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Analysis of the behavior of reinforced concrete buildings with and without non-buckling braces under the effect of earthquake loads

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Abstract

The moment frame is one of the most widely used seismic resistant systems in the world, due to its high formability and flexibility, this system causes a lot of displacement in the structure and force exceeding the capacity of the structural components. The bracing system is a suitable method to control the lateral displacement of the structure and the seismic improvement of the bending frame. The new type of bracing system that is used in the design of new systems and the improvement of old structures is non-buckling bracing, and in this research, their effect on the performance of 4, 7, and 10-story concrete moment frames under the Northridge, San Salvador, and Tabas earthquake has been investigated. The research method in this research is analytical-applied, which the results of this study showed; In the 4-story structure, the amount of wasted energy under the 3 considered earthquakes is equal to 0%, 0%, and 1% without buckling braces and 39%, 48% and 50% in the case with non-buckling braces and in the 7- story structure, the amount of energy consumed under the mentioned 3 earthquakes is equal to 0%, 0% and 0% without buckling braces and 40%, 45% and 51% in the case with non-buckling braces and also in the 10- story structure, the amount of energy consumed under the above 3 earthquakes is equal to 1%, 0% and 11% without buckling braces and 35%, 42% and 45% in the case with non-buckling braces. So, it was concluded that the performance of the structure in the case with non-buckling braces is better than in the case without non-buckling braces.
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"Keywords: Seismic performance, reinforced concrete frame, non-buckling bracing, Moment frame."

1. introduction

The moment frame system is one of the most widely used seismic resistant systems in the world, due to its high formability and flexibility, this system causes a lot of displacement in the structure and force exceeding the capacity of the components in the structure, and the failure of structural components and it will lead to non-structure [1]. The brace is a stiffening member of the structure against lateral forces such as wind or earthquake forces. Due to the fast implementation compared to the shear wall, it has become very popular among the public, but their incorrect implementation in the building not only does not cause stability but also causes twisting [2]. One of the important problems that occur in ordinary

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braces during an earthquake is the issue of buckling of the compression member. During an earthquake, the length of the brace is gradually increased permanently, and in return, this increase in inelastic length leads to premature buckling of the brace, and in the next cycles, it shows late resistance, and this causes more energy to be absorbed in the non-replaceable members and connections of the frame. bending and also increasing the lateral displacement of the structure. The bracing system is a very suitable method to control the lateral displacement of the structure and seismic improvement of the bending frame. The new type of bracing system that is used in the design of new systems and the improvement of old weak structures is non-buckling bracing, and in this research, its effect on the performance of the concrete moment frame is investigated. The non-buckling brace is one of the lateral load-bearing systems that has been expanding its use in structures in the last two decades. This lateral bracing system has replaced conventional braces (buckling braces) in convergent bracing frames due to its good performance. Compared to conventional braces, non-buckling braces exhibit more stable and symmetrical cyclic performance, resulting in significant energy dissipation capacity. The non-buckling brace consists of a ductile steel core. This steel core is placed inside a rectangular or round cross-section that is filled with concrete or mortar. Concrete or mortar that fills between the round or square steel core will delay the local buckling of the brace. The surface of the steel core is covered with a non-stick material to separate the concrete from the steel section. This non-stick material reduces the friction between steel and concrete as much as possible and reduces the transmission of axial force from the steel core to the concrete and the section of the steel shell. Also, because the Poisson effect causes the expansion of the steel core under pressure, so a small distance is needed between the steel core and the concrete. Also, in the compressive area, normal braces have an unstable hysteresis loop and energy absorption is low, while braces braced against buckling in the compressive area have stable hysteresis loops, and energy absorption in the compressive area is equal to the tensile area. This type of structural system acts like a hysteresis damper.

Parvri and Mazaheri (2010), in an article, investigated the effect of connecting beam length on the stiffness and ductility of divergent braces. Divergent EBF braces are among the lateral load-resistant systems that are used together with simple frames or bending frames to deal with the forces caused by earthquakes. Due to the compatibility of such braces with architectural conditions, their use in ordinary buildings is very common. The main advantage of divergent braces compared to convergent braces is their proper plasticity along with their hardness. For this reason, the use of this system in tall buildings where it is not possible to use converging braces is increasing day by day [3].

Jae-Do Kang, and Hiroshi Tagawa (2013), investigated the " Seismic response of steel structures with seesaw systems using viscoelastic dampers ". In his research, he evaluated a new vibration control system based on the seesaw mechanism using BRB. This mechanism can increase the ductility of the brace according to the configuration of the damper system. Seismic response analysis for steel bending frames was done with the proposed control system. The results of displacement periodic time showed that the proposed system can effectively reduce the seismic response of the frame [4].

Shakri et al. (2012) conducted a seismic evaluation of wind-braced structures with CFR columns equipped with viscous dampers. He stated in his research. The amount of damping in normal structures is very low, and therefore these buildings displace a lot under the influence of strong dynamic forces such as earthquakes by passing through the elastic range. The results showed that due to the many advantages of structures with CFT columns and their suitable seismic performance in both areas of hardness and resistance, their seismic behavior is very useful for a seismically prone country like Iran [5].

Asgar (2012), investigated the effects of converging bracing arrangement in the seismic evaluation of steel frames. In this research, three important seismic parameters, which are regulated in most of the seismic regulations, were examined as follows: 1- The maximum global displacement of the roof 2- The maximum relative displacement angle of the floor 3- The maximum local moment with Examining the mentioned indicators in each of the studied frames, the appropriate level is suggested to change the bracing type [6].

Black et al. (2014), review the Design of Seismically Resistant Tree-Branching Steel Frames Using Theory and Design Guides for Eccentrically Braced Frames. This article describes how the theories, protocols, and legal requirements of eccentrically braced frames (EBFs) were applied to the 2009 International Building Code (IBC) and the 2010 California Building Code (CBC) for prestressing steel frames. provide the earthquake and allow the construction of these incompatible geometries [7].

Azad, S. K., & Topkaya (2016), A review of research on steel eccentrically braced frames. The findings of numerical investigations on the seismic performance of EBFs are discussed to provide insight into the appropriate response factors used in the design of these systems. In addition, specific topics and applications of EBFs such as replaceable links are provided. The impact of the research findings on the design of EBFs systems considering AISC seismic regulations for steel structure buildings has been proven [8].

Chang-Hwan Lee et al. (2016); In his research, he addressed the numerical and experimental analysis of the combined behavior of shear-type friction damper and non-uniform strip damper for multi-level seismic protection. The obtained results showed that for metal frame structures of about 8 floors and less consisting of CBF and EBF bracing if the ratio of the number of EBF panels to CBF in each main direction is greater than or equal to three and ≥ 0.3, it can be the coefficient of the behavior of the EBF bracing system was used in the design of structures. By examining the proposed MBF bracing system, it was observed that for 4, 6, and 8-story models, the behavior coefficient of these structures with increasing height tends to the behavior coefficient of the EBF bracing system with medium plasticity, i.e., 7. One of the other advantages of this system is passing through a critical earthquake without destroying the roof beams of the MBF beam floors. The structure returns to its original state. In addition to these advantages, MBF has the possibility of opening installation and has better compatibility with architectural designs [9].

2. Methodology

In this research, a concrete moment frame system with and without non-buckling braces is investigated using the finite element method and using SAP 2000 software. Assuming that the structure is loaded in the form of the load-bearing width of the opening, and also based on the steel and concrete regulations of Iran, the design of the concrete structure is done. In the following, according to the regulations of 2800 4th edition and ASCE07-10, applied earthquakes are scaled concerning the mentioned structure. Then the cyclic curve of force displacement, energy consumption, and damping are investigated and drawn and compared for both systems.

Based on the present study, using the available resources and related tools, the following goals have been considered:

1- Comparison of the base shear stress applied to the structure in the concrete frame compared to the non-buckling brace

2- Calculation of the maximum displacement of the structure for the concrete frame system with and without buckling braces

3- Investigation of energy consumption and absorbed energy in the concrete frame system with the non-buckling brace

4- Investigating the behavior of force-displacement of non-buckling brace used due to different earthquakes

Buckling-resistant bracing frames (BRB) are a special type of convergent bracing frame in which the buckling of the bracing is prevented by special measures. Figure (1) shows a comparison between the behavior of a non-buckling brace and a normal convergent brace in a loading cycle.

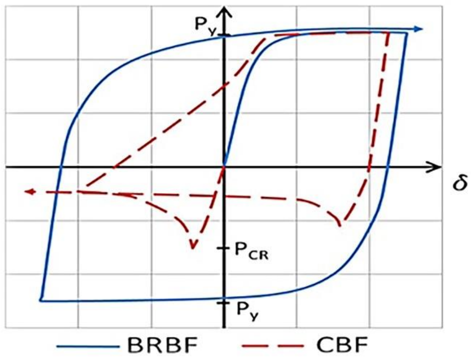
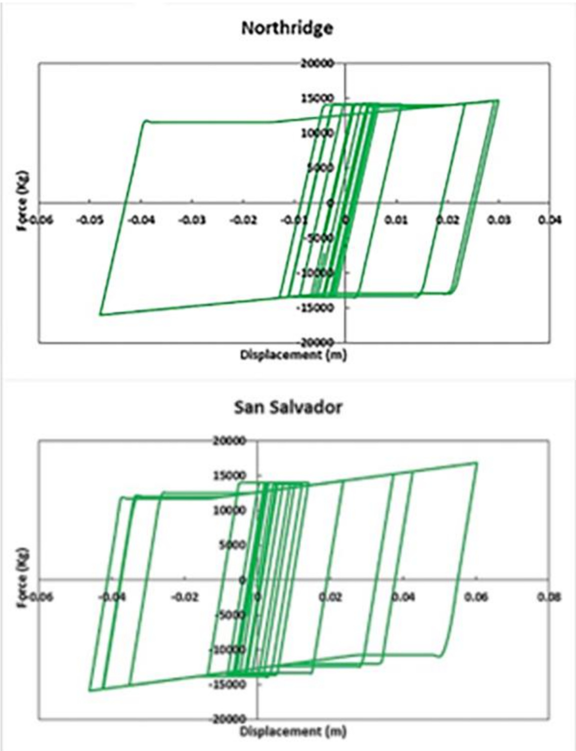


Fig. 1. Behavioral comparison between normal braces and non-buckling braces [10]

In this study, the buildings are the residential type with medium importance and in the area with relatively high risk. The land used is type II and the building is of moment frame concrete type. The floors have a rigid diaphragm, and also in the design of the models, the topics of the National Building Regulations, ASCE07-10, Publication 360, and the 2800 Regulations (4th Edition) have been used.

3. Results and discussion

According to the hysteresis diagram of the 4-story structure, it was observed that the bracing entered the non-linear range in the Tabas earthquake and has a larger area under the diagram. The hysteresis curve of the brace in all earthquakes has the same dissipated force but different displacement. The non-buckling brace behaves in the same way as tension in compression, so its hysteresis curve has positive and negative areas. The maximum longitudinal displacement of the brace was equal to 10 cm. Figure (2) shows a comparison between three considered earthquakes for a 4-story structure.



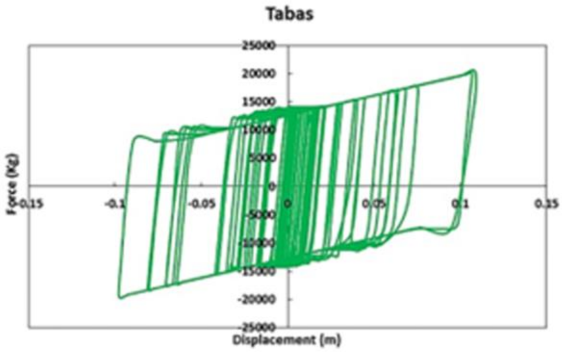
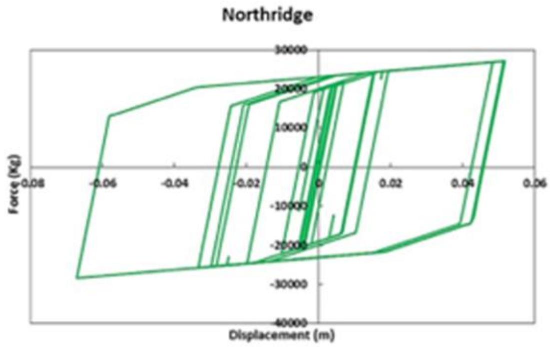


Fig. 2. Hysteresis behavior of non-buckling bracing in a 4-story building under three earthquakes: Northridge, San Salvador, and Tabas

According to the hysteresis diagram of the 7-story structure, it was observed that the bracing entered the non-linear range in the Tabas earthquake and the area under the diagram is larger. The hysteresis curve of the brace in all earthquakes has the same dissipated force but different displacement. The non-buckling brace behaves in the same way as tension in compression, so its hysteresis curve has positive and negative areas. The maximum longitudinal displacement of the brace was 10.5 cm. Figure (3) shows a comparison between three considered earthquakes for a 7-story structure.



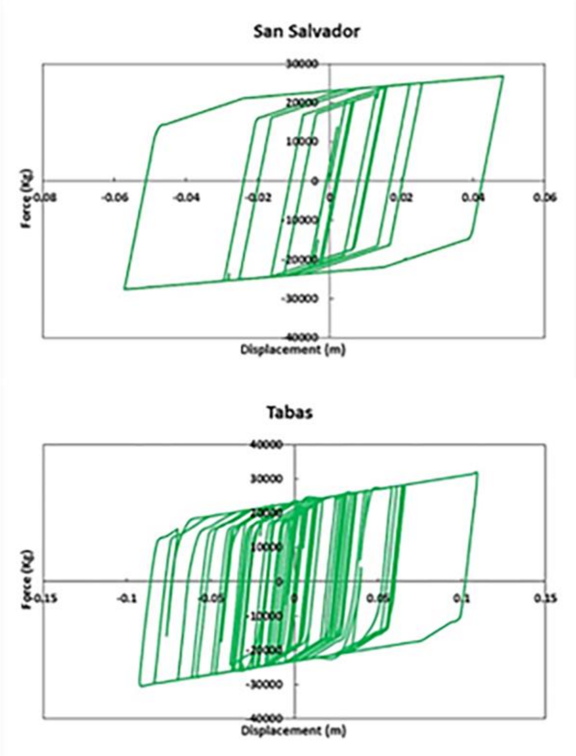


Fig. 3. Hysteresis behavior of non-buckling bracing in a 7-story building under three earthquakes: Northridge, San Salvador, and Tabas

According to the hysteresis diagram of the 10-story structure, it was observed that the bracing entered the non-linear range in the Tabas earthquake and has a larger area under the diagram. The hysteresis curve of the brace in all earthquakes has the same dissipated force but different displacement. The non-buckling brace behaves in the same way as tension in compression, so its hysteresis curve has positive and negative areas. The maximum longitudinal displacement of the brace was equal to 10 cm. Figure (4) shows a comparison between three considered earthquakes for a 10-story structure.

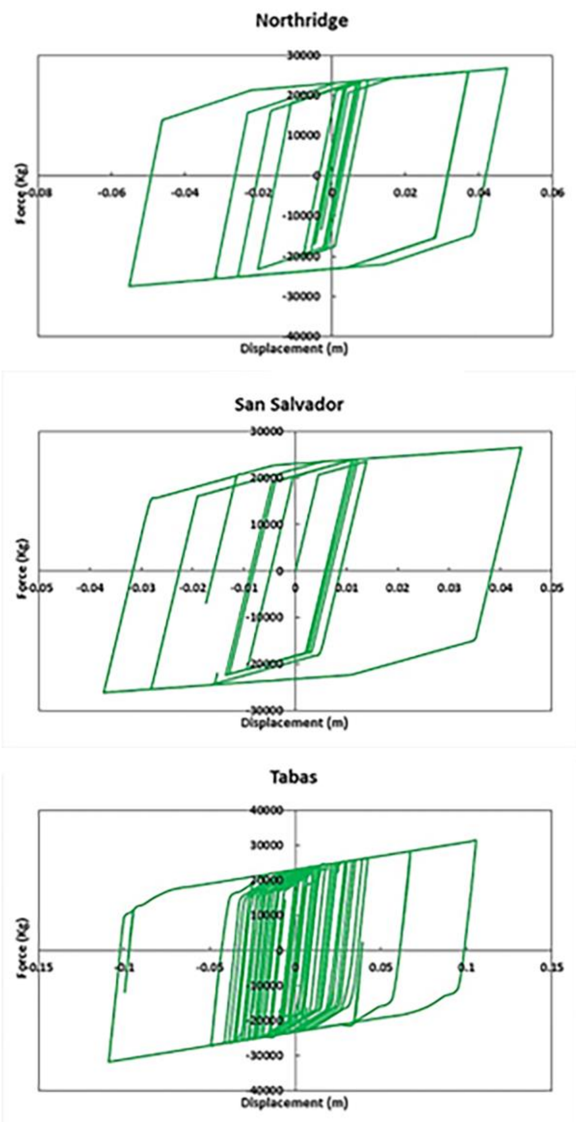


Fig. 4. Hysteresis behavior of non-buckling bracing in a 7-story building under three earthquakes: Northridge, San Salvador, and Tabas

4. Conclusions

In the present study, the general results of the analysis of 4, 7, and 10-story buildings under renovation with passive non-buckling bracing systems have been obtained as follows.

- In the 4-story structure, the amount of energy consumed under the 3 earthquakes of Tabas, Northridge, and San Salvador in the case without non-buckling braces is equal to 0%, 0%, and 1% and in the case with non-buckling braces is equal to 39%, 48% and it is 50%.

- In the 7-story structure, the amount of energy consumed under the 3 earthquakes of Tabas, Northridge, and San Salvador in the case without buckling brace is equal to 0%, 0%, and 0% and in the case with buckling brace is equal to 40%, 45% and 51 % is
- In a 10-story structure, the amount of energy consumed under the 3 earthquakes of Tabas, Northridge, and San Salvador in the case without buckling braces equals 1.1%, 0%, and 11%, and in the case with braces equal to 35%, 42% and it is 45%.
- In each earthquake, the amount of energy consumption is different, but in general, the average energy consumption in 4, 7, and 10-story structures was higher, respectively, and this average decreased with the increase in height.
- as the results say; The performance of the structure in the case with non-buckling bracing is better than in the case without non-buckling bracing. High consumption of energy in the structure reduces the effects of earthquakes on the structure and also reduces seismic damage in non-structural elements and joinery.
- The displacements of the structure by using non-buckling braces have been significantly reduced and this reduction of displacements has caused the control of the drift of the structure.
- In examining the displacement of the 4, 7, and 10-story structures, the maximum displacement occurred in the structure under the Tabas earthquake, which is 100, 185, and 240 cm without non-buckling braces and 63, 98, and 167 cm in the case with non-buckling braces. The fact that the structure has had a lot of displacement should be investigated in the environmental conditions of the structure, whether the structure can have this amount of displacement or is there a limit.
- In the examination of foundation shear of 4, 7, and 10-story structures, the maximum amount of foundation shear occurred in the structure under the Tabas earthquake, which is 1,400, 2,000, and 1,800 tons without non-buckling braces, and 1,000, 1,300 And 1700 tons with braces. The shearing of the foundations of the structure by using non-buckling braces has been significantly reduced, and this reduction of shearing of the foundation has led to the control of the structure, and therefore, the use of light sections and low earthquake force on the structure makes the design more economical.

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