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The Applicability of the Zipper Strut to Seismic Rehabilitation of Steel Structures

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Abstract**—**Chevron frames (Inverted-V-braced frames or V-braced frames) have seismic disadvantages, such as not good exhibit force redistribution capability and compression brace buckles immediately. Researchers developed new design provisions on increasing both the ductility and lateral resistance of these structures in seismic areas. One of these new methods is adding zipper columns, as proposed by Khatib et al. (1988) [2]. Zipper columns are vertical members connecting the intersection points of the braces above the first floor. In this paper applicability of the suspended zipper system to Seismic Rehabilitation of Steel Structures is investigated.

The models are 3-, 6-, 9-, and 12-story Inverted-V-braced frames. In this case, it is assumed that the structures must be rehabilitated. For rehabilitation of structures, zipper column is used. The result of researches showed that the suspended zipper system is effective in case of 3-, 6-, and 9-story Inverted-V-braced frames and it would increase lateral resistance of structure up to life safety level. But in case of high-rise buildings (such as 12 story frame), it doesn't show good performance. For solving this problem, the braced bay can consist of small "units" over the height of the entire structure, which each of them is a zipper-braced bay with a few stories. By using this method the lateral resistance of 12 story Inverted-V-braced frames is increased up to safety life level.

Keywords**—**chevron-braced frames, suspended zipper frames, zipper frames, zipper columns.

I. Introduction

INVERTED-V-braced frames (IVBF or chevron frames) are one of Ordinary Concentrically Braced Frame (OCBF) type, in which the centerlines of members form a vertical truss system to resist lateral forces such as earthquake forces. The behavior of such system is controlled by the buckling of the first story braces in compression, resulting in a localization of the failure and loss of lateral resistance. In general, this system does not exhibit much force redistribution capability and has not performed well in past earthquakes.

By using new design provisions, the performance of Special Inverted-V-Braced Frames (SIVBF) was improved rather than of Ordinary Inverted-V-Braced Frames (OIVBF) by limiting width-to-thickness ratio of the bracing members, requiring closer spacing of stitches of the bracing members, and providing special design and detailing of end connections (gusset plates) for the bracing members. However, SIVBFs still exhibit a typical braced frame design problem. Because of continuous lateral displacement, the compression brace buckles and its axial capacity decreases while the tension brace force continues to increase until it reaches yield. This creates a large unbalanced vertical force on the intersecting beam. In order to prevent undesirable deterioration of the lateral strength of the frame, current design provisions require that the beam shall possess adequate strength to resist these two potentially significant post-buckling forces in combination with appropriate gravity loads [1], resulting in very large beams.

The inappropriate effect of this unbalanced force can be mitigated by adding zipper columns, as proposed by Khatib et al. (1988) [2] and shown in Fig. 1. The intent of SIVBFs with zipper columns is to tie all brace-to-beam intersection points together, and force all compression braces in a braced bay to buckle simultaneously. This results in a better distribution of energy dissipation over the height of the building.

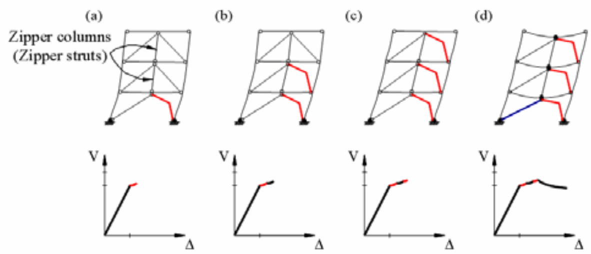

Fig. 1 Full-height zipper mechanism [1]

Simultaneous brace buckling over the height of a building will result in a more uniform distribution of damage that leads us to our desirable goal. However, instability and collapse can occur once the full-height zipper mechanism forms due to the reduced lateral capacity of the frame after a full mechanism has formed [3], and this drawback has limited the applicability of this system.

Yang (2006) [4] solved the disadvantages of a full-height zipper mechanism by introducing a suspension system, labeled the *suspended zipper frame*. In a suspended zipper frame, the top story bracing members are designed to remain elastic when all other compression braces have buckled and the zipper columns have yielded. Since the primary function of the suspended zipper struts is to sustain tension forces, and the suspended zipper struts support the beams at the mid-span,

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the beams can be designed to be flexible. These results are leading us to the significant savings in the amount of steel for the beams in SIVBFs with suspended zipper struts. Moreover, the force path is also so evident that a capacity design for all structural members is straightforward.

In this paper the buildings were designed as if located on site class III and the seismic zone with high danger. Then seismic rehabilitation of these frames with using suspended zipper system and seismic behavior of rehabilitated frames and using of suspended zipper concept in case of high-rise buildings with limiting the number of stories in height of the structure is investigated.

II. INTRODUCTION OF THE SELECTED MODELS

The models are 3-, 6-, 9-, and 12-story Inverted-V-braced frames. The design code used was the ASCE-7 (2005) [1] for loads and the AISC LRFD (2005) [5] and seismic provisions for member and frame design. The buildings were designed as if located on site class III and the seismic zone with high danger. The height of each story is 3 meter and the bay has 5 meter length. The structures are residential and an importance factor of 1 was assigned to the models.

III. PERFORMANCE OF THE SUSPENDED ZIPPER FRAMES

The models were designed by the SAP2000 software and the curve performance of them was obtained by the OpenSEES [6] software. By using the capacity spectrum and the acceptation criterion in the FEMA273 [7], the performance point determined and the seismic behavior of the models in the safety life level evaluated. At first zipper elements size is obtained from the SAP2000 software and the results are compared with the Yang [4] method.

The criterion of buildings stiffness control in the allowable level of stresses is the allowable story drift limit 0.015H where H is the story height.

This ratio for models shows that all models have story drift ratio under the allowable level. So models have enough strength and stiffness in the serviceability level. For determination of the structural and non structural damages and necessity of seismic rehabilitation, these models also in safety life level were evaluated.

In table 1 spectral displacement in safety life level for all of frames is showed. As shown in Figs. 2-4, Spectral displacement in performance point for 3, 6, and 9 story models is less than spectral displacement in safety life level. So we can use suspended zipper system as an effective method in seismic rehabilitation for these frames.

As it visible in the Fig. 5, 12 story frames can't satisfy conditions of safety life level. This problem is because these models have many stories. Zipper-braced frames are applicable to high-rise buildings by increasing the number of braced bays in a frame. However, the size of the zipper struts increases rapidly with the number of stories, presenting practical limitations to the usable height of the system. To make the suspension concept applicable to a tall building, the braced bay can consist of small *units* over the height of the entire structure which each of them is a zipper-braced bay with a few stories. So, 12 story frames is divided to 4 small *units* and each of them is designed as a suspended zipper-braced frame. After nonlinear static analysis, it was observed (Fig. 5) that the lateral strength of frame is increased and it can satisfy conditions of safety life level.

TABLE I SPECTRAL DISPLACEMENT IN LIFE SAFETY LEVEL

Frame	spectral displacement in life safety level
3 story	10.28cm
6 story	18.43cm
9 story	28.06cm
12 story	32.84cm

IV. CONCLUSIONS

The applicability of the suspended zipper system to Seismic Rehabilitation of Steel Structures is investigated. For this, models with different stories were analyzed. The results showed that:

The suspended zipper braced system is useful in improving the seismic behavior of inverted-v-braced frames. The zipper element removes important problem of these frames which is result of the buckling of first story compression brace. The unbalanced force, after buckling of the first story compression brace, transmits through the zipper columns to top stories and with more uniform distribution of damage, increase the energy dissipation, strength and ductility of the structure.

In high rise-building the zipper element can't be useful as well as few and moderate story buildings and these structures don't show considerable increase in strength and ductility. But if the braced bay considered that consists of small "units" over the height of the entire structure and each of them is a zipper-braced bay with few stories, the performance of structure improves considerably.

The use of suspended zipper concept to rehabilitation and strengthening of existing structures is economical and practical.

The theoretical load path was validated. Once buckling had occurred in the braces, the zipper strut functioned as a tension member, providing support at mid-span of the floor beams and transmitting the unbalanced vertical forces upwards to mobilize the unbuckled braces.

The inverted-V-braced frames have more elastic stiffness than suspended zipper braced frames, but immediately catch to dropping in strength while the zipper braced frames show more ductility and strength

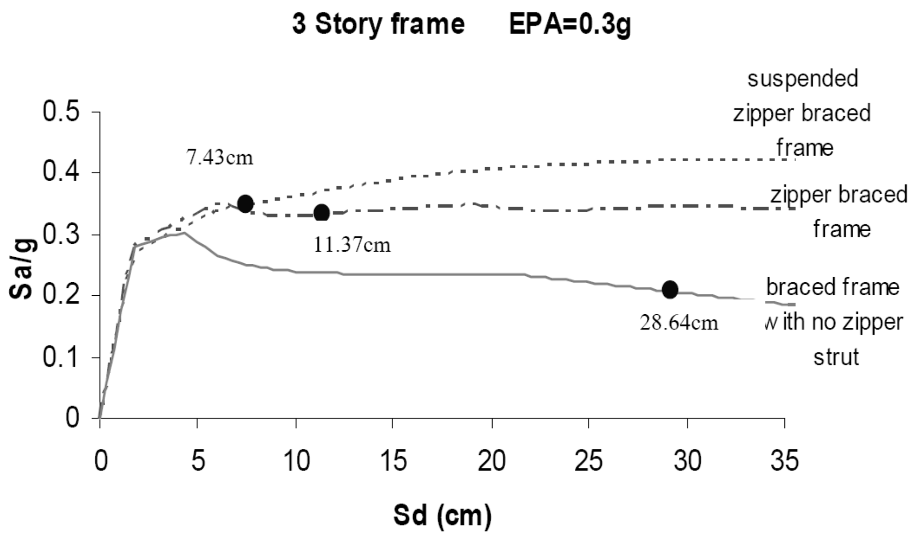

Fig. 2 Capacity curves for 3 story frames in ADSR format

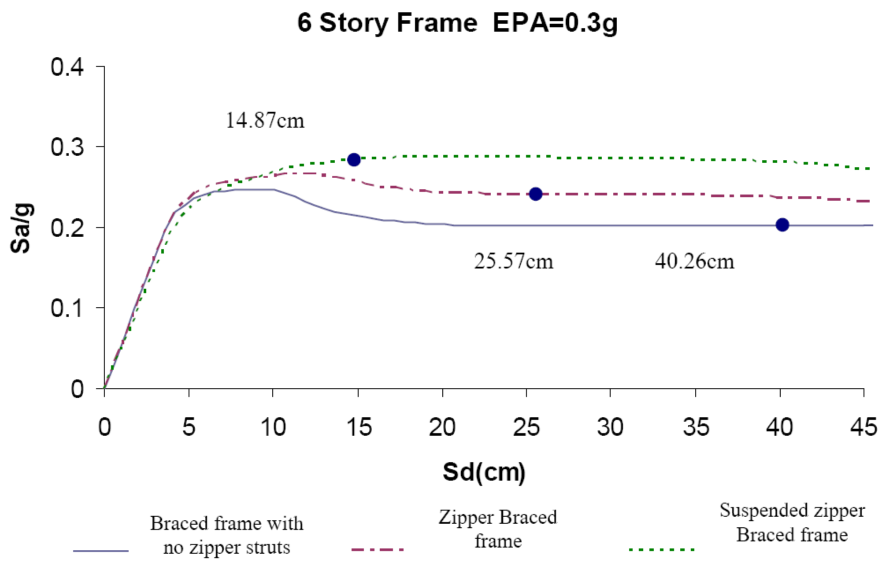

Fig. 3 Capacity curves for 6 story frames in ADSR format

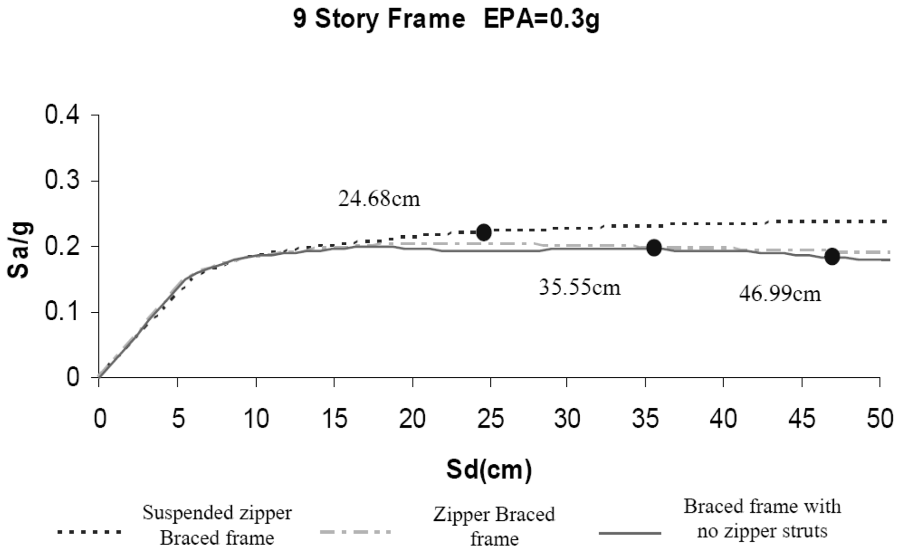

Fig. 4 Capacity curves for 9 story frames in ADSR format

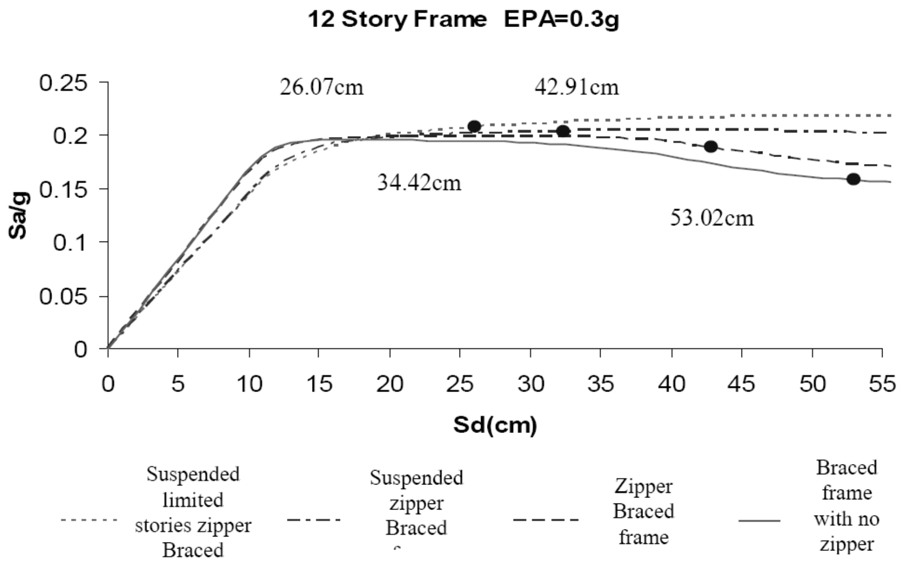

Fig.5 Capacity curves for 12 story frames in ADSR format

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