Introduction of a New Member to Promote the Seismic Behavior of Concentrically Braced Frames

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Abstract

Concentrically braced frame is known as an economic and common structural system by civil engineers. On the other hand its seismic behavior has some faults. Early buckling of compressive brace, unbalanced force distribution between braces after buckling, residual elongation of tension brace, boarding reduction and impact in gusset plate during next cycles and low energy loss are some important faults of this structural system. In this paper a new cross shape member including cylinders, spring, pistons and slip possibility which its interior space is full with a compressive liquid and placed at the center of braces intersection is introduced. Modeling of the frames including new member have been done with Ansys FEM software and the effects of new member on force distribution and buckling potential of braces has been studied and also the hysteresis curves of the frames under cyclic load have been compared with concentrically braced frames. The results show that the distribution of force in braces of frames with new member is balanced and the maximum axial load and the buckling potential of braces experience a high reduction. The reduction of axial load causes lower design expenses. The comparison of the area of hysteresis curve loops shows that in frames with new members the areas have increased and it means the ductility of these frames and their seismic behavior have promoted.

Keywords: Buckling potential, Seismic behavior, Hysteresis curves, new member

1. Introduction

As early buckling of compressive braces has been an undesirable behavior in concentrically braced frames and led to reduction in stiffness and loading, many researchers have tried to resolve this problem. In concentrically braced frames (CBFs), braces resist against lateral loads. It means the braces undergo axial loads originated from lateral loads. During a cycle, one of the braces undergoes tension force and the other one compressive force. If the compressive force in the braced exceeds the buckling limit force, that brace buckles and the frame experience a high reduction in stiffness and loading in compressive brace so the tension brace should resist against a bigger force and the distribution of the force in the braces will be unbalanced. Many researchers tried to solve the early buckling problem in CBFs. Pall and Marshal [1] introduced a new friction damper including some steel plates and friction bolts which placed at the center of brace intersection and they could ban the early buckling of compressive brace. Malek et al [2] by placing a circular member made of steel plates at the center of CBF braces and using the yielding of this member before buckling of compressive brace could delay the early buckling of braces. Mahbanoui and beheshti-aval [3] by introduction of a combination of circular member and friction bolt connection called FYDBF could promote the behavior of CBFs. All of these researchers tried to control the axil compressive load of the braces by using the mechanism such as yielding, damage concentration on one part and friction slipping not to exceed buckling limit load.

2. Introduction of the New Member

The new member introduced in this paper is made of two cylinders connected like a cross and four pistons attached to the cut braces. The internal volume of cylinders is filled up with an incompressible liquid. There is a slipping force between each piston and cylinders and a spring behind each piston head. Figure 1 shows the placement of the new member in a CBF.

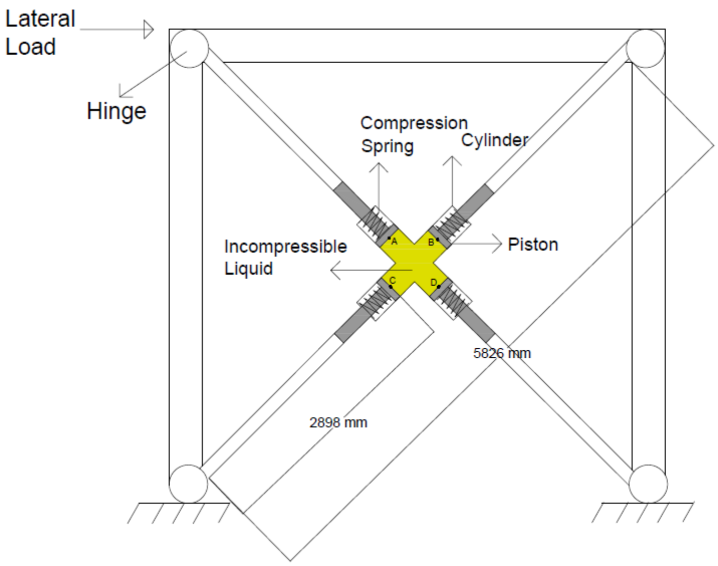

Figure1. A CBF equipped with the new member

As it is seen in Figure 1, the new member after cutting braces place at the center of braces intersection. The parts of the new member and the applied forces are shown in figure 2.

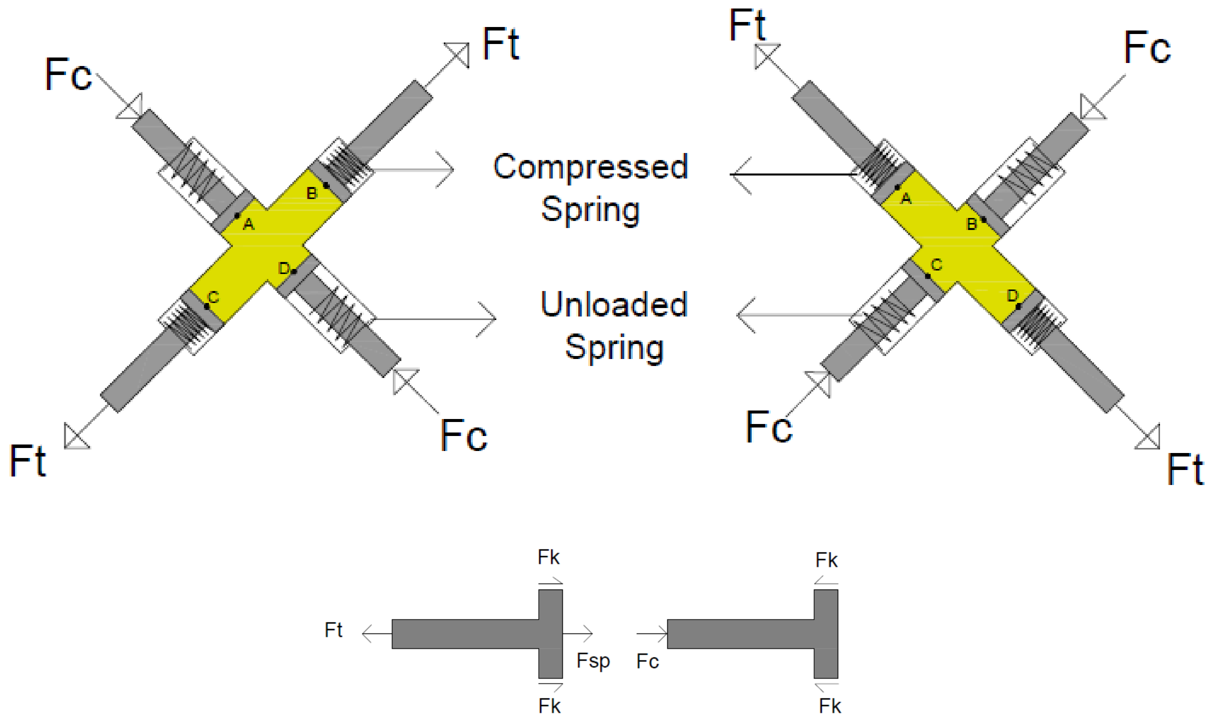

Figure2. Parts of the new member and applied forces

As it is seen above, the new member is made of springs, cylinders and pistons and there is a specified slipping (F_k) force for pistons. It important that only are loaded the springs of tension brace and other two springs do not participate in loading. The reason of using springs in the new member is not to let frame stiffness get zero after slipping and the reason of adding slipping force is to let frame has it first stiffness witch is equal to CBF first stiffness.

3. FEM Modeling of Frame and New Member

In this research, a CBF which studied in an experimental research [4] has been selected. This CBF has been modeled with and without new member in the Ansys FEM software. The goal of this modeling is to study the effects of using parts of new member on the behavior of the CBF frames. The CBF name is X1B and some static, buckling and cyclic analyses are done on a X1B frame without new member, a X1B frame with only spring and three X1B frames with new members including different spring stiffness. The column profiles of all these frames are I-shape sections named W12x106 and the beam profiles of these frames are Channel sections named 2C15x50 and the braces profiles are RHS102x76x4.8 boxes. The members of the frames such as columns, beams and braces have been modeled with Beam188 element and for modeling of the springs, Combin11 element has been used and also Combin39 element has been used for slipping limit load.

3-1. Static Analysis of Frames

In the static analysis, a unit lateral load applied to the frames. Three different spring stiffness are selected for the frames including new member. The slipping limit load in this analysis is assumed zero to only study the effect of incompressible liquid and springs on the distribution of axil load in two braces. The stiffness of springs is a percentage of axial stiffness of brace. The frames specifications and the results of analyses are shown in table1 below.

Table1. Distribution of load in braces

Frame Name	X1B without new member	X1B with Liquid & spring, K=1%	X1B with Liquid & spring, K=10%	X1B with Liquid & spring, K=100%	X1B with only spring, K=10%
Lateral Load (N)	1	1	1	1	1
Axial Load of compression brace (N)	-0.625	-0.595	-0.622	-0.624	0
Axial Load of tension brace (N)	0.625	0.595	0.622	0.624	1.243

It is observed from the comparison of X1B frames including liquid and spring with the frame including only spring that the presence of liquid in the new member causes equal distribution of applied lateral load in two braces. In the frame including only spring, only undergoes the tension brace axial load and the compressive brace does not participate in loading.

3-2. Buckling Analysis of Frames

For the buckling analysis frames, a unit lateral load is applied and the buckling lateral load is computed by software. The buckling analysis results of all frames are compared with the ordinary CBF (X1B without new member) to study the buckling potential of compressive members. In the table2 the results are observed.

Table2. Results of buckling analyses

Frame Name	X1B without new member	X1B with Liquid & spring, K=1%	X1B with Liquid & spring, K=10%	X1B with Liquid & spring, K=100%	X1B with only spring, K=10%	X1B with slipping load
Buckling Lateral load (N)	650	769	681	670	No buckling	765
Percentage of Buckling Potential Reduction	0	18%	4.8%	3.1%	No buckling	18%

In the table2 the buckling load of frames with liquid and spring, with only spring and with only slipping load have been presented. To investigate the buckling potential of the frames before slipping load, the buckling analysis of the X1B with slipping load is investigated and the results shows that the presence of new member makes the braces shorter and reduce the buckling potential of compressive brace up to 18 percent.

3-2. Cyclic Analysis of Frames

In this step, for the cyclic analysis, the load pattern used in an experimental test of reference [4] is selected and it is applied to two frames; ordinary CBF (X1B) and a frame (X1B) including all parts of new member. The target of this step is to compare the differences of maximum axial load of braces after the buckling and yielding of braces and the hysteresis curves of these two different frames. Fiqure3 shows the load pattern used for cyclic analysis.

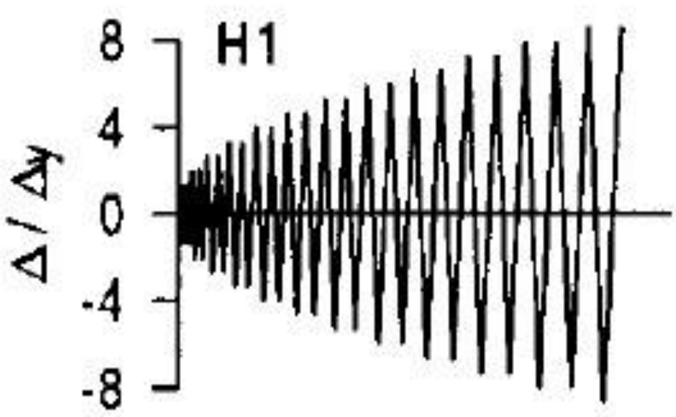

Figure3. Applied cyclic load pattern to two frames [4]

According to this load pattern, displacement of the first cycle is 0.5Δy that Δy is the displacement which tension brace stress equals yielding stress. The second cycle displacement is Δy and during the next cycles two thirds of Δy is added to the displacement amplitude so the third cycle displacement is 1.66Δy and it is 2.33Δy for cycle four. The displacement and load in which the tension brace yields (Δy) was determined by a push-over loading of CBF that the displacement computed 10 millimeters and the load 1000 kilo Newton. To ban the displacement of frame during the weak earthquakes or winds, a slipping load can be added between the cylinders and pistons and to let the frame have lower stiffness when the displacements of earthquake increase, the percentage of springs stiffness should not be a lot to increase the ductility of frame and decrease the internal force to the frame. The axil buckling load of frame braces with presence of slipping load is 765 kilo Newton. In this paper a frame including slipping load equal 70 percent of axial buckling load of braces and springs with five percent of axil stiffness of brace and liquid is selected and it is compared with the a ordinary CBF (X1B) under the cyclic load pattern. Figure4 shows the hysteresis curves of these two frames.

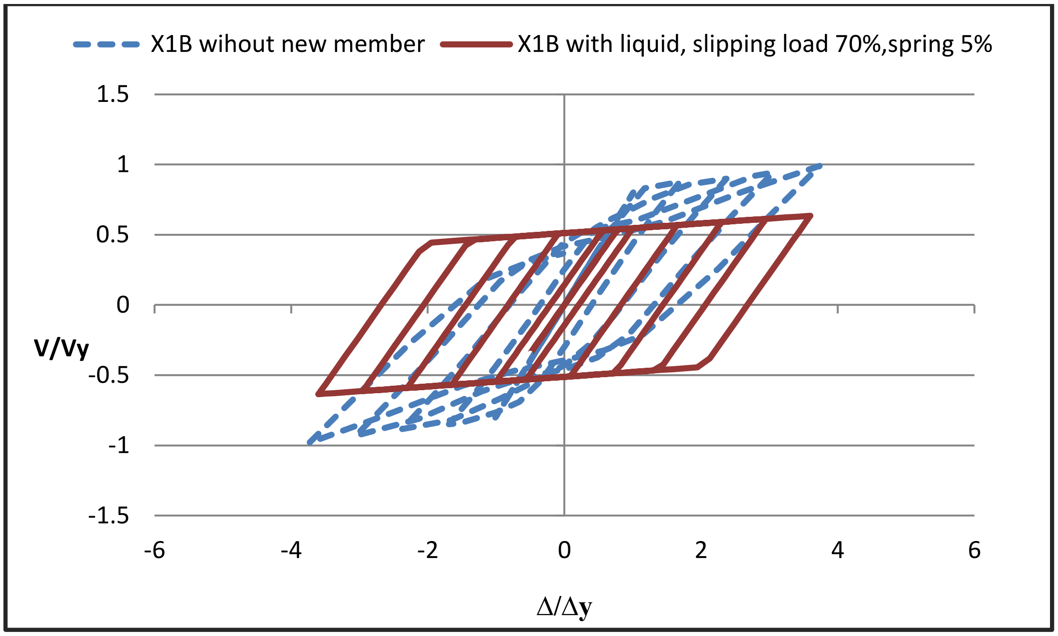

Figure4. Hysteresis curve of two frames

The horizontal axis of figure4 shows the base shear force in terms of yielding base shear and the vertical axis shows the displacement in terms of yielding displacement. The reason that slipping load selected 70 percent of buckling axial load is to make sure that buckling does not happen before slipping happens. If the springs be hard, the maximum load of braces will increase. The axil stiffness of braces is 1115 Newton to Millimeter so the stiffness of each spring will be 55.75 Newton to Millimeter. Controlling the axial load of braces in CBFs is the most important target to ban the early buckling happening. Figure5 shows the maximum axial load of X1B frame with and without new member under the cyclic load pattern.

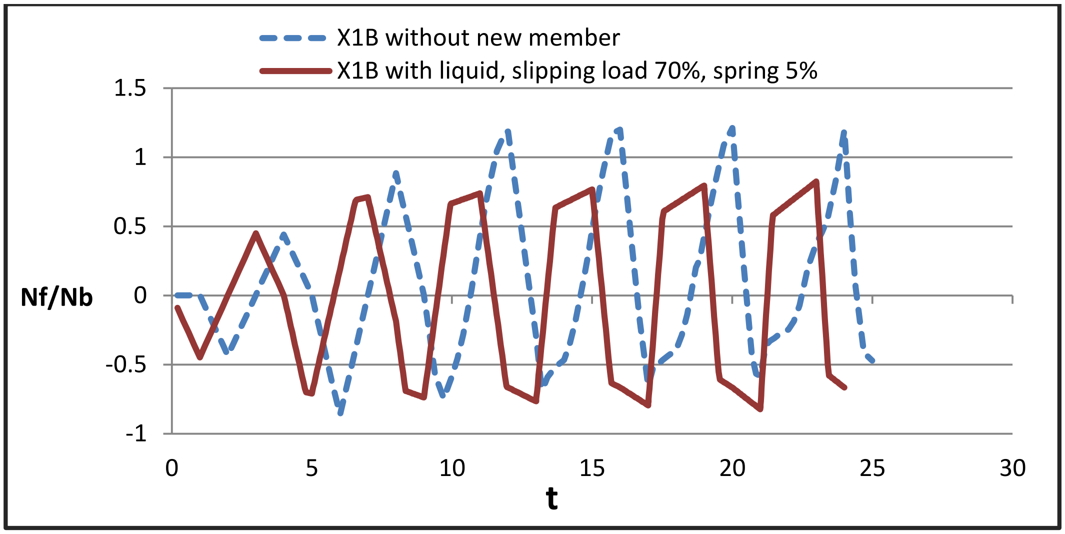

Figure5. Axial load of braces of two frames

The vertical axis of figure5 shows the axial load of brace in terms of buckling axial load of braces in frame including slipping load and the horizontal axis shows the virtual time of cyclic analysis.

4. Conclusion

1. Adding incompressible liquid and soft springs to the CBFs decrease the buckling potential of compressive braces.
2. Presence of slipping load to the CBFs makes the effective length of buckling shorter and decreases the buckling potential of compressive brace up to 18 percent.
3. The computation of the area of hysteresis curve loops shows that the loops area in frame with new member is 48 percent more than CBF without new member. It means this new frame is more ductile and will have a better seismic behavior.

4. By using new member in CBFs the maximum axil load of braces have experienced reduction up to 40 percent.
5. The reduction of maximum axial load in braces means design sections will be smaller and the weight and expenses of structure will decrease.

5. references

1. A. S. Pall, C. Marsh, "Response of friction damped braced frames," vol. 108, no. ST6, May 1981,PP. 1313-1323, 1982.
2. S. Malek, P. Pabsang, A. Lohghadam, "Introduce a new passive damper system and compare it with the so-called damper TADAS." Proc.1st International Conference on Seismic Retrofitting,Tehran.
3. S. B. Beheshti-Aval, H. Mahbanoui, F. Zareian, "A Hybrid Friction-yielding Damper to Equip Concentrically Braced Steel Frames," vol. 13, no. 4, pp. 1–11, 2013.
4. R. Tremblay, M. Archambault, and A. Filiatrault, "Seismic Response of Concentrically Braced Steel Frames Made with Rectangular Hollow Bracing Members," no. December, pp. 1626–1636, 2003.
5. R. Tremblay, P. Timler, and M. Bruneau, "Performance of steel structures during the 1994 Northridge earthquake," vol. 360, pp. 338–360, 1995.
6. B. K. Ikeda, S. A. Mahin, and M. Asce, "Cyclic Response of Steel Braces," vol. 112, no. 2, pp. 342–361, 1986.
7. A. M. Remennikov and W. R. Walpole, "Analytical prediction of seismic behavior for concentrically-braced steel systems," *Engineering*, vol. 26, no. January, pp. 859–874, 1997.
8. R. Tremblay, "Inelastic seismic response of steel bracing members," vol. 58, pp. 665–701, 2002.
9. K. Lee and M. Bruneau, "Energy Dissipation of Compression Members in concentrically Braced Frames: Review of Experimental Data Data," 1992.
10. A. Watanabe, Y. Hitomi, E. Saeki, A. Wada and M. Fujimoto, "Properties of brace encased in buckling-restraining concrete and steel tube," Proc 9th World Conference on Earthquake Engineering, Tokyo-Kyoto, Japan, 1988.
11. M. Mirtaheri, A. P. Zandi, S. S. Samadi, and H. R. Samani, "Numerical and experimental study of hysteretic behavior of cylindrical friction dampers," Eng. Struct, 2011.
12. B. Shaback and T. Brown, "Behaviour of square hollow structural steel braces with end connections under reversed cyclic axial loading," pp. 745–753, 2003.
13. K. D. Palmer, C. W. Roeder, M. Asce, D. E. Lehman, M. Asce, T. Okazaki, C. Shield, and M. Asce, "Experimental Performance of Steel Braced Frames Subjected to Bidirectional Loading," no. August, pp. 1274–1284, 2013.
14. ANSYS Mechanical APDL Element Reference Release 15

15. C. Y. Tsai, K. C. Tsai, C. H. Lin, C. Y. Wei, K. J. Wang, Y. J. Yu, and A. C. Wu, “Cyclic responses of three 2-story seismic concentrically braced frames,” Front. Archit. Civ. Eng. China, vol. 4, no. 3, pp. 287–301, 2010.
16. J. H. Yoo, C. W. Roeder, and D. E. Lehman, “Simulated behavior of multi-story X-braced frames,” Eng. Struct., vol. 31, no. 1, pp. 182–197, 2009.
17. D. Finite, E. Analysis, F. F. Steel, H. Tagawa, T. Miyamura, and T. Yamashita, “Title : Detailed Finite Element Analysis of Full-scale Four-story Steel Frame Structure subjected to Consecutive Ground Motions,” 2015.
18. K. M. Ward, R. B. Fleischman, and G. Federico, “A cast modular bracing system for steel special concentrically braced frames,” *Eng. Struct.*, vol. 45, pp. 104–116, 2012.
19. G. Federico, R. B. Fleischman, and K. M. Ward, “Buckling control of cast modular ductile bracing system for seismic-resistant steel frames,” *J. Constr. Steel Res.*, vol. 71, pp. 74–82, 2012.