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Comparison of chevron and suspended-zipper braced steel frames

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ABSTRACT

Suspended-zipper braced frame is a modified configuration of chevron braced frame in which zipper columns are added between story beams and a hat truss is attached between top two stories in order to redistribute the unbalanced vertical forces emerging following the brace buckling to avoid the use of deep beams. In this study, three- and nine-story chevron and suspended-zipper braced frames are analyzed to compare their seismic performances. The beams, columns, braces and zipper columns are modeled using nonlinear force-formulation frame elements and nonlinear geometric effects are included by utilizing corotational transformation. Nonlinear static analyses are performed until reaching a roof drift ratio of 3% and a set of twenty ground motion records scaled to match a 10% probability of exceedance in 50 years is used for nonlinear time-history analysis. The results appear to indicate that the lateral load capacity and drift demands for both low-rise chevron and suspended-zipper braced frames are very similar; however, the mid-rise chevron braced frame has a better performance compared to the mid-rise suspended-zipper braced frame.

1. Introduction

Chevron braced steel frame, also known as inverted-V braced frame (IVBF), is a concentrically braced frame (CBF) configuration commonly used in practice [Fig. 1(a)]. Primarily resisting the lateral load with truss action, the IVBF provides very high lateral elastic stiffness and strength [1]. In each story of a braced bay, one of the braces resists the lateral load in tension and the counter one resists in compression. In the elastic range, i.e., before the buckling of the compression brace, the braces share the lateral load equally; as a result, the resultant of the brace forces has only a horizontal component. After the buckling, the compression brace loses most of its axial load capacity while the tension brace retains it, which results in an unequal distribution of the lateral force between the braces. Due to the unequal distribution of the lateral force, a vertical component emerges in addition to the horizontal component of the resultant of the brace forces [Fig. 2]. This vertical force causes a large bending moment demand in the intersecting beam that might cause a plastic hinge at the mid-span of the beam, soft-story formation and collapse. To avoid these undesirable failure modes, the AISC Seismic Provision [2] requires the beam to be designed in accordance with the outlined capacity design rules which generally results in heavy and deep beams.

To avoid the use of deep and heavy beams, adding struts between the story beams was proposed by Khatib et al. [3] to transfer the vertical forces emerging after the buckling of the compression braces to the adjacent story braces that still retain their axial load capacity. Another advantage of this configuration, called zipper braced frame (ZBF), is that the redistribution of the forces between the stories also leads to the redistribution of the deformation demands, which results in more uniform drift demands and inelastic action along the frame height. The main drawback of this configuration is that when all the story compression braces buckle, the unbalanced vertical forces need to be transferred to the columns by the story beams, which will form plastic hinges in the beams; as a result, the frame might collapse [4]. To overcome this stability and potential collapse problem, Leon and Yang [5] added a suspension system, called hat truss, between the top two stories which is to be designed to remain elastic when the braces and zipper columns reach their ultimate capacity. This CBF configuration is called suspended-zipper braced frame (SZBF) [Fig. 1(b)]. In addition to having a uniform drift demand distribution along the frame height and avoiding the use of deep beams, another advantage of the SZBF is that the clear force path makes the design more straightforward [6].

The ZBF has become more popular and several researches have worked on ZBFs recently [7,8,9,10]. Stravridis and Shing [7] studied the behavior of low-rise SZBFs. The influence of lateral load patterns on the seismic design of 4, 8 and 12-story ZBFs was studied by Tirca and Chen [8]. Yu et al. [9] studied the performance of 10-story ZBFs with respect to IVBFs and concluded that ZBFs perform better under seismic loadings. Razavi and Sheidaii [10] compared the behavior of SZBF and a new SZBF, called cable zipper-braced frame, which deploys high-strength prestressed cables instead of zipper struts.

In this study, three- and nine-story IVBFs and SZBFs designed for the same lateral load demand are analyzed under static and dynamic loads to provide a detailed comparison of both systems.

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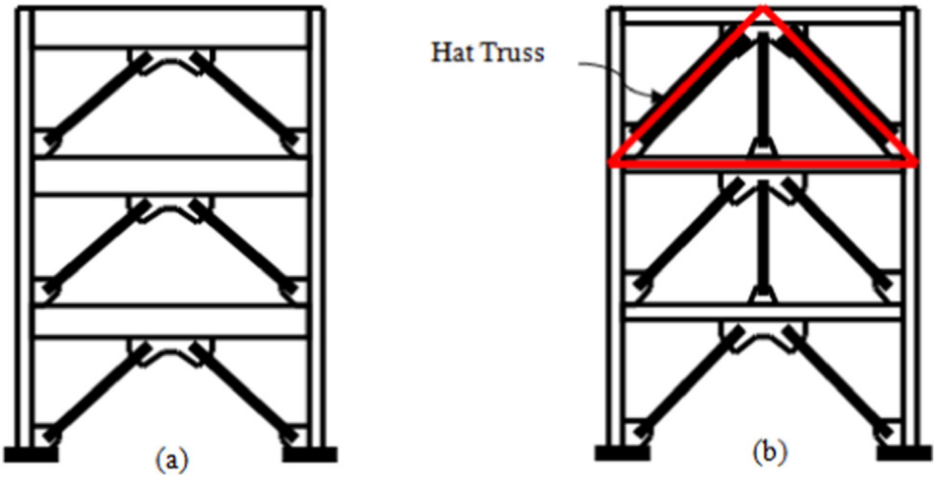

Fig. 1. Chevron (a) and suspended-zipper (b) braced frames [1].

2. Methodology

To compare the seismic performance of the SZBF and the IVBF, two-dimensional, three- and nine-story buildings are analyzed employing nonlinear static and time-history analysis methods using OpenSEES [11].

2.1. Building models

Three- and nine-story prototype buildings in the SAC steel project [12] located in Los Angeles designed by Yang et al. [6] as SZBFs are adopted as a benchmark for this study. The authors redesign these SZBFs as IVBFs by removing the hat truss and zipper columns, and by providing story beams designed in accordance with the AISC Seismic Provisions [2] to carry the unbalanced vertical forces emerging in the post-buckling range [Fig. 2].

For the design of the frames, the equivalent lateral load method prescribed in IBC 2000 [13] is implemented using mapped spectral accelerations of 2.16 g and 0.72 g for the short period and 1 s period, respectively. The response spectrum is constructed using the following parameters: (1) a soil profile of Class D (stiff soil), (2) an importance factor of 1.5, and (3) a response modification factor of 6 [14].The total seismic weight of the frames are calculated as 4821 kN and 14,712 kN, and the design base shears are calculated as 1736 kN and 2942 kN for three- and nine-story frames, respectively. The first three elastic periods of the frames are given in Table 1.

Although the AISC Seismic Provisions [2] require having moment connections at beam-column joints to rely on frame action to help the seismic force resisting system, other seismic provisions such as the Turkish Earthquake Code [15] allow having simple connections at beam-column joints. In this study, the latter option is selected and all beam-column connections and all other connections are assumed to be pinned connections; therefore, the contribution of frame action in this regard is excluded. P-Δ effects are included in the models by adding a leaner column with no flexural stiffness, which carries all gravity loads, connected to the braced frame with horizontal rigid truss elements. ASTM A572 Grade 50 steel (nominal yield strength of 345 MPa) is used for columns and beams, and ASTM A500 Grade B steel (nominal yield strength of 317 MPa) is used for braces and zipper columns. The member sizes of 3-story and 9-story frames are tabulated in Tables 2 and 3, respectively.

2.2. Member modeling

The seismic performance of CBFs is highly dependent on the brace behavior; therefore, the brace model used in an analytical study has to

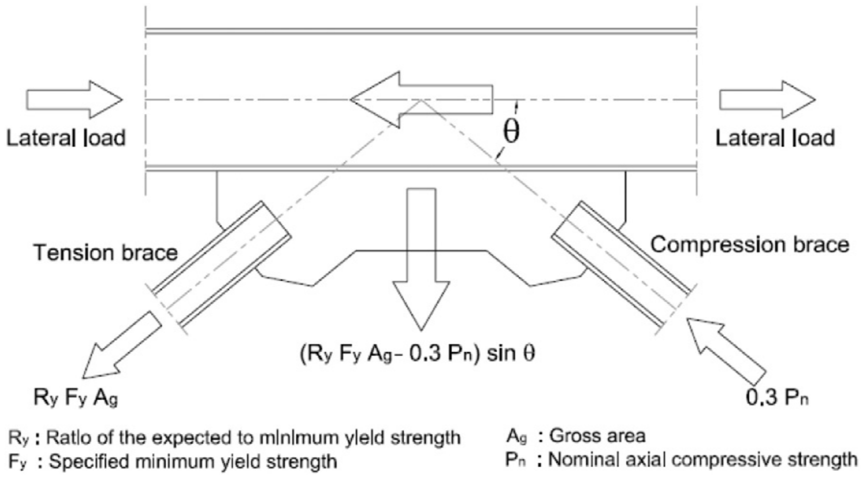

Fig. 2. Brace forces in post-buckling range.