

Comparative Study of X-Concentrically Braced Frame, Zipper Frame and Strong Back System

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ABSTRACT: Buildings are often subjected to lateral loads like earthquake, wind etc. So it is necessary to provide additional lateral load resisting systems to them in order to ensure safety. Many of the lateral load resisting systems used nowadays are prone to cause damage concentrations in single storeys resulting in ultimate collapse by soft storey mechanism. The work in this paper is the comparative study of conventional concentric X braced frame along with new systems like Zipper frame and Strong Back System. These three systems are analysed under linear and non-linear static lateral load cases using FE software SAP2000. From the results it is clear that Strong Back system outperformed other two bracing systems.

KEYWORDS: X- Concentrically Braced Frame, Zipper Frames, Strong Back System, SAP2000, Linear Static, Non-linear Static Pushover Analysis

I. INTRODUCTION

Buildings are often subjected to lateral loads like earthquake, wind etc. So it is necessary to provide additional lateral load resisting systems to them in order to ensure safety. Many of the lateral load resisting systems used nowadays are prone to cause damage concentrations in single storeys resulting in ultimate collapse by soft storey mechanism. It is well-known that during strong earthquake ground shaking, conventional steel concentrically braced frames are prone to form a weak-story mechanism. Several approaches have been explored by various researchers to reduce damage concentration and achieve smaller residual displacement. Strong Back System (SBS) is a hybrid system based on the strong-back truss system that remains elastic within a braced bay or system along with inelastic action of buckling restrained braces which can theoretically distribute the inter story drift more evenly.

The work in this paper is the comparative study of conventional concentric X braced frame along with new systems like Zipper frames and SBS. These three systems are analysed under linear and non-linear static lateral load cases. Paper is organized as follows. Section II describes the related studies on different types of bracing systems. The modelling features and parameters are described in Section III. Section IV presents analytical results showing results of linear and non-linear static lateral load analysis. Finally, Section V presents conclusion.

II. RELATED WORK

With advances in braced frame technology, new systems with increasingly better earthquake resistance are coming into existence. It is well-known that during strong earthquake ground shaking, conventional steel concentrically braced frames are prone to form a weak-story mechanism. This concentration of deformations in one or a few stories intensifies damage to braces at these levels, leading to greater non-structural and structural damage at these levels, and

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

premature rupture of the braces, compared to systems with more uniform distribution of damage over height. Weak stories are also likely to have significant residual displacements, which can be costly or infeasible to repair.

Over the years, researchers and engineers have explored many ideas in an attempt to improve the behaviour of braced frame systems. An obvious example is the development of buckling-restrained braces (Watanabe et al. 1988). This kind of brace significantly improves the hysteresis behaviour and the energy-dissipation capacity at the component level (Watanabe et al. 1988; Chen et al. 2001; Mahin et al. 2004). Although the entire system behaviour benefits from the higher brace ductility capacity, the deformation concentration and the system's permanent deformations are not generally ameliorated, and may be even larger than observed in conventional concentric braced frames (Sabelli et al. 2003; Kiggins and Uang 2006).

As such, it is desirable to provide concentric braced frames with improved capabilities to avoid the concentration of deformations and damage in a few stories. If a system is able to mitigate soft- or weak-story behaviour, the peak deformation demands on individual braces and maximum residual displacements might be reduced. Several approaches have been followed to modify the system behaviour of braced frames to develop large deformation capacity, reduce damage concentration, and achieve smaller residual displacement. These systems include: (1) dual systems, where a moment frame is used in addition to the braced frame; (2) zipper or vertical tie-bar systems; (3) rocking/uplifting systems; and (4) masted or strong-back hybrid systems.

Previous research on reducing weak story behaviour in braced frame systems designed zipper braced frame systems and tie-bar-to-ground braced frame systems to prevent weak-story mechanisms. The responses of these systems were compared with other basic braced frame systems. In the zipper or tie-bar-to-ground systems, the vertical struts at the center of the bays were designed to promote the formation of the same mechanism at each level. In the case of the zipper system, the unbalanced force at the center of a chevron brace pattern would normally tend to displace the beam intersected by the braces in the vertical direction. With the addition of the vertical strut, this vertical movement would be transferred to the floors above and below. In these zipper/tie-bar systems, the braces on both sides of the central strut were expected to yield: one by tensile yielding and the other through buckling. The authors showed that this approach was effective but did not indicate how to size or proportion the vertical struts. In the tie-bar-to-ground system, the unbalanced forces simply accumulated, requiring that the vertical tie bar carry large forces. Its size increased as a result, and it simply became another column in the system. That is, the system became a two-bay frame with a single diagonal brace in each bay. The analytical studies found that both these systems performed better than the chevron braced frame system preferred in practice at that time.

Strong Back System (SBS) is a hybrid system based on the strong-back truss system by Mahin and Lai. The intent is to incorporate a vertical truss that remains elastic within a braced bay or system. The vertical elastic truss provides a strong back or mast that imposes a nearly uniform story deformation over the height of the structures. The braces used in the system could be either conventional, buckling restrained, or self-centering braces. With proper sizing of the strong back mast system, the designer may have greater flexibility in locating and orienting the braces that yield. This system is not limited to vertical trusses, and other essentially elastic systems, such as steel or reinforced concrete structural walls, large plate girders, and so on, could be used for the strong back mast. For braces with significant differences in tension and compression capacities, it is expected that the overall structural system for a structure would include two strong back bays along each frame line so that an equal number of yielding braces at a floor are loaded in tension and compression.

III. MODELLING

5 bay 6 storey frames are adopted for linear static & non-linear static pushover analysis by keeping the weight of each structure comparable. 3 models are developed using the FE software SAP2000. First one is concentric X braced frame as shown in figure 1 (a). Other two models are new systems like Zipper frames and SBS shown in figure 1(b) and (c). Buckling restrained braces are modelled as multi-linear plastic link elements with kinematic hysteresis behaviour. Properties of buckling restrained braces are taken from Star Seismic provisions.

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Vol. 6, Issue 5, May 2017

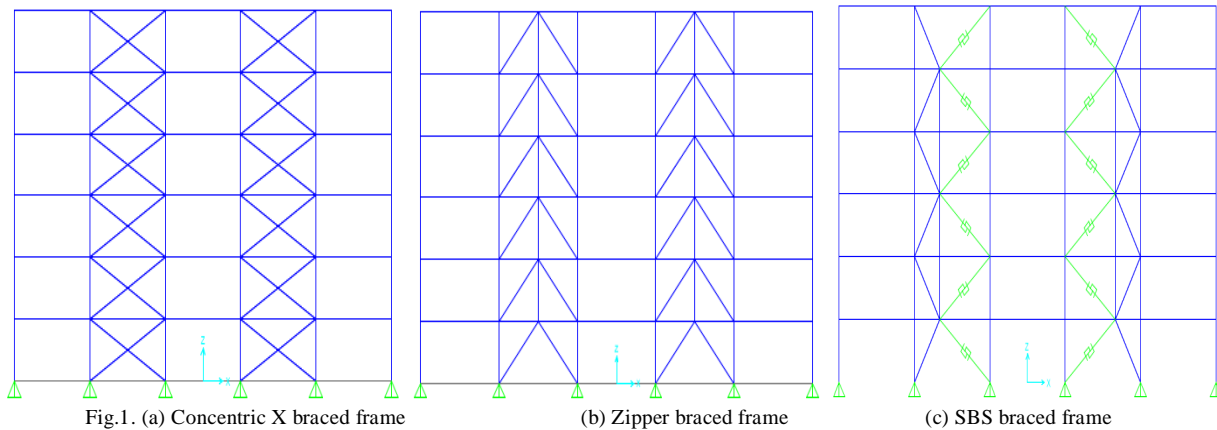


Table 1 shows the Seismic Design Parameters used for analysis. The governing code used for the study is ASCE-7-2005. Other parameters like Importance factor, Seismic design category, Site class etc. which are given as input in the finite element software SAP2000 is provided in this table.

Table 1 Seismic Design Parameters

Design parameters	Values
Governing Code	ASCE-7-2005
Importance factor (I)	1.0
Seismic design category	D
Site class	D
Response modification factor (R)	6
System over strength factor (Ω_o)	2.0
Deflection amplification factor (C_d)	5.0
S_1 (g)	0.787
S_s (g)	2.014
F_a	1.0
F_v	1.5
S_{D1} (g)	0.787
S_{DS} (g)	1.343

IV. RESULTS AND DISCUSSION

Linear static & non-linear static pushover analysis has been conducted on each model to study the effect of lateral forces. Lateral deformation and the sequence of plastic hinge formation of each model are noted and compared to reach the conclusions.

Fig.2 (a) and (b) shows the graphical representation of Inter-Storey Drift ratio and roof drift obtained by linear static analysis. Inter-Storey drift ratio of SBS is lower when compared to other two models. Also it is uniformly distributed in each storey. Zipper frames has larger values of inter-storey drift ratio. Also roof drift is also higher for Zipper frames when compared to other two models. Strong Back System has the lowest roof drift among the models with 35.5% decrease with respect to X concentrically braced frame.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

Hence Strong Back System has better performance and Zipper frame has poor performance after linear static analysis.

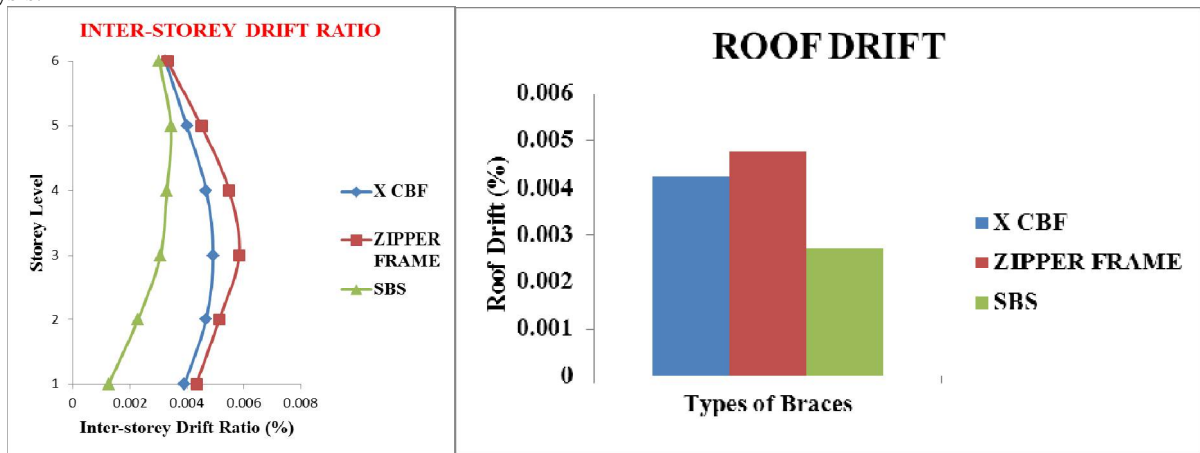


Fig.2.(a) Inter-Storey Drift ratio (b) Roof Drift obtained by linear static analysis

Fig.3 shows the Inter-Storey Drift ratio obtained by non-linear static pushover analysis. A push of 0.3048 m is given to each frame. X-CBF and Zipper frame collapsed before reaching target displacement. Hence inter storey drift is lower for these frames due to lower displacements and these storey drift is concentrated in lower storeys as shown in fig. 3 resulting in soft storey formation leading to premature failure of braces on top storeys. But strong back system sustained without failure during the entire monotonic pushover analysis resulting in higher and uniform distribution of inter-storey drift ratio along the entire height of the frame as shown in fig. 3.

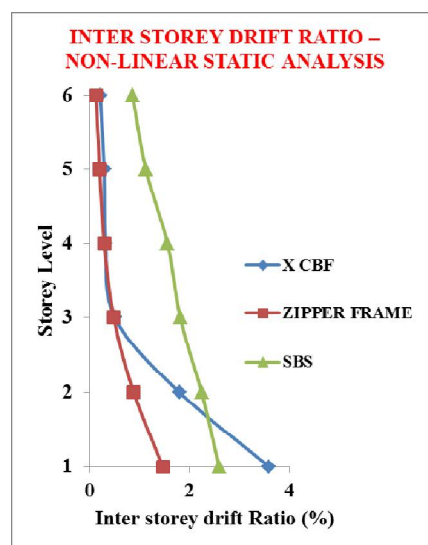


Fig.3. Inter-Storey Drift ratio obtained by non-linear static pushover analysis

Plastic hinge formations of the members in the frame are obtained after conducting static pushover analysis in SAP2000 and are shown in figure 4. Performance level of building based on the hinge formation is given in Table 2.

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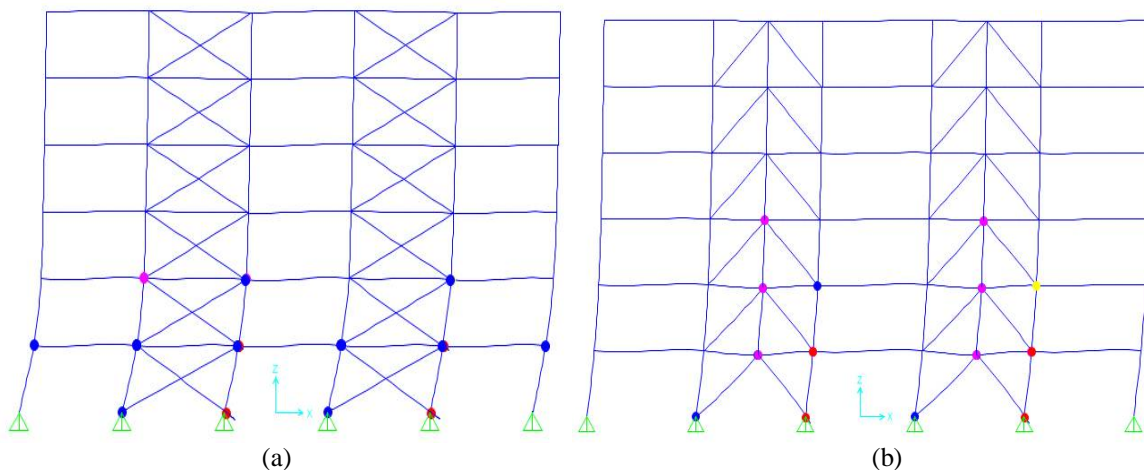
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The colour scale showing the hinge states is shown in fig. 4 (c). Each colour hinge indicates each level of performance of building under given seismic loading as described in the table below.

Table 2. Performance level of building

Level	Abbreviation	Description
Operational	B	Very light damage, no permanent drift, structure retains original strength and stiffness, all systems are normal
Immediate Occupancy	IO	Light damage, no permanent drift, structure retains original strength and stiffness, elevator can be restarted, Fire protection operable
Life Safety	LS	Moderate damage, some permanent drift, some residual strength and stiffness left in all stories, damage to partition, building may be beyond economical repair
Collapse Prevention	CP	Severe damage, large displacement, little residual stiffness and strength but loading bearing column and wall function, building is near collapse

Fig. 4 (a) shows the hinge formation of X-CBF. Plastic hinges are formed on the lower storeys and buckling failure of conventional braces has occurred. In fig. 4 (b), hinge formation of Zipper frame is shown. There also hinges are formed in the lower stories resulting in column failure. Therefore soft storey failure has been occurred in these two models leading to the premature failure of braces on the top storeys. But in fig. 4 (c), hinges are formed uniformly in all storeys resulting in the complete utilisation of the capacity of each member which eventually leads to the effective mitigation of damage concentrations in a particular storey. Also, red coloured hinges indicating final collapse is not formed in SBS, like other models showing higher reserve strength in it.



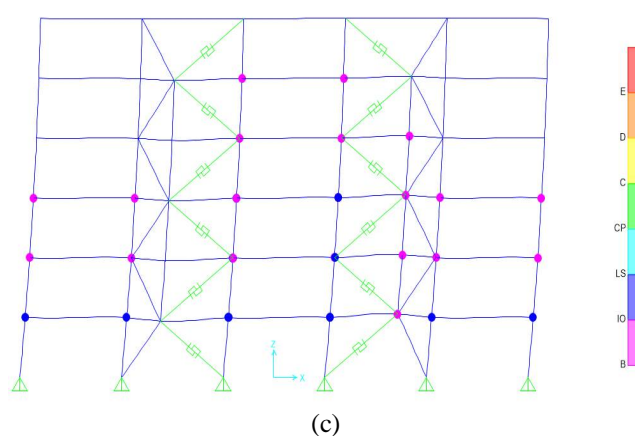


Fig.4. Hinge formation after non-linear static pushover analysis: (a)X-CBF (b) Zipper braced frame (c) SBS

From these results, it is clear that SBS shows lesser lateral deformation under linear static loads and the same system sustained more deformation without failure under non-linear static pushover analysis. Other two models, i.e. X-CBF and Zipper frame showed higher lateral deformation under linear static analysis and they failed before reaching the target displacement under non-linear static analysis.

V. CONCLUSIONS

From the results, it is clear that lower stories exhibit soft storey mechanism in concentric X braced frame resulting in the premature failure of brace members above that storey which is not desirable. Also, Zipper braces reached collapse mechanism at low displacements due to low ductility resulting in the premature failure of brace members above that storey which also is not desirable. SBS has uniform storey drift distribution with enough ductility. SBS has 35.5% decrease in roof drift with respect to X CBF under linear static load condition. Therefore, SBS has better linear and non-linear behaviour when compared to other models. Hence this system outperformed all other bracing systems.

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