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Experimental investigation of the ductility and performance of steel rings constructed from plates

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ABSTRACT

Extensive research has been performed to increase the ductility of concentric braces over the past several decades. One method to increase the ductility is to use energy-dissipator members situated at the intersection of the braces. Along these lines, the usage of steel rings made of steel pipes as an energy dissipator has been studied analytically and numerically. These studies show that the brace with the steel ring exhibits a steady and wide hysteresis curve; in addition, the steel ring is easily positioned and replaced. Experimental observations show that the structural members of the bracing system remain in their elastic zones, except for the steel ring. In addition, the destruction was limited to the steel ring. As the variety of steel pipes forming the required steel rings are limited, this article describes an experimental investigation of three steel rings made of two half-rings. As the type of connection affects the ring performance, these experiments investigate the effects of different types of half-ring connections. To complete the investigation, some numerical studies have been performed using ANSYS software. The results of this investigation show that the hysteresis curve of the steel specimen made of steel plates is wide and that a tensile ductility factor of 8.68 is achieved.

1. Introduction

Seismic performance of concentric braces is low because of their poor ductility [1]. Therefore, some building codes, limit their usage [2]. Various methods have been studied to increase the ductility of concentric braces. The use of energy-dissipating fuses with bending is one such method [3–5]. One possibility is using the steel ring at the point of connection between the brace and the corner connection plate. Using a steel ring at the end of the bracing system causes non-elastic bending operation during earthquakes and consequently the dissipation of earthquake energy. The usage of steel rings made of steel pipes as an energy dissipator has been studied analytically. These studies show that a brace with a steel ring exhibits a steady and wide hysteresis curve; in addition, the steel ring can be easily positioned and replaced. Experimental observations show that the structural members of the bracing system remain in their elastic zone, except for the steel ring. Furthermore, the destruction is limited to the steel ring. With the variety of steel pipes being limited, the experimental and numerical analysis of steel plates consisting of two half-rings formed by the rolling of steel plates has been presented in this article. The appropriate selection of the material and size of the steel plates allows the preparation of various rings that are suitable for specific applications. Steel half-rings formed by the pressing and rolling of steel plates are welded or pinned to two attaching plates to form a steel ring. In this article, three rings made of two half-rings are studied experimentally. The effect of the type of half-ring connection to the splice plates on the performance and bearing capacity was investigated. Additionally, numerical investigations for steel ring had been conducted, using ANSYS software.

2. Literature review: Recent studies

Developing effective seismic protective systems for structures requires striking a balance between stiffness, strength and energy dissipation. It is not economically feasible to design a structure that can remain elastic during a moderate seismic event. The primary options to effectively design a structure for seismic events are to allow the structure to dissipate energy through inelastic deformation of the structural members [6,7]. Using Y-shaped braces has also been suggested for managing seismic loads [8,9]. Extensive experimental and numerical studies have been performed on various buckling modes in these braces, such as elastic and inelastic and out-of-plane buckling [10,11]. Various new designs have been developed and tested for resistance against seismic loads. These designs include passive control systems in which positioning an energy-dissipator device at one point of the structure such that it attracts destructive forces prevents damage to the other structural members [12,13]. Using hyperelastic material in the construction of toggle brace systems, which is a combination of rubber viscous elastic behavior and the nonlinear features of steel, is representative of these studies [14].

This research investigates a energy-dissipator member comprised of a ring, as studied numerically and experimentally in previous studies by

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Abbasnia et al. [15] and implemented in the construction of a diagonal bracing system, which demonstrated the suitable performance of the ring [15]. This ring was also used in the construction of the off-center brace, and the ductility and energy absorption of this new system were studied [16,17]. The ring is depicted in the diagonal brace in Fig. (1) and the off-center brace system in Fig. (2).

The rings investigated by Bazzaz et al. [16,17] and Abbasnia et al. [15] are made from seamless Mannesmann pipe. Seamless Mannesmann pipes are not available in every diameter and thickness. To overcome this limitation, the ring made from two half-rings is studied in this article. Half-rings are made from steel plates which are formed with pressing. Two middle connecting plates are placed between two half-rings for connecting to brace or other members. The type of connection of the half-rings affects the performance of the ring, and three experiments have been conducted with various connecting types to evaluate the effect of the connection type on the operation of the ring. The experiments were conducted in the structural engineering laboratory of Semnan University.

3. Material strength relationship and geometric specifications of the models

The material strength relationships between force and variation of the ring diameter and its internal forces in the elastic zone under load P are shown in Fig. (3) and the following equations [18]:

$$M^{+} = 0.3183PR \qquad \theta = \frac{\pi}{2} \tag{1}$$

$$M^{-} = 0.1817PR \qquad \theta = 0 \tag{2}$$

$$I = \frac{1}{12}t^3 l \tag{3}$$

$$\delta_y = -0.149\frac{PR^3}{EI} \tag{4}$$

$$\delta_x = +0.137\frac{PR^3}{EI} \tag{5}$$

$$T = \frac{1}{2}P\cos\theta \tag{6}$$

$$V = -\frac{1}{2}P\sin\theta \tag{7}$$

Fig. 1. The ring in the diagonal bracing system.

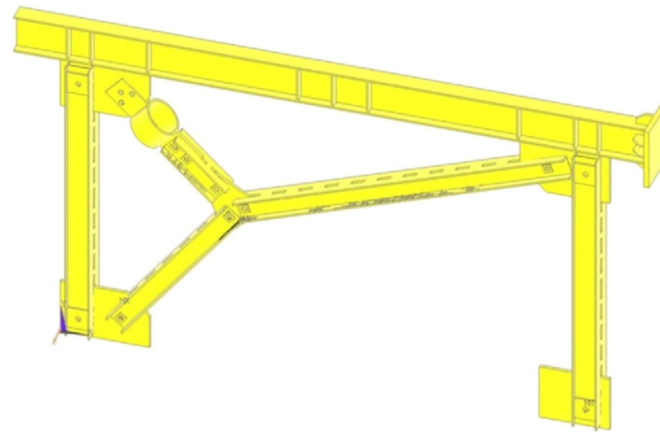

Fig. 2. The ring in the off-center bracing system.

By increasing the load, four plastic hinges are produced in the ring, as shown in Fig. (4), and the balance relationship in the plastic limit state are as follow:

$$2M_P = \frac{PR}{2} \Rightarrow P = \frac{4M_P}{R} \tag{8}$$

$$M_P = \frac{t^2 l\sigma_y}{4} \tag{9}$$

$$P = \frac{t^2 l\sigma_y}{R} \tag{10}$$

As observed, the bearing load capacity of the ring is directly correlated with its length, yielding stress, and ring thickness squared and inversely correlated with its radius.

To create the specimens for each experiment, we use two half-rings with two middle plates. A 12 × 150 × 220-mm is used to make the half-ring, and the middle plate is 20 × 250 × 400 mm in size. ST37 steel is used. A hydraulic press is used to bend the half-ring plate. To perform bending and formation, a cast compatible with the size of the half-ring and made of the high tensile nickel chrome steel material (VCN

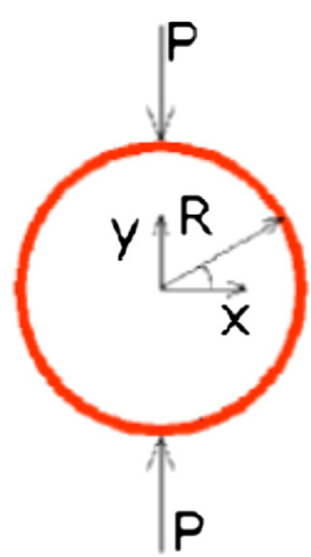

Fig. 3. Schematic of the ring.