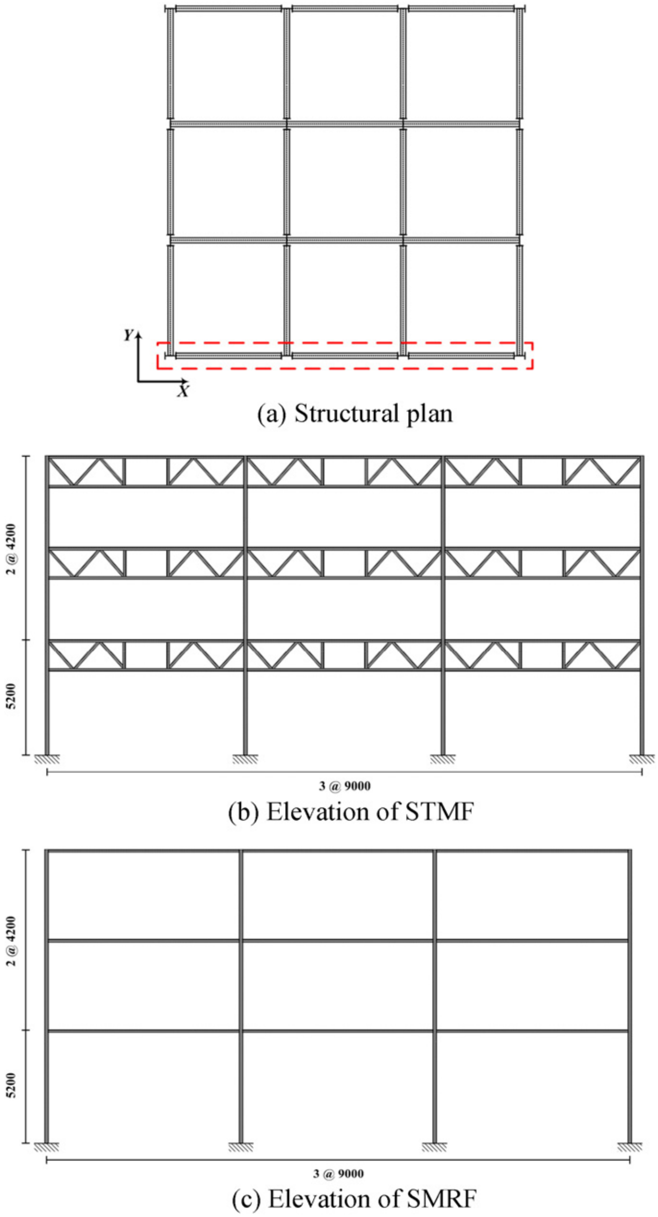

Fig. 2. Configuration of analysis model structures.

found to show more predictable seismic response and cost savings due to reduced member forces. Ölmez and Topkaya [17] carried out finite element analysis of STMF and found that the expected shear strength formulation presented in the AISC Seismic Provisions for Structural Steel Buildings was overly conservative. Based on the analysis results they proposed a new expected shear strength formula for STMF. Pekcan et al. [19] proposed a design procedure of special truss moment frame (STMF) with a buckling restrained brace in a special segment based on the performance-based plastic design procedure. In their study the chord members in the special segments were assumed to be pin connected and the diagonal BRBs were designed to dissipate all seismic input energy. Kim and Park [15] investigated the progressive collapse potential of the special truss moment frames and proposed a design procedure to provide an alternate load path in the case of sudden column removal. It was shown that the model structures redesigned using the developed design procedure turned out to remain stable after a column was suddenly removed. Recently, Heidari and Gharehbaghi [12] proposed a new configuration of STMF systems including buckling resistant braces located at the side of beam-column connections as the top and bottom members of truss-girders. They showed that the proposed configuration of STMF with buckling resistant braces improved the seismic safety of STMF. Currently, STMF is considered as one the seismic force-resisting systems in the ASCE 7-13 [3], and the design process is provided in the ANSI/AISC 341-10 specification [1].

Viscous dampers have been widely used to mitigate earthquake induced damage of structures effectively. Lavan and Levy [16] carried out performance based optimal seismic retrofitting of yielding plane frames using added viscous damping devices. They derived the gradients of the constraints with respect to the damping coefficients via optimal control theory, and obtained the optimal solution by assigning damping only to stories for which the local performance index has reached the allowable value. Silvestri et al. [24] investigated seismic design procedure of a precast RC structure equipped with viscous dampers. They confirmed the effectiveness of viscous dampers as compared with traditional lateral-resisting stiff braces for the seismic design of precast concrete structures. Kim et al. [14] investigated the feasibility of using viscous dampers for preventing progressive collapse of building structures. They found that the viscous dampers, designed to reduce earthquake-induced vibration, were effective in reducing vertical displacement of the structures caused by sudden removal of a column. Serror et al. [23] proposed the seismic force reduction factor for steel moment resisting frames with supplemental viscous dampers. A parametric study was performed using time history analyses and the N2-method, and an equation was proposed for reduction factors based on regression analysis. Recently, Farghaly et al. [11] investigated the seismic performance of two adjacent buildings with different heights connected with viscous dampers. They found that the response of connected structures system founded on soft soil is more critical than those founded on stiff soil. Tzimas et al. [26] carried out seismic design and assessment of steel self-centering moment-resisting frames (SC-MRFs) with viscous dampers within the framework of Eurocode 8 (EC8) and showed that the SC-MRFs with viscous dampers have superior collapse

Table 1
Member sizes of STMF model structures.

		Conner columns	Exterior columns	Exterior chords	Exterior diagonal member	Exterior vertical member
3-story	1F	W10 × 68	W14 × 176	2 L5 × 5 × 5/8 × 3/8	2L3 × 3 × 5/16 × 3/8	2L8 × 8 × 5/8 × 3/8
	2F	W8 × 67	W12 × 120	2 L5 × 5 × 1/2 × 3/8	2L3 × 3 × 1/4 × 3/8	2L6 × 6 × 5/8 × 3/8
	3F	W8 × 31	W10 × 100	2 L4 × 4 × 1/2 × 3/8	2L2 − 1/2 × 2 − 1/2 × 1/4 × 3/8	2L5 × 5 × 3/8 × 3/8
10-story	1F	W14 × 257	W14 × 730	2L6 × 6 × 7/8 × 3/8	2 L3 − 1/2 × 3 − 1/2 × 3/8 × 3/8	2L8 × 8 × 1 − 1/8 × 3/8
	2F	W14 × 176	W14 × 370	2L6 × 6 × 3/4	2 L3 − 1/2 × 3 − 1/2 × 3/8 × 3/8	2L8 × 8 × 1 × 3/8
	3F	W14 × 159	W14 × 342	2L6 × 6 × 7/8 × 3/8	2 L3 − 1/2 × 3 − 1/2 × 3/8 × 3/8	2L8 × 8 × 1 × 3/8
	4F	W14 × 132	W14 × 311	2L6 × 6 × 3/4 × 3/8	2 L3 − 1/2 × 3 − 1/2 × 3/8 × 3/8	2L8 × 8 × 1 × 3/8
	5F	W14 × 109	W14 × 283	2L6 × 6 × 5/8 × 3/8	2 L3 − 1/2 × 3 − 1/2 × 5/16 × 3/8	2L8 × 8 × 7/8 × 3/8
	6F	W14 × 90	W14 × 257	2L6 × 6 × 9/16 × 3/8	2 L3 − 1/2 × 3 − 1/2 × 5/16 × 3/8	2L8 × 8 × 7/8 × 3/8
	7F	W12 × 79	W14 × 233	2L5 × 5 × 5 / 8	2 L3 − 1/2 × 3 − 1/2 × 5/16 × 3/8	2L8 × 8 × 3/4 × 3/8
	8F	W10 × 68	W14 × 193	2L5 × 5 × 1/2 × 3 / 8	2L3 × 3 × 5/16 × 3/8	2L8 × 8 × 7/8 × 3/8
	9F	W8 × 48	W14 × 132	2L4 × 4 × 5/8 × 3 / 8	2L3 × 3 × 1/4 × 3/8	2L6 × 6 × 5/8 × 3/8
	10F	W8 × 48	W10 × 88	2L4 × 4 × 7/16 × 3 / 8	2 L2–1/2 × 2–1/2 × 1/4 × 3/8	2L5 × 5 × 7/16 × 3/8