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Numerical evaluation of ductility and energy absorption of steel rings constructed from plates

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ABSTRACT

Several studies have been performed to increase the ductility of concentric braces in the past decades. Incorporating an energy-dissipator member in the braces is one of the novel approaches to increase the ductility of the braces. Experimental and numerical studies have shown that steel rings made of steel pipes can be an effective energy-dissipator in the braces. However, due to the limitations on the size of the steel pipes, it is not always possible to find an appropriate pipe to be used in the braces. In the current study, performance of the steel ring made of two half-steel rings is investigated. In addition, effect of the welding or utilizing bolts, thickness of the ring, and material properties on the ductility and energy absorption of the braces is evaluated. Results indicated to the appropriate ductility and energy absorption of made-up steel rings.

1. Introduction

Several unexpected issues were observed in the rigid connections of special moment frames after the Northridge earthquake in 1994. Extensive studies were performed to develop new connections that undergo significant inelastic behavior; such as reduced beam section (RBS) [1,2] and reduced web section (RWS) [3–5] connections. However, stringent design criteria of these connections made the engineering society hesitant to widely use these systems [6]. Braced frames are another type of lateral load resisting systems that became more popular after 1994. In this system, earthquake energy is dissipated through inelastic behavior of the braces. However, premature fracture of the concentric braces of this system in the previous earthquakes has risen doubts about using this member [7] and strict limitations on utilizing these braces are implemented in the design codes [8]. Extensive investigations have been performed with the purpose of increasing the ductility of the braces and several approaches are proposed to avoid the premature fracture in the braces [9–24]. Among the proposed methods, utilizing flexural energy-dissipating fuses is one of the most effective methods to date [25–27]. In this approach, a steel ring can be used in the braces adjacent to the gusset plate connection. Flexural inelastic behavior in the braces due to the steel ring added to the end of the brace leads to significant energy dissipation during an earthquake. Numerous experimental and numerical studies have been done on utilizing steel rings made of steel pipes. It is observed that adding the steel ring to the end of the steel braces results in stable hysteretic behavior of the braces [28–30] and after earthquake, replacing the steel rings is simple and not expensive. Experimental studies have shown that the majority of the damage occurs in the steel ring and other portion of the brace remains elastic. Due to the limitation on the steel pipe size, numerical study on the behavior of steel rings consist of two half-rings formed by rolling of steel plates has been presented in this article. Variety of material and size of steel plates allows the preparation of various steel rings with different capacities. In this paper, numerical study on the performance of three steel rings made up of two half-rings are presented. Previous studies showed the seismic performance of bracing will affect by the connection details [31], so the effect of the steel ring connection to the gusset plate, thickness of the steel rings, and material properties on the behavior of the steel rings is investigated.

2. Literature review

One of the most important features of a lateral load resisting system is possessing an appropriate stiffness, strength, and capability of energy dissipation, simultaneously [32–35]. On the other hand, it is not economically justifiable to design a structure to remain elastic under a moderate earthquake [36–38]. Therefore, based on current seismic

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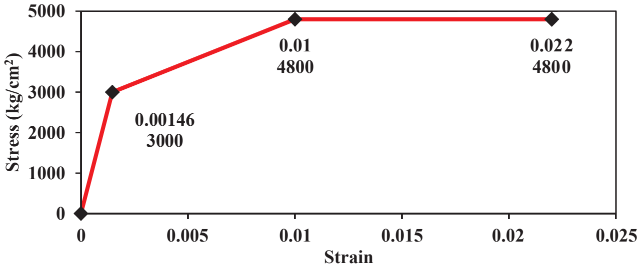

Fig. 1. Stress-strain diagram defined in the software for CT20 Steel.

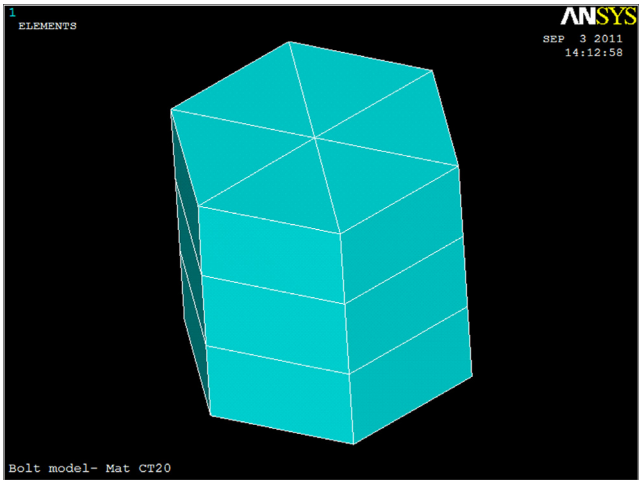

Fig. 2. Bolt modeling using ANSYS.

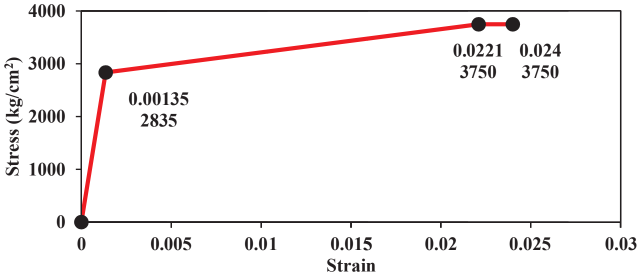

Fig. 3. Stress-strain diagram defined in the software for ST37 Steel.

design approach, it is important that structure experiences an inelastic behavior to dissipate earthquake energy [39–46]. Y-shaped braces are one of the bracing configurations that can be used to resist seismic loads [47,48]. Experimental and numerical studies have been performed on the Y-shaped braces' various buckling modes, such as elastic, inelastic, and out of plane buckling [49,50]. Numerous novel methods have been developed to have a seismic resistant design [29,30,51,52]. Using a passive control system in the structures is among the recently developed methods. In this method, an energy-dissipator member is utilized in the structure to absorb the damages to the structure and to prevent the failure of other members [53,54]. Using hyperelastic material, in a toggle bracing systems is one of these methods [7,55,56].

In the present study, performance of steel ring as an energy dissipator member is investigated. Abbasnia et al. performed an experimental and numerical study on the behavior of the steel rings used in diagonal braces [57]. It was observed that steel rings can effectively improve the behavior of the braces [57]. Steel rings also are innovatively utilized in the off-center braces and their performance are assessed in terms of ductility and energy dissipation [55,57–68].

In the previous studies, a seamless Mannesmann pipe was used as the steel ring. However, dimension and thickness variety of these pipes are limited and it hinders widely usage of this system [55,57–68]. Moreover, pipe installation may not be applicable by ordinary contractors in construction industry [69–71]. In the current article, the steel pipe is replaced with two half-rings and a connecting plate between them to solve the aforementioned issues. Three different models with various connections are simulated in ANSYS to study the effect of the steel ring connection on their performance. In addition, influence of material properties and half-ring' thickness is also evaluated.

3. Modeling

In the first step, based on the experimental results, steel material properties were defined in the ANSYS software. Fig. 1 presents the CT20 steel stress-strain diagram defined in the software. Solid 45, Contact 174, and Target 170 three dimensional elements were used in the simulation and solid elements were employed to model the bolts. Surface to surface Contact 174 elements were used to connect plates and bolts as shown in Fig. 2. In order to model weld, nods were merged together at the location of weld beads. Fig. 3 presents the ST37 steel stress-strain diagram. Steel rings and connection plates were merged together, and simulation of weld is neglected in the current study assuming that failure does not occur in the welds. Surface-to-surface contact was defined between the connection plate and steel rings to simulate the actual behavior of the steel ring. Fixed boundary condition was applied to one end of the model while an axial force was applied to the other end to investigate the behavior of the model. A mesh size of 7 mm was utilized in the finite element simulation and a total number of 3556 and 3120 elements were used in bolted and welded models, respectively. Table 1 summarizes simulated models specifications. The phrase "ST37/CT20" indicates the type of steel used. The expression "TH12/TH20" is an abbreviation for the thickness of a 12 mm half-ring or 20 mm half-ring, "P" means pin connectors and use for models with bolts, and "SW" stands for semi-weld. Figs. 4 and 5 show the Schematic details of models used in ANSYS, which are respectively called ST37-TH12-SW and CT20-TH12-P for brevity. Figs. 4 and 5 present schematic details of model ST37-TH12-SW and CT20-TH12-P, respectively.

4. Geometrical specification of the ring

The relationships between strength of material, variation of the ring diameter, and its internal forces in the elastic zone under load *P* are shown in Fig. 6. Moreover, Eqs. (1-7) represent the same concept. According to Castigliano's second theorem [72], $\delta_y = \partial U/\partial V$, $\delta_x = \partial U/\partial H$,

Table 1
Details of the simulated models.

Model type	Steel type	Outer diameter (mm)	Thickness (mm)	Length (mm)	Connection plates length (mm)	Connection plates width (mm)	Connection plates thickness (mm)	Connector type (mm)
CT20-TH12-C	CT20	220	12	100	220	170	12	7 Fillet
CT20-TH12-P								Bolts
CT20-TH12-SW								7 Fillet
ST37-TH12-SW	ST37							
ST37-TH20-SW			20					