Journal of Constructional Steel Research 74 (2012) 49–57

Contents lists available at SciVerse ScienceDirect

Journal of Constructional Steel Research

Seismic performance of cable zipper-braced frames

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ARTICLE INFO

Article history:
Received 12 October 2011
Accepted 11 February 2012
Available online 16 March 2012

Keywords:
Braced frames
Zipper
Time history analyses
Cable
Seismic behavior

ABSTRACT

Zipper elements of stories transfer unbalanced vertical forces of the lower stories to the upper ones. The tensile forces generated in these elements extremely increase in upper stories. Accordingly, these zipper elements need an impractically large cross-section to be designed. This problem induces some limitations on the use of zipper bracing systems, especially in high-rise buildings. Therefore in this study a novel approach is presented to resolve this problem. The proposed solution is using cables with appropriate pre-stress ratios as zipper elements. Accordingly, the seismic behavior of cable zipper-braced frames with different pre-stress ratios is investigated. For this purpose, nonlinear time history (NLTH) analyses were conducted on several structural models with different numbers of stories. Comparison of the obtained results with those of conventional suspended zipper-braced frames (SZBF) demonstrates the efficiency and viability of the new technique. Moreover it is shown that use of the suggested system with appropriately pre-stressed cables enhances the seismic performance of zipper-braced systems.

1. Introduction

Inverted-V-braced frames, which are also called chevron-braced frames, are a common type of concentrically braced frame. The seismic behavior of such a system is controlled by the buckling of the first-story braces in compression (Fig. 1). In general, this system does not exhibit much force redistribution capability and has not performed well in earthquakes [1,2].

Because more emphasis has been placed in the last two decades on increasing both the ductility and the energy dissipation capabilities of structures in seismic areas, design provisions for a new type of braced frame, called a special concentrically braced frame (SCBF), were developed. Within these provisions, the performance of special inverted-V-braced frames (SIVBF) was improved compared with that of ordinary inverted-V-braced frames (OIVBF) [3,4]. However, SIVBFs continue to exhibit a typical braced-frame design problem. With continued lateral displacement, the compression brace buckles and its axial load capacity decreases, whereas the tension brace force continues to increase until it reaches a yield statement. This creates a large, unbalanced vertical force on the intersecting beam.

To prevent deterioration of the lateral strength of the frame, current design provisions require that the beam to have adequate strength to resist the potentially significant post-buckling force in combination with appropriate gravity loads, resulting in very strong beams [5]. This adverse effect of the unbalanced force can be mitigated by adding zipper columns between brace-to-beam intersection points, as shown in Fig. 2. Such an improved system was first proposed by Khatib et al. [6]. In this bracing system, the unbalanced force transmitted through the zipper element increases the compression force applied to the upper story compression brace, eventually causing it to buckle (Fig. 2a,b). The near simultaneous buckling of braces over the height of a building will result in a more uniform distribution of damage, which is a desirable goal. Accordingly, instability and overall collapse can occur once the full-height zipper mechanism forms (Fig. 2d) [7].

The disadvantages of a full-height zipper mechanism can be overcome by introducing a suspension system, called a "suspended zipper-braced frame," (SZBF) as shown in Fig. 3. In a SZBF, the top-story bracing members are designed to remain elastic while all other compression braces have buckled and the zipper elements have yielded. Because the primary function of the suspended zipper struts is to sustain tension forces and the suspended zipper struts support the beams at the midspan, the beams can be designed to be flexible. This result in significant savings in material and cost in suspended zipper frames. Moreover, the force path is so evident that a capacity design for all structural members is straightforward [2].

Yang et al. performed an experimental pushover test on a one-third-scale model of a SIVBF with zipper struts. In their study, the zipper elements demonstrated their ability to activate buckling in all stories except the top one by redistributing the loads in the structure and minimizing strength losses [8]. Chen refined the existing design method for CBF with strong zipper columns and validated the refined design method by studying the performance of CBF systems with strong zipper columns for low-, mid- and high-rise buildings [9].

Zipper elements of stories transfer unbalanced vertical forces of the lower stories to the upper ones. The tensile forces generated in these elements extremely increase in upper stories. Accordingly,

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doi:10.1016/j.jcsr.2012.02.007