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ARTICLE

Numerical Study of the Behavior of Steel Frame with Concentric Buckling Restrained and Conventional Braces

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ABSTRACT

In this paper, a method is proposed to provide a simple model of buckling restrained braces. After introducing the elements, taking into account all parts of buckling restrained braces, a sample of this type of braces is modeled in finite element Abaqus software. After confirming the numerical model using the available laboratory results, which is carried out by static nonlinear analysis, moment frame model with chevron bracing is compared with moment frame with chevron buckling-restrained bracing. In this study, the behavior of buckling restrained braces as a hysteretic damper was investigated and a good performance was observed in energy absorption compared to conventional bracing.

1. Introduction

Several types of control systems including active, semi-active and passive control systems have been developed to systematically control the structure under destructive effects of earthquakes[1][2][3][4][5]. The Buckling-Restrained Bracing Frame (BRBF) is a new type of braced system with energy dissipation that uses to improve the behavior of concentric brace frames. In this system, the brace element is placed in a sheath that prevents buckling of the element. With this equipment, the behavior of the brace is the same as its behavior in tension with yielding (rather than buckling) under pressure, and thus resulting in improved ductility and energy dissipation than in conventional braces. The elastic stiffness of the bracing frames is comparable in terms of the stiffness of the frames that have eccentric braces. The results of real-dimensional experiments on these members show that the equipped frames with buckling restrained systems using this method and proper implementation details are included. These systems show stable and symmetrical behavior under pressure and elasticity, and even in very large deformations[1][2][3][4][5]. In addition, the ductility and energy-absorbing capacity of these frames are in the range of special steel moment frames (steel frames with a high ductility) and more than special bracing frames, which is a result of the high level of ductility resulting from the enclosure of the steel core of the braces against buckling[1][2][3]. In order to prevent possible damage to existing buildings in future earthquakes and to develop these buildings, their performance and their behavior are

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quintessential. Methods of reinforcing these structures as well as their design criteria are possible in different ways. The reinforcement of steel frames by using bracing systems has been considered by many researchers as one of the most practical and effective methods[4][5][6][7][8][9][10]. Therefore, it is necessary to develop the use of steel braces conducting a number of investigations. The results of experiments carried out in 2002 on buckling restrained braces showed that the gusset plates actually created a rigid opening and the the rotation of the nodes would be considered due to the high rigidity of the gusset plate in analysis and design[7]. Rahnavard et al. (2018) studied the numerical methods of buckling restrained bracing modeling. They presented the method of using spring as an alternative method for modeling concrete and casing, the results of which were more accurate than the complete modeling of concrete and casing[8][9][10][11][12]. In 2005, Choi and Kim, using the hysterosic energy spectrum, presented a method for designing frames equipped with buckling restrained braces[13]. In this method, it is assumed that the beams and columns remain under gravity loads in an elastic state, and energy dissipation and the resulting damage occur only in buckling restrained braces. In 2006, Fahnestock and his colleagues presented a research program on buckling restrained braces[14]. Jea et al. (2014) studied and compared the analysis of the periodic function of moment frame system with buckling restrained brace and moment frame without bracing. Their results showed that moment frame with buckling restrained braces tolerated shear force more than twice that of a moment frame without bracing[15].

1.1 Buckling Restrained Braces

Shocking statistics published on the status of existing buildings, the observation of urban construction and a look at the causalities and financial losses of earthquakes in recent years, is an indicative of the vulnerability of most of the existing buildings in the face of a relatively severe earthquake. With this in mind, precise control over the calculation and execution of buildings is an important factor in preventing or reducing casualties is necessary. However, it should be noted that there are a bulk of buildings built in the past, and some actions should be taken to improve their seismic performance. In addition, buildings damaged by earthquakes need structural reinforcement, due to several factors including the following:

• Due to their lack of sufficient lateral stiffness and strength, these structures require lateral reinforcement and drift control.

• Due to some weaknesses, such as infilled frames or brick infilled frames as part of a seismic isolation system, or the inability to use suitable bracing or ductility systems, there is a potential for sudden and crisp destruction, and as a result, in addition to damages to the structure, there is no chance for escape from the collapse of the inhabitants, and casualties will increase.

• It may be necessary to increase the number of floors, increase the level of floors, or change in utilization. Due to the increase in loads and the change in the structural characteristics of the structure, reinforcement may be needed

The idea of using a yielding steel element to absorb energy was introduced more than 30 years ago. The new approach was to squeeze the compression element before buckling. The important point is that the yielding does not take place locally and its distribution throughout the element is appropriate and uniform, so that the depreciated energy reaches its maximum during a reciprocal loading, such as an earthquake. This research was based on the prevention of buckling of the compression bracing using concrete coating around it. In this kind of braces, the pressure bearing is obstructed by the steel core, and the concrete coating only prevents the buckling of the steel core, which causes the lateral distribution of the internal pressure in the coating concrete[3][4][5][6]. Figure 1 shows the ideal behavior of the buckling-restrained brace.

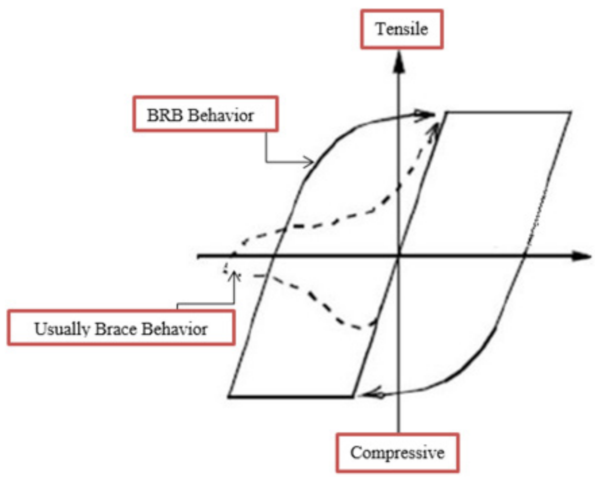

Figure 1. The Ideal Behavior of Buckling-restrained Brace[9]

In order to avoid the axial compressive force transmitted to the concrete from the steel core, a thin layer of special material is placed on the joint surface of steel and concrete. This layer, by preventing the friction between the core and the concrete, transmits the compressive force due to the lateral displacement of the core steel to a single wide load transverse to concrete. Ultimately, this way of transferring force in the buckling element has led to the use of this type of braces as an unbonded brace. Figure 2 shows a variety of buckling restrained braces.

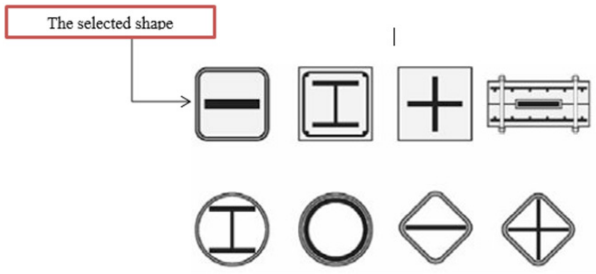

Figure 2. Variants of Buckling Restrained Braces

The use of this type of braces began in Japan in the 1980s. In the 1990s, researchers from the United States carried out extensive research on unbounded bracs, which led to the use of this type of braces in various buildings to improve seismic rehabiliation. The research is ongoing in other countries in the world, including India and Taiwan. The devastating consequences of an earthquake, combined with loss of life and economic damage, make it more important than ever to perceive the proper understanding of the behavior of structures under earthquake vibratory stimulations. This is one of the main concerns of civil engineers in designing various structures and forcing them to design strong structures against earthquake forces. In the design of structures, a combination of resistance, ductility and energy absorption capacity should be provided. Given that the inherent capacity of most structures to absorb energy from earthquake forces is very low, a certain level of ductility and volnirability in structures will be acceptable. The damages to structures are largely unrecoverable and will result in high economic costs. The use of buckling braces can significantly increase the energy absorption capacity of the structure and ultimately reduce structural damage[3][4][5][6].

In this research, moment frame modeling with chovern conventional brace and moment frame with chovern buckling restrained brace are compared with each other using finite lement method and using ABAQUS. Moreover, new method for BRB modeling is presented.

2. Numerical Modeling

The purpose of such studies is to estimate and calculate the design parameters of these elements. In this step, loading will only be done in the form of reciprocal displacement. The loading procedure in this case is considered as a linear increase load applied to the two ends of the columns as a cyclic loading. Given that in the step stage, the analytical method is nonlinear static, so it is possible to study the nonlinear behavior of the models. In Figure 1, the overall model used for conventional and buckling restrained braces is shown. These models are called VCBF (Shervon CBF) and VBRB (Shervon BRB), respectively. The length of the openings in this model is 6 meters and the height of each floor is 3.4 meters. The sections IPE27 and 2IPE27 are considered respectively for columns and beams. Also, 2UNP12 and PL110 × 10 mm were used for conventional and buckling restrained braces.

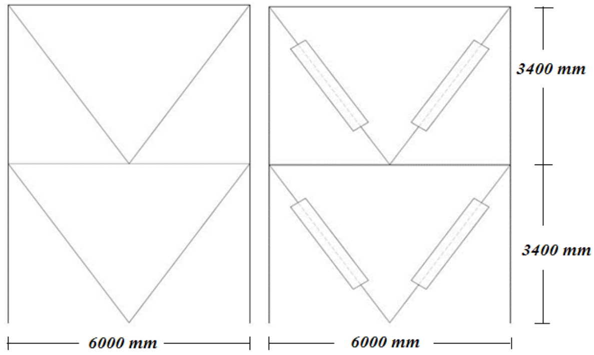

Figure 3a. Moment Frame Model with Conventional Chovern Brace (VCBF)

Figure 3b. Moment Frame Model with Buckling Restrained Chovern Brace (VBRB)

In this section, for evaluating and comparing the laboratory sample and numerical model, we study the modeling of the moment frame with buckling restrained braces. To achieve this goal, the laboratory model of Jea et al. was selected[15]. Figure 4 shows the geometric dimensions of the laboratory model. A spring was used for modeling the casing and filler concrete. All parts of the model were also performed using the S4R shell element. This element has four nodes and six degrees of freedom for each node. To determine the mechanical properties of steel, the value of the elasticity module is 210 GPa, and the amount of final yielding and stress for the core are 263 MPa and 379 MPa, for beams 261 MPa and 413 MPa, and for the enclosing steel and the column are 298 MPa and 366 MPa, respectively. Steel hardness is also used for isotropic and kinematic combinations. This hardening shows a good behavior in cyclic loading[16][17][18][19][20][21][22][23][24][25][26]. To load the models of this research, two types of near and far loading SAC have been used (Figure 4). Figure 5 shows a kernel-spring numerical model. In Fig. 6, we show curves drawn from laboratory and numerical models or springs. As can be seen in the figure, the behavioral hysteresis curves in both the software and the laboratory are very close in each case and have a good fit.

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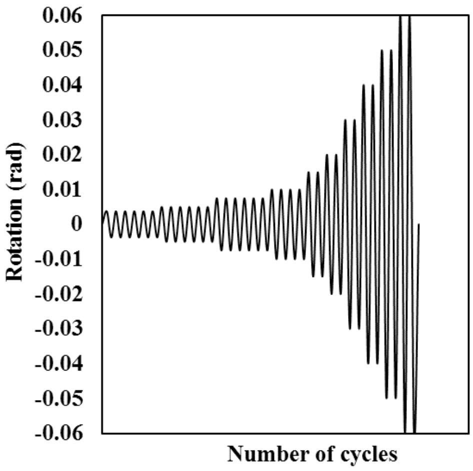

Figure 4a. Sac Cyclic Loading (Far Fault)

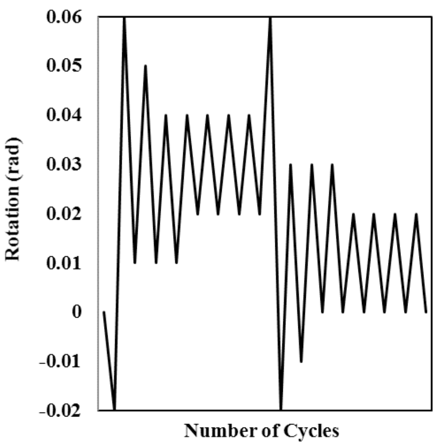

Figure 4a. Sac Cyclic Loading (Near Fault)

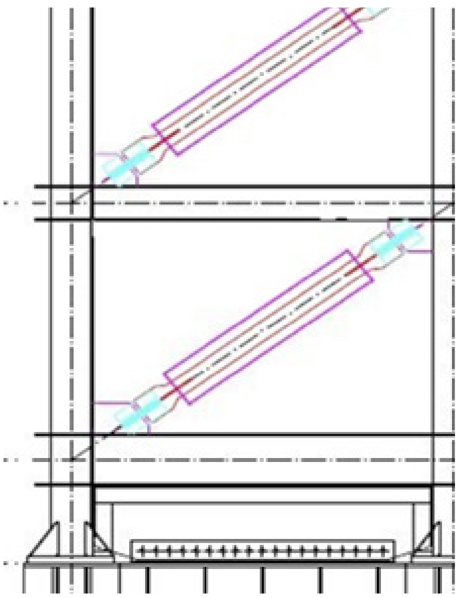

Figure 5. Geometry of the Laboratory Model (mm) [14]

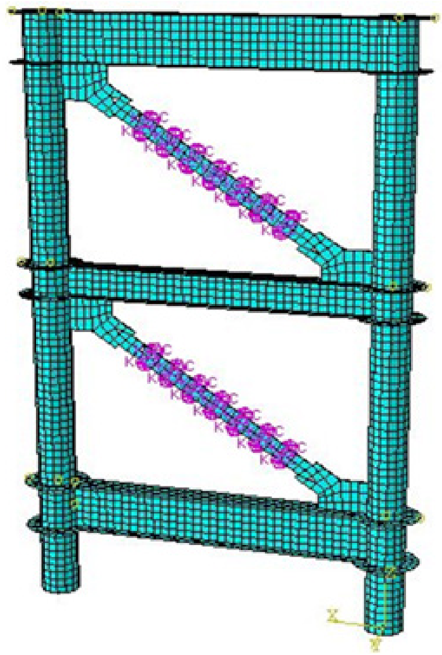

Figure 6. Numerical Model Constructed Based on Laboratory Model [14]

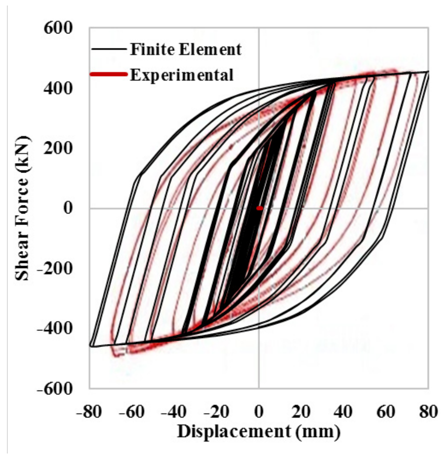

Figure 7. Comparison of Hysteresis Curves of the Numerical Model and Laboratory Samples

3. Analysis of Results

After finite element analysis of these two models in the Abaqus software, the results will be visible in the Visualization section. Therefore, the required results have been extracted and compared.

3.1 Plastic Stress and Strain Contour

In Fig. 8, the contour related to the distribution of stress in a moment frame with a conventional brace and a moment frame with buckling restrained braces is shown. As can be seen, in the conventional brace, the focus of stress in the middle of the openning has led to the buckling of the brace and the intermediate beam. In

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the buckling restrained brace, there is no buckling due to the bracing of the steel core. On the other hand, by observing the distribution of stress in the steel core, as shown in Fig. 8b, due to the stress distribution along the steel element, the maximum stress in this element has also been reduced. Given that in the conventional brace, the structural element experiences buckling and enlarged deformation during the first loading process, and that the hardness and strength of the element disappears, so it makes it impossible to use this member under pressure load. Consequently, in buckling restrained braces, due to improved compression strength of the member, these types of braces can be used to withstand tensile and compressive loads.

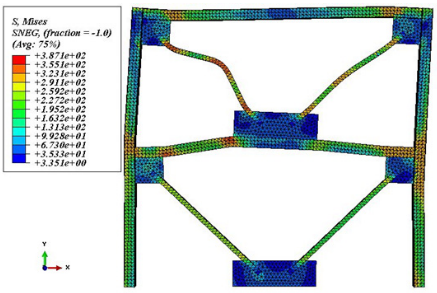

Figure 8a. Conventional Brace Stress Contour

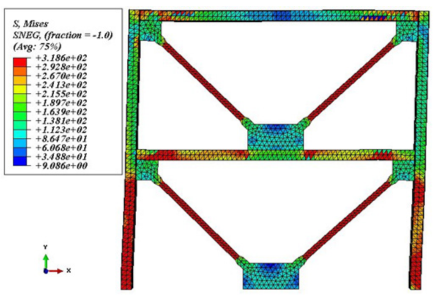

Figure 8b. Buckling Restrained Brace Stress Contour

In Fig. 9, the plastic strain distribution contour related to moment frame with a conventional brace and moment frame with buckling restrained braces is shown. As can be seen, in conventional brace, the focus of plasticization is in the middle of the openning, the brace and the gusset spring of the column. On the other hand, by observing the distribution of plastic strain in the steel core, as shown in Fig. 9b, due to the strain distribution along the steel member, its intensity in other elements was reduced. Due to the fact that in the conventional brace, the structural member during the first loading process is plasticised and the stiffness and strength of the element disappears, it is impossible to use this member under pressure load. Consequently, in buckling restrained braces, due to improved compression resistance of the member, these types of braces can be used to dissipate energy in the plastic region. To explain the same distribution observed along the conventional brace for both the stress and the strain, it is probably due to the proportionality between the stress and the strain.

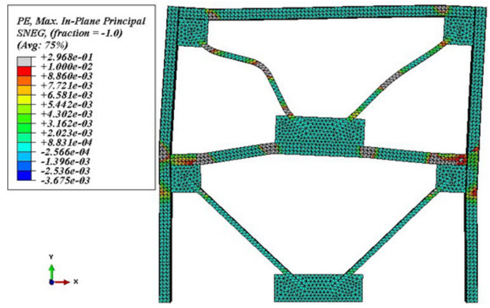

Figure 9a. Stress Contour of Conventional Brace

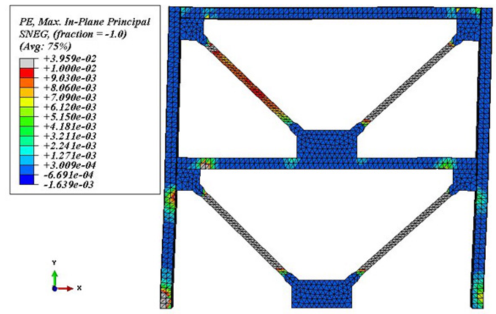

Figure 8b. Buckling Restrained Brace Stress Contour

3.2 Evaluation of Hysteresis Curve Under Far Load Pattern

In Fig. 10, the force-displacement diagram of the moment frame with a conventional brace and the moment frame with buckling restrained braces is shown under a far loading pattern. As it is seen, in the moment frame with a conventional brace, after a 30 mm displacement, the frame is accompanied by a sharp collapse. The reason for this deterioration is the buckling resistance of the brace under the influence of compressive force. As shown in Fig. 10a, this frame tolerates the force of 1800 kN in the first cycles, but after the bracing buckling, the shear force is about 950 kN. As seen in Fig. 10b, in the moment frame with buckling restrained brace, after a 300mm displacement, the frame experiences with an intangible collapse. As shown in Fig. 10b, this frame can withstand 1800 kN in all cycles. This means that the buckling restrained brace shows a uniformity of behavior in successive cycles. Comparison of the two diagrams shown in Figure 10 shows that the resistance decline in in the moment frame with buckling restrained brace (300 mm) decreases by up to 10 times compared to the moment frame with the buckling brace (30 mm). Moreover, the curving cycles in the moment frame model with the buckling restrained braces are more obtuse.

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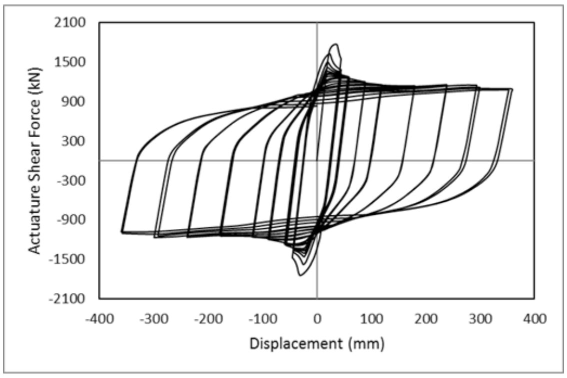

Figure 10a. Force-displacement Diagram under the Influence of Far Pattern (Frame with Conventional Brace)

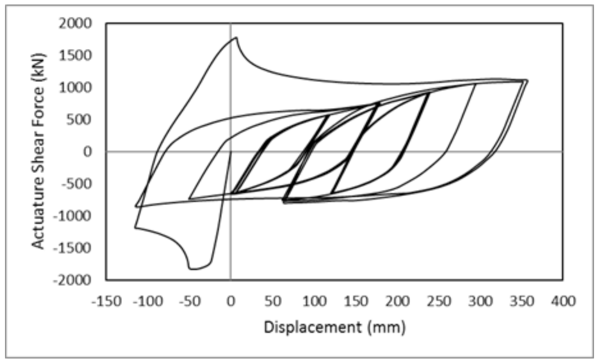

Figure 11a. Force-displacement Diagram under the Influence of Near Pattern (Frame with Conventional Brace)

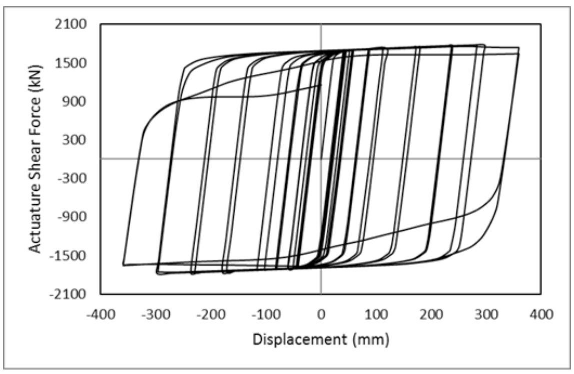

Figure 10b. Force-displacement Diagram under the Influence of Far Pattern (Frame With Buckling Restrained Brace)

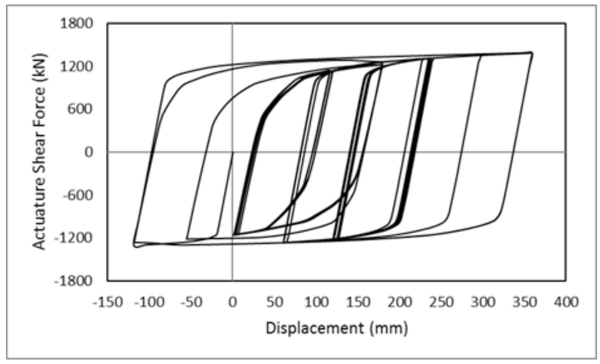

Figure 11b. Force-displacement Diagram under the Influence of Near Pattern (Frame with Buckling Restrained Frame)

3.3 Evaluation of Hysteresis Diagram under Near Load Pattern

In Fig. 11, the force-displacement diagram in the moment frame with a conventional brace and a moment frame with buckling restrained braces is shown under near loading pattern. As it is seen, in the moment frame with a conventional brace, after 50 mm displacement, the frame is associated with a severe collapse. The reason for this deterioration is the buckling resistance of the brace under the influence of compressive force. As shown in Fig. 11a, this frame can withstand a force of 1,750 kN in the first cycles, but after buckling, the shear force is about 850 kN. As seen in Fig. 11b, in the moment frame with buckling brace, after displacing a 350mm the frame experiences an intangible collapse. As shown in Fig. 11b, this frame can withstand 1800 kN in all cycles. This means that the buckling brace shows a uniformity of behavior in successive cycles. The comparison of the two diagrams in Fig. 11 shows that resistance reduction in the moment frame with the buckling restrained brace is up to 7 times as compared to the moment frame with the buckling brace. Also, the curving cycles in the moment frame model with the buckling restrained braces are much more obtuse.

4. Conclusion

In this study, using finite element method, two moment frame models with conventional chovern brace and with buckling chovern brace were compared under SAC far and near loading patterns. The use of buckling restrained braces led to increased bracing strength and ductility. Therefore, it creates a symmetry in the resistance of the element under the axial load of the strain and compression, and therefore the full capacity of braces in strain and pressure is used in the structural frame systems in which the braces are used double. Given that the main task of braces is to withstand lateral loads, the use of buckling restrained braces, in addition to increasing the safety of the structure, will make the rest of the structure thin, making the design more economical. The use of buckling restrained braces makes the structure of the frame function symmetrical, and therefore the performance of these structures will be improved against actual loads such as earthquakes that have reciprocal nature. Proper reinforcement, based on ease in executive problems as well as economic considerations, provides this structural optimization method with a very good performance for resistance, stiffness and ductility, which is one of the

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basic principles for an optimization plan. Also, the results indicate that collapse in resistance in buckling bracing system is 10 times slower than the conventional frame system. Moreover, this results are supported by other research investigation[10].

References

[1] American Institute of Steel Construction, Inc. (AISC). (1999). Load and Resistance Factor Design Specification for Structural Steel Buildings. AISC, Chicago, IL, December 27.

[2] Rohola Rahnavard, Robert J. Thomas, (2019). Numerical evaluation of steel-rubber isolator with single and multiple rubber cores, Journal of Engineering Structures, https://doi.org/10.1016/j.engstruct.2019.109532

[3] El-Tayem, A. A., and Goel, S. C. (1986). Effective Length Factor for the Design of X-bracing Systems. Engineering Journal, AISC, vol. 24, page 41-45.

[4] El-Tayem, A. A., and Goel, S. C. (1986). Cyclic Load Behavior of Angle X-Bracing. Journal of Structural Engineering, vol. 112, Issue 11, pages 2528-2539.

[5] Kathib I. F., Mahin, S. A. (1987). Dynamic inelastic behavior of chevron braced steel frames. Fifth Canadian Conference on Earthquake Engineering, Balkema, Rotterdam, pages 211-220.Perotti, F., and Scarlassara, P. (1991). Concentrically Braced Steel Frames under Seismic Actions: Non-linear Behavior and Design Coefficients. Earthquake Engineering and Structural Dynamics, vol. 20, pages 409-427.

[6] Elghazouli, A. Y. (2003). Seismic design procedures for concentrically braced frames. Proceedings of the Institution of Civil Engineers: Structures and Buildings. volume 156, issue 4. Pages 381-394.

[7] Lopez, W. A., Gwie, D. S., Saunders, C. M., Lauck, T.W., (2002), "Lessons learned from largescale tests of unbonded braced frame subassemblages ", Proceedings 71st Annual Convention, Structural Engineers Association of California, Sacramento, California.

[8] Rohola Rahnavard, Akbar Hassanipour, (2015). Steel Structures analysis using ABAQUS, Kerman: Academic Center for Education, Culture and Research, Publishing Organization of Kerman branch

[9] Rohola Rahnavard, Mohammad Naghavi, Maryam Abudi, Mohamed Suleiman, (2018). Investigating Modeling Approaches of Buckling-Restrained Braces under Cyclic Loads, Case Studies in Construction Materials, Case Studies in Construction Materials 8 476–488

[10] Mohammad Naghavi, Rohola Rahnavard, Robert J. Thomas, Mohsen Malekinejad, (2018). Numerical evaluation of the hysteretic behavior of concentrically braced frames and buckling restrained brace frame systems, Journal of Building Engineering, Volume 22, Pages 415-428

[11] Rohola Rahnavard, Akbar Hassanipour, Ali Mounesi, (2016). Numerical study on important parameters of composite steel-concrete shear walls, Journal of Constructional Steel Research 121 441–456.

[12] Rohola Rahnavard, Akbar Hassanipour, Mohamed Suleiman, Ali Mokhtari, (2017). Evaluation on eccentrically braced frame with single and double shear panel, Journal of Building Engineering 10 13–25

[13] Choi, H., Kim, J., (2006), "Energy-based seismic design of buckling-restrained braced frames using hysteretic energy spectrum ", Engineering Structures, 28(2006), 304-311.

[14] Fahnestock, L. A., Sause, R., and Ricles, J. M., (2006), "Seismic response and performance of buckling-restrained braced frames ", Journal of Structural Engineering, ASCE, September 2007, pp. 1195-1204.

[15] Mingming Jia, Dagang Lu, Lanhui Guo, Lin Sun, Experimental research and cyclic behavior of buckling-restrained braced composite frame, Journal of Constructional Steel Research 95 (2014) 90–105.

[16] Rohola Rahnavard, Robert J. Thomas, (2018). Numerical Evaluation of the Effects of Fire on Steel Connections; Part 1: Simulation Techniques, Case Studies in Thermal Engineering. Vol 12, page 445-453

[17] Rohola Rahnavard, Robert J. Thomas, (2018). Numerical Evaluation of the Effects of Fire on Steel Connections; Part 2: Model results, Case Studies in Thermal Engineering. Vol 13, https://doi.org/10.1016/j.csite.2018.11.012

[18] Sahar Radkia, Rohola Rahnavard, Farhad Abbas Gandomkar, (2018). Evaluation of the effect of different seismic isolators on the behavior of asymmetric steel sliding structures, Journal of Structural and Construction Engineering, doi: 10.22065/JSCE.2018.114089.1428

[19] R Rahnavard, A Hassanipour, N Siahpolo, (2015). Analytical study on new types of reduced beam section moment connections affecting cyclic behavior, Case Studies in Structural Engineering 3, 33-51.

[20] Kelly, J. M., Skinner, R. I., and Heine, A. J., (1972), "Mechanism of energy absorption in special devices for use in earthquake resistant structures ", Bull. N.Z. Nat. Soc. Earthquake Eng. 5(3):63-88.

[21] Rohola Rahnavard, Navid Siahpolo, Mohammad

  DOI: https://doi.org/10.30564/jbmr.v1i1.992

Naghavi, Akbar Hassanipour, (2014). Analytical Study of Common Rigid Steel Connections under the Effect of Heat, Advances in Civil Engineering, vol. 2014, Article ID 692323, 10 pages. doi:10.1155/2014/692323

[22] Akbar Hassanipour, Rohola Rahnavard, Ali Mokhtari, Najaf Rahnavard, (2016). Numerical investigation on reduces web beam section moment connections under the effects on cyclic loading", J. Multidiscip. Eng. Sci. Technol.(JMEST) 2 (8), 3159-0040

[23] Rohola Rahnavard, Maziyar Taghi Khaje, Akbar Hassanipour, Navid Siahpolo, (2017). Parametric Study of Seismic Performance of Steel Bridges Pier Rehabilitated with Composite Connection", Journal of Structural and Construction Engineering, (DOI): 10.22065/JSCE.2017.92128.1259

[24] Rohola Rahnavard, Faramarz Fathi Zadeh Fard, Ali Hosseini, Mohamed Suleiman, (2018). Nonlinear analysis on progressive collapse of tall steel composite buildings, Case Studies in Construction Materials 8 359–379

[25] Sahar Radkia, Farhad Abbas Gandomkar, Rohola Rahnavard, (2018). Seismic Response of Asymmetric Sliding Steel Structure with Considering Soil-Structure Interaction Effects, Journal of Structural and Construction Engineering, doi: 10.22065/JSCE.2018.105638.1384

[26] Rohola Rahnavard, Navid Siahpolo, (2017). "Function comparison between moment frame and moment frame with centrically braces in high-rise steel structure under the effect of progressive collapse, Journal of Structural and Construction Engineering, Volume 4, Issue 4 - Serial Number 14, Page 42-57, doi: 10.22065/jsce.2017.77865.1084