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A parametric study into the new design of a steel energy-absorbing connection

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ABSTRACT

Several studies have investigated the ways of increasing the ductility of braced frames. A full ring comprised of steel half-ring plates as a novel energy-absorbing connection is among the ways that have been proposed to increase ductility. Experimental tests conducted in Semnan University have shown that besides high energy dissipation and high ductility, this element enjoys diversity in construction, ease of installment and replacement. Therefore, it can provide an appropriate substitute for damper rings. Low strength is the main shortcoming of this element which can be compensated by welding. But as the slit is welded, this contradicts the ductility of the rings. Based on finite element (FE), this study proposes an innovative improved model of half-ring connections through employing two supplementary steel plates so that welding is no longer required at the slit of the half-rings and strength would increase as a result. First, a nonlinear FE model for ring and two half-rings were proposed and then they were verified through experimental tests. Then, using this model, an improved FE model was proposed and nonlinear cyclic analyses were undertaken on it and on previous models in order to compare its global response and yielding performance with those of ring and half-ring models. In the next step, a set of parametric studies was performed in which the result of thickness and overlap variation on the hysteresis behavior of the new model was investigated. The results conveyed that using supplementary plates increased strength and energy dissipation in the new model compared to ring and half-ring models. These plates with a length of overlap improve ductility and their connection zone with half-ring plates is placed in an elastic zone. Parametric studies showed that variation in the thickness and overlap of supplementary plates greatly influenced the strength, ductility and the yielding effect of the half-rings. As the thickness and overlap increase, strength also increases, but this increase is limited to a certain level of strength. Thus, there is a significant relationship between the variation in thickness as well as the overlap length with the yielding effect in the connection zone of the supplementary plates with the half-ring, and some values are not recommended to be employed in thickness and overlap.

1. Introduction

Many studies have been done in order to increase the ductility of braced frames which shows the high significance of energy dissipation in braced frame systems for engineers [1–6]. It is also worth mentioning that a number of studies have been devoted to different aspects of hysteretically behaving bolted connections [7–11]. A recent study is concerned with numerical analyses [12–16] and experimental tests [17] on the use of damper rings and their connection to the end of diagonal braces [18] (Fig. 1 (a) and (b)). The results showed that using damper rings increases ductility and energy dissipation. Through inelastic deformations, this element causes energy dissipation in a way that forms system's whole inelastic behavior. Like a fuse, damper rings hinder or postpone brace buckling. Using these dampers at the end of the braces reduces the costs compared to buckling restrained braces and limits maintenance and repair only to the end of the brace by merely changing the ductile element.

To advance this line of research, extensive studies were undertaken in the University of Semnan. These studies culminated in a proposal for a novel model for damper rings which includes two steel half-ring plates (Fig. 1(c)) rolled by pressing and the final element is the result of their joining together by means of steel plates [19]. Bolted connection rather than welding was among the main achievements of this element which facilitated ease of installment and replacement. It also had a greater diversity according to the available plates with different strengths and thicknesses. Its main

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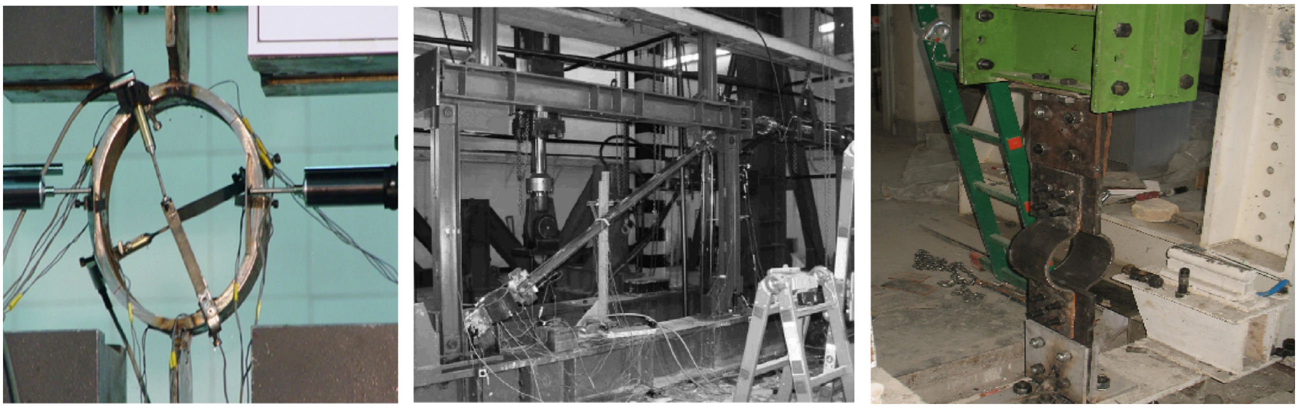

(a) Ring specimen [17]

(b) Diagonal braced frame with ring [18]

(c) A two half-rings specimen [19]

Fig. 1. Previous experiments and tests setup.

shortcoming was the decline in strength due to opening of half-rings which was compensated for through welding the slit. However, this affected ductility in a negative way as it was located at the zone of plastic hinge formation. In spite of that, previous tests confirmed wide hysteresis curves and high ductility [19]. All these observations motivated further interest in more extensive explorations of this new model as an energy absorber.

The main objective of this study was to propose an improved model for the half-ring element based on FE by using two supplementary steel plates to increase strength and to avoid welding the slit of these two half-rings. First, a nonlinear FE model was provided for ring and half-ring tests by OpenSees software [20], and each was later verified through experimental tests. Then, by employing the verified model, an improved model was proposed (Fig. 2 illustrates the different stages of this research extending from ring element to the improved model). Then, nonlinear cyclic analyses were conducted on ring, half-ring and improved FE models to compare their performance. Witnessing the acceptable results of the improved model, a parametric study was performed on the improved model in order to determine the impact of the thickness and the overlap length of plates on hysteresis behavior of models and their yielding.

2. Assessment of the behavior of the improved and previous models

In order to assess the behavior of the improved model and previous models, a specimen of ring test [17] and a specimen of half-ring test [19] conducted in Semnan University were selected (Fig. 3 (a), (b)). Thickness and average diameter for plates in these tests were 12 and 208 mm, respectively. The specimen's length in the case of the ring test was 100 mm and was subjected to a modification that enlarged it to 150 mm in order to ensure its geometrical homogeneity with the primary geometry of half-ring test. These conditions were created in order to provide identical configuration in ring, two half-rings, and improved models. Nominal yielding strength was 440 MPa for the steel material used in the ring and it was 360 MPa for the one employed in the half-ring test. The specifications of the improved model will be offered in the next section.

2.1. Improved half-ring element

The improved model is illustrated in Fig. 3(c). Its geometrical and mechanical properties were adapted from the primary configurations and the mechanical properties of the two half-ring test specimen. This adaptation facilitated the comparison of the numerical results of the improved model and those of the half-ring element. Previous tests have already shown that half-ring plates had fissures, and hence there was a decline in their strength. This was compensated for through welding the slit, but this affected ductility in a negative way as it was located at the zone of plastic hinge formation. The improved model does not use welding at the slit of the half-rings. Instead, it employs two supplementary steel plates of the same thickness and of the same curvature with those of half-rings. These could be connected to the half-rings either by welding or bolting at their ends. They can be made out of available steel plates of different thicknesses, lengths and strengths simultaneously with the half-rings in the pressing system. In the primary scheme, the overlap zone between the supplementary plates was up to 37 degree, equal to 35% of the half-ring plate length (Fig. 3(c)). Similar to previous tests, all cyclic analyses were displacement-based and their displacement history was applied according to ATC24 loading protocol [21] as shown in Fig. 3(d).

2.2. Computer modeling

The behavior of the ring-shaped part of plates is a dominantly nonlinear behavior and is a key element in the hysteresis performance of the whole connection. Such a behavior must be simulated in a nonlinear model. Using a continuum FE model involving a

Fig. 2. Research hierarchy from ring to the improved half-ring element.