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ELSEVIER

Engineering Structures

Volume 246, 1 November 2021, 112991

Application of buckling-restrained braces to earthquake-resistant design of buildings: A review

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https://doi.org/10.1016/j.engstruct.2021.112991

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Highlights

- Provide a state-of-the-art review of buckling restrained braces (BRBs).
- Discuss the development and classifications of BRBs.
- Outline the advantages and limitations of the various types of BRBs.
- Explore some innovative applications of BRBs in earthquake-resistant design of buildings.

Abstract

As an earthquake-resistant structural element, buckling-restrained brace (BRB) not only adds strength and stiffness but provides excellent energy absorption capability to a structure. Since its inception in the late 1980s, BRB has been the subject of research by many researchers. Different types of BRBs have been proposed for use to address miscellaneous structural requirements by researchers and practitioners primarily in Japan, U.S. and China. Research is continuing toward the development of BRBs that are more efficient, compact, lightweight, less expensive to fabricate and easier to install. This paper summarizes the development of BRBs in the past few decades including their history, classifications, applications and scientific research. A discussion on the advantages offered by different types of BRBs and some insights into the future prospects for BRBs are also given.

Introduction

During the past few decades, advances in energy dissipation technology have made it possible for buildings to dissipate seismic energy through the use of supplementary damping devices. In addition, energy dissipation structural elements such as braces, shear walls, beam links and friction connectors can also be used to protect structures from damage or collapse by dissipating earthquake energy through friction or inelastic hysteresis from bending, shear and torsional deformations. The use of damping devices has gained popularity because they have been proven to be effective against severe structural damage from large earthquakes.

Steel braces are often used for seismic design and retrofit of steel frame structures. Steel braced frames have been shown to exhibit good seismic performance under strong earthquakes. However, as shown in Fig. 1, steel braces are prone to buckling under strong dynamic loads caused by earthquake and wind. This instability problem can be alleviated or even avoided if restraining units are provided outside or inside of the braces, turning them into buckling-restrained braces (BRBs). BRBs not only strengthen and stiffen a building, they are also capable of dissipating earthquake energy.

The construction of a BRB is relatively simple and robust. As shown in Fig. 2, a typical BRB often consists of three components: (1) an axial force-carrying brace (the core brace), (2) a restraining unit that prevents the brace from undergoing buckling, and (3) a separation unit to allow the axial force carrying member to slide freely on the restraining unit. The separation unit is commonly made of an unbonded material such as rubber, polythene and silicone. Because instability is suppressed, BRB can achieve almost the same strength and stiffness under both tension and compression. When compared with normal steel braces, BRBs have enhanced energy dissipation capacity. As a result, BRBs have been widely used in seismic engineering design and structural restoration projects since it first application in 1989 in Japan.

Section snippets

Birth of BRB

The first representative and practical BRB was developed in 1988 [1], [2], [3], which to a great extent was attributed to research conducted in Japan. In the early 20th century, researchers in Japan were focused on steel reinforced concrete (SRC) [4] which at that time was widely used in high-rise buildings because of its sound seismic performance. Although the load-carrying capacity of SRC is higher than that of steel or reinforced concrete structure, neither the ductility nor energy…

Classifications of BRBs

In addition to the classical BRBs made from concrete-filled steel tubes, various types of BRBs have been developed or used over the years. As shown in Fig. 3, they can be classified according to the type of materials used, or the manner the core brace or restraining unit is constructed.…

Selection criteria for BRBs

Most novel BRB designs are the result of introducing unique and innovative components to the basic BRB construct. By using new materials, modifying component configurations, or improving the interactions between components, BRBs can be relied upon to meet various structural or architectural requirements. Enhancing a BRB's energy dissipation capacity, stiffness, tensile and compressive capacities, cost effectiveness, while maintaining its lightweight and durability have been the foci of…

Applications of BRBs

Since the first prototypes were commercialized in Japan, BRBs have promptly been adopted for use in various new buildings in the U.S., Canada, China, Turkey, and New Zealand. This innovative lateral load resisting element with good energy dissipation capability immediately gains popularity in the construction industry, especially in countries such as the U.S. and China. In this section, several important applications of BRBs are briefly described.…

Failure mechanisms of BRBs

In this section, some commonly observed failure mechanisms and studies on these potential BRB failures are discussed.…

Experimental study of BRBs

Scaled uniaxial quasi-static reciprocating testing is the most frequently used method for testing new BRB designs. Compared with dynamic testing, quasi-static testing is more cost-effective and, in most cases, can predict the performance of BRBs well. As shown in Fig. 27, the test setup generally includes an actuator, a directional sliding device, a reaction block and the BRB specimen. In addition, strain gauges and displacement meters can be placed in selected positions to monitor the…

Concluding remarks and future prospects

This paper summarizes the research, development, classifications, and applications of buckling-restrained braces (BRBs) over the past few decades. While our understanding of the basic concept and behavior of some conventional BRBs are quite good and these BRBs have already been used by engineers and designers in a variety of engineering projects, new materials and innovative configurations are continued being conceived, proposed, researched and tested for future applications.

Failure of BRBs is…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

Acknowledgment

The authors would like to acknowledge the support of Guangzhou University overseas joint training program of graduate students.…

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