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Evaluation of the seismic performance of suspended zipper column concentrically braced steel frames

K.K. Wijesundara [a], R. Nascimbene [b,*], Gian A. Rassati [c]

[a] Faculty of Engineering, University of Peradeniya, Peradeniya, Sri Lanka
[b] European Centre for Training and Research in Earthquake Engineering (EUCENTRE), Via Ferrata 1, Pavia 27100, Italy
[c] Department of Civil and Architectural Engineering, University of Cincinnati, Cincinnati, OH, USA

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ABSTRACT

The performance of the most common type of concentric braced configuration, i.e. Chevron braces, is governed by buckling of first story braces in compression, resulting in a localization of the failure. To improve the performance of chevron concentric braced frames, zipper columns were introduced to transfer the unbalanced forces; over-strength braces were further introduced to avoid the complete collapse of the frame. Such concentric braced frames are called suspended zipper concentric braced frames.

The objective of this study is to evaluate the seismic performance of suspended zipper concentric braced frames designed according to Eurocode 8 and to compare their performance with conventional concentric braced configurations. It is important to highlight that this study introduces a novel design methodology to size braces, zipper columns, beams and columns in suspended zipper frames. For this purpose, two concentric braced frame structures from each suspended zipper configuration and stud-to-ground configuration are designed and analysed for a ground motion with a probability of exceedance equal to 10% in 50 years, i.e. a return period of 475 years, with peak ground acceleration of 0.3 g.

Based on the comparison of results, it can be concluded that the performance of suspended zipper frame is better than that of conventional concentrically braced frames in medium-rise buildings, but not in low-rise buildings. Furthermore, the novel design methodology is proven to be satisfactory in sizing the structural elements of suspended zipper concentric braced frames when considering the inelastic time history analyses results.

1. Introduction

In general, braced frames are very effective in resisting lateral loads induced by an earthquake due to their high elastic stiffness and strength characteristics compared to those of moment resisting frames. Of all different bracing configurations of Concentrically Braced Frames (CBFs), the most common is the chevron braced configuration (Inverted-V) as it provides more open space for the placement of doorways, windows and mechanical systems. However, the behaviour of chevron CBFs is governed by buckling of the first story braces in compression, resulting in a localization of the failure and the loss of lateral resistance as the lateral displacement increases. In general, this system does not exhibit much force redistribution capability and has not performed well in past earthquakes [5,9,12,13,15,16].

Khatib et al. [9] conducted a study on five alternative configurations to conventional chevron CBFs. They were VREG, XREG, SLITX, STG, and ZIP as shown in Fig. 1. The strut-to-ground (STG) braced configuration includes a vertical column that links all brace-to-beam intersection points directly to the foundation. It resists the vertical unbalanced forces that develop following brace buckling at the brace-to-beam intersections. The advantages of this configuration identified by Khatib include that tension braces can develop their yield strength, additional axial load in columns due to vertical unbalanced forces in the beams in the braced bay are avoided, and trilinear hysteretic response can be achieved.

Furthermore, as shown in Fig. 1(f), to improve the performance of chevron CBFs, the insertion of middle columns intended to carry the unbalanced forces at brace-to-beam intersection points was studied. This type of CBF is called a “Zipper CBF” and the middle columns are called “zipper columns”. The unbalanced force transmitted through the zipper columns increases the compression force in the second storey compression brace, eventually causing it to buckle. If the excitation is still continuing on the structure in the same direction, the unbalanced force will propagate up in the structure such that ultimately all compression braces will buckle. Near simultaneous brace buckling over the height of a building will result in a more uniform distribution of damage. However, instability and collapse can occur once the full-height zipper mechanism forms due to the reduced lateral capacity of the frame [17], and this drawback has limited the applicability of this system.

* Corresponding author.
E-mail address: roberto.nascimbene@eucentre.it (R. Nascimbene).

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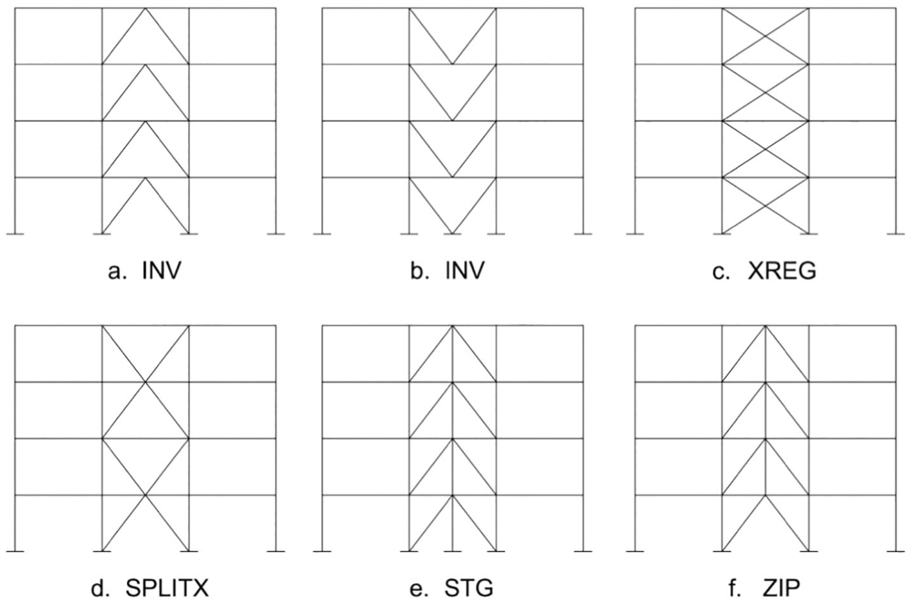

Fig. 1. Alternative concentrically bracing configurations (Extracted from Khatib et al. [9].

In order to avoid the formation of a full height mechanism, the top pair of braces is designed to remain elastic while all other compression braces buckle. Since the zipper columns resist the unbalanced loads developed at the brace-to-beam intersection points and support the beam at the mid span, beams can be designed to be flexible. An experimental and analytical study of this configuration was conducted by Yang et al. [18,19]. This study concluded that zipper braced configuration can avoid instability problems due to the formation of a full height zipper mechanism. This configuration can achieve a more uniform distribution of damage over the height without using excessively stiff beams. However, to the best of the author's knowledge, a comprehensive comparison of the performance of suspended zipper CBFs and conventional CBFs cannot be found in literature. Furthermore, it is important to validate the design methodology of suspended zipper CBFs using inelastic time history analyses.

Therefore, the objective of this study is to evaluate the seismic performance of suspended zipper CBFs designed according to Eurocode 8 (EC 8) [7] and to compare their performance with conventional CBF configurations. It is important to highlight that this study introduces a novel design methodology to size braces, zipper columns, beams and columns in suspended zipper CBFs which is validated by means of nonlinear time history analyses. However, this study uses only the STG braced configuration as a conventional braced configuration for this comparison.

For this purpose, two concentrically braced frames in each STG and Suspended Zipper configuration are designed for a ground motion with a probability of exceedance equal to 10% in 50 years, i.e. a return period of 475 years with a peak ground acceleration of 0.3 g using EC 8 [7] specification. Each configuration consists of four and eight storey frames as shown in Fig. 2(a) and 2(b). In order to evaluate the seismic performance of the CBFs, nonlinear time history analyses are performed using the OpenSEES [11] finite element software applying a suite of nine real accelerograms. These were selected to match their average spectrum to the design spectrum. Finally, the comparison of the seismic performance of the two CBF configurations is performed in terms of interstorey drift ratio and storey shear distributions over the height.

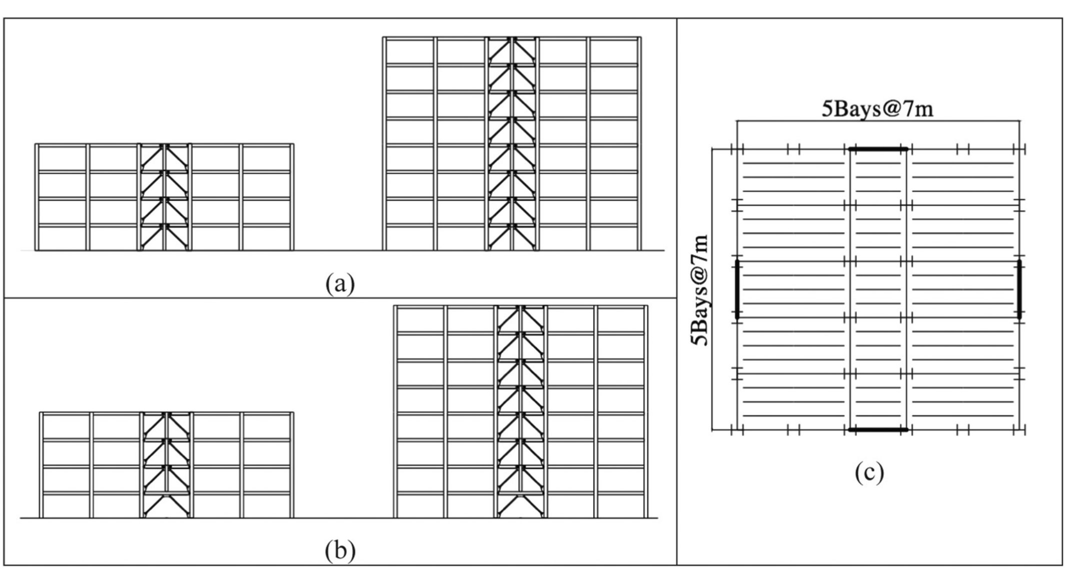

Fig. 2. Elevations of (a) STG (b) suspended zipper CBFs and (c) plan view.