Proposing a new bracing system with bending yielding circular plates under cyclic loading

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ABSTRACT

The most prevalent way to deal with lateral loads in steel structures is using common bracing systems like concentric bracing system. One of the major drawback of this system is the buckling when the compression force exceeds the elastic buckling strength, thereby being unstable before reaching the yield limit. In other words, the behavior of these braces is asymmetric under tension/compression forces leading to reduce the ability of the system in absorption of the most exciting energy and can lead to additional structural and non-structural damages due to the change in the direction of the inertial forces. To tackle these problems and in order to improve the performance of bracing systems, in this work for the first time, a new bracing system called fan bracing system has been introduced. Fan brace enhances the ductility and energy absorption of the system by removing harmful buckling effects through replacing axial deformations by flexural ones, tends to make the system softer and thus increase the natural vibration period of the structure and reduce the earthquake shear force. In this study, the proposed brace is studied using numerical modeling under affecting cyclic excitation based on the loading protocol of ATC-24. The advantages of this system include the symmetrical behavior even in the large cyclic deformations, as well as high energy absorption and lighter weight in comparison with the buckling-restrained brace (BRB).

KEYWORDS

Fan bracing system, numerical modeling, cyclic loading, energy absorption, seismic loading.

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1. Introduction

It is widely accepted that earthquake is one of the natural disasters that can still cause devastating loss of life and property. Considering the seismicity of many heavily populated urban areas, the only way to mitigate the impacts of earthquakes is to rehabilitate the existing structures and strictly enforce seismic codes on new structures to ensure adequate protection against this phenomenon.

The use of conventional bracing systems to deal with lateral loads is the most common way from the past to the present. The drawbacks of this systems are the buckling under compressive forces that reduce ductility and energy absorption of the structure as well as damage to structural and non-structural components. In recent decades, engineers have conducted many studies to improve the seismic performance of structures. Notable examples of this studies include buckling-restrained braces (BRB) [1], Added Damping and Stiffness (ADAS) and Triangular Added Damping and Stiffness (TADAS) dampers [2], using Cast Steel Yielding (CSY) fuse at the end of braces [3], and drawer bracing system (DBS) [4].

This paper introduces a new brace design called the fan brace. The mechanism of this brace is similar to the CSY and DBS. The main difference between FBS and two others is locating the yielding disks inside the steel case in a brace instead of a limited length absorber. Other innovations of this study are presenting construction technique and the seismic characteristics of this brace such as strength and energy dissipation.

2. Methodology

The schematic view and internal components of a fan brace are shown in Figure 1.

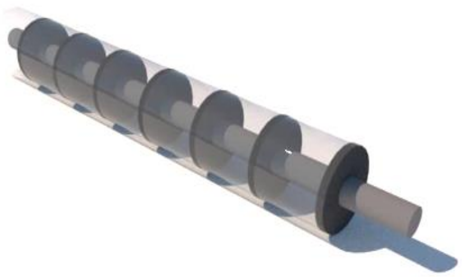

Figure 1. Schematic view and internal component of FBS.

This brace consists of three sections: steel fans, a central shaft, and a steel casing. The steel shaft passes through the middle of the steel fans, which are connected to the shaft by special mechanical connections or welding. The inner wall of the casing has several grooves with the same width as the fans (with suitable tolerance), which provide a place for the fans to fit in once the system of shaft and fans is installed inside the casing. Figure 2 shows the arrangement of components of the fan brace.

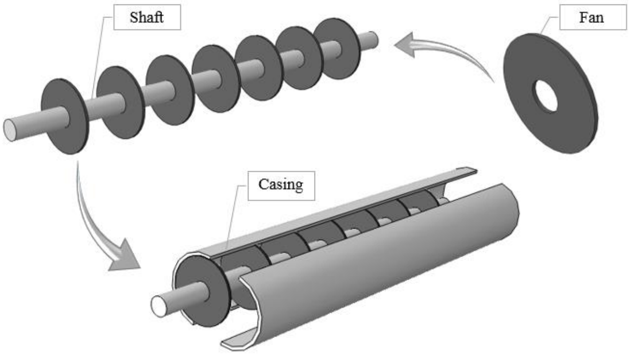

Figure 2. The arrangement of components of the FBS.

In the introduced brace, the axial force applied to its connection with the frame is transferred to the shaft and then to the attached fans. The fans transform this axial force into bending, thereby providing the necessary stiffness, strength, and energy dissipation. Since there is much greater deformation potential in yielding by bending force than by axial force, plastic deformation of the fans allows the system to provide considerable energy dissipation along with extensive ductility (unlike BRBs, which offer less ductility in yielding because of the high stiffness of the cross-section under axial loads).

3. Discussion and Results

The structure considered in this study was a 4-story 3-span residential building with a square plan and a span length of 5 meters and a story height of 3.2 meters, which was assumed to be located in an area with high seismic risk (Figure 3). The lateral load-bearing system in both sides was considered to be bracing. The structure was designed according to ASCE/SEI 7-16 [5]. To determine the seismic coefficient, the structure was designed using the equivalent static method with the importance factor considered to be 1 and the soil type was considered to be B. Considering the lack of any prior study on the behavior factor of the fan brace, this factor was set to be 7 (between the behavior factor of BRB and that of special concentric brace).

The proposed brace was modeled in the finite element software Abaqus [6].

The cyclic load applied according to the ATC-24 loading protocol [7] is shown in Figure 4 and the hysteresis curve of the modeled fan brace under this load is illustrated in Figure 5.

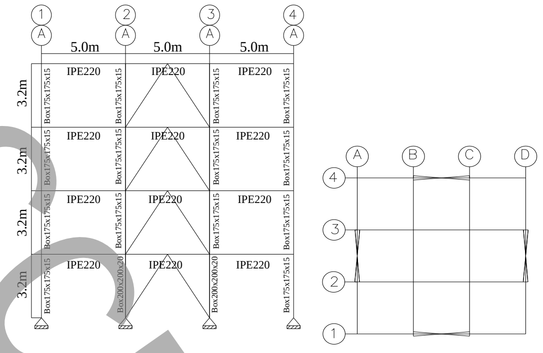

Figure 3. (a) Plane and (b) elevation of considered building.

According to the Von Mises stress distribution plotted in Figure 6, the stress created in all fans is approximately uniform. This reflects the good dimensions and materials of the shaft and casing, which have allowed all fans to contribute to energy dissipation. Also, the distribution of stress in the core and the casing is such that the maximum stress has emerged at the end of the casing that is connected to the frame and the minimum stress has occurred in the free end of the casing.

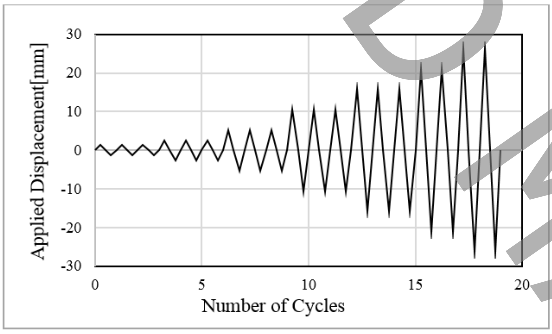

Figure 4. The cyclic load applied according to the ATC-24 loading protocol.

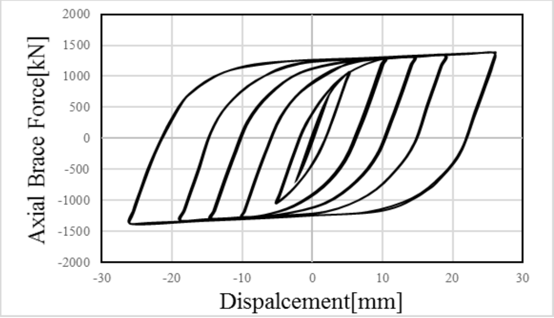

Figure 5. The hysteresis curve of the modeled FBS.

1. Conclusion

In this paper, the concept of a new bracing system, called fan bracing, was introduced. The following conclusions can be drawn based on the numerical results presented in this study:

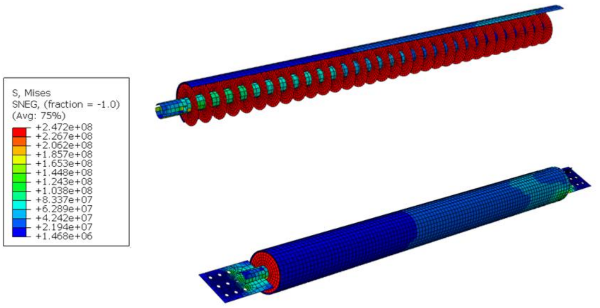

Figure 6. Von Mises stress distributions of FBS at ultimate displacement (Pa).

1) According to the cyclic loading curves and obtained results for the fan brace samples, this bracing system has a favorable performance and high energy absorption under lateral loading.

2) In the FBS, stiffness, strength, ductility and energy absorption can be controlled by a range of parameters including geometry, material, number, thickness, and internal and external radius of fans. But in BRBs, seismic behavior is only controlled by the specifications of the core, and this ties the hands of the designer in modifying stiffness, strength, ductility, and energy absorption by limiting adjustment options to the yield surface and yield strength of the core.

4. References

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