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Experimental and Numerical Evaluation of an Innovative Diamond-Scheme Bracing System Equipped with a Yielding Damper

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ABSTRACT: Application of the steel ring as a type of seismic fuse has been one of the efforts made by researchers in recent years aiming to enhance the ductility of the bracing systems which in turn, possesses various advantages and disadvantages. Accordingly, to alleviate these disadvantages, an innovative bracing system with a diamond scheme equipped with a steel ring is introduced in this paper. In this system, the braces and yielding circular damper act in parallel whose main functionality is to increase ductility, energy absorption, and mitigate drawbacks of the existing bracing systems, in which the braces and yielding circular damper act in parallel. To conduct the experimental tests, specimens with three types of rigid, semi-rigid, and pinned connections were built and subjected to cyclic loading so that their performance could be analyzed. Promisingly, the results indicated both great applicability and efficiency of the proposed system in energy absorption and ductility. Moreover, it was concluded that as the braces and damper are in parallel, the use of a steel ring with a smaller size and thickness would result in higher energy absorption and load-resisting capacity when compared to the other existing systems. Finally, to assess the potential of numerically modeling the proposed system, its finite element model was simulated by ABAQUS software and observed that there is a great agreement between the numerical and experimental results.

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1- Introduction

Numerous studies have been carried out within the last two decades on improvement in the ductility of the concentrically-braced frames (CBFs). Despite advantages of the CBFs such as ease of execution and adequate reparability, seismically-induced ultimate displacements of the frames braced by the CBFs, have raised concerns. Moreover, the low ductility of the CBFs has resulted in their inadequate performance during seismic events [1, 2]. To improve the ductility of the CBFs, various approaches have been proposed such as the use of the circular elements made out of hyper-elastic materials in the dual moment resisting frame (MRF) and CBF [3]. By the way, most of these approaches require special materials and technology to assemble the braces. Thus, the application of the steel ring as the seismic fuse has been proposed by which ductility and energy absorption could be significantly enhanced [4, 5, 6-8].

2- Methodology

Cyclic tests were carried out on three types of bracing systems with pinned, semi-rigid, and rigid connections. Accordingly, connections, geometric and dimensional details are presented in Fig. 1. The components of this system include steel channels, plates, bolts, and nuts as well as the steel ring.

Notably, a difference of the pinned, semi-rigid, and rigid model concerns inclusion or exclusion of the ring in the system and type of channels connections to the other components of the system. Accordingly, in both rigid and pinned cases, the steel ring has been utilized in such a way that in the case of rigid connection, channels are connected to the central plate using welds and bolts but in contrast, channels are bolted to the central plate (i.e. bearing type connection) in the case of pinned connection. In the case of a semi-rigid model, the channel connections are similar to those of the pinned model but the only difference is that the steel ring is not included and instead, the two connection plates are continuously welded. In Fig. 2, it has been attempted to far better demonstrate the differences of the models. Moreover, one of the constructed specimens is shown in Fig. 3. It should be mentioned that the layout, diameter, and properties of bolts have been determined under AISC 358-16 [9]. All bolts and nuts are M27, length of 15 cm, and strength grade of A490.

One of the notable features of the models concerns the low angle (15.6°) between the diagonals. Accordingly, it has been attempted to develop a minimum possible angle between the elements considering all executive limitations, so that the global buckling potential of the system reaches the lowest extent.

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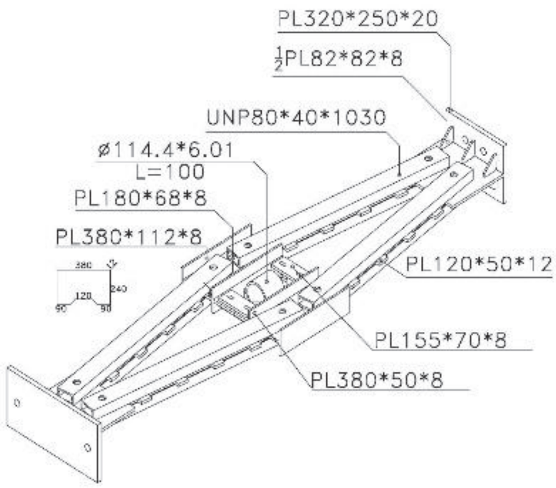
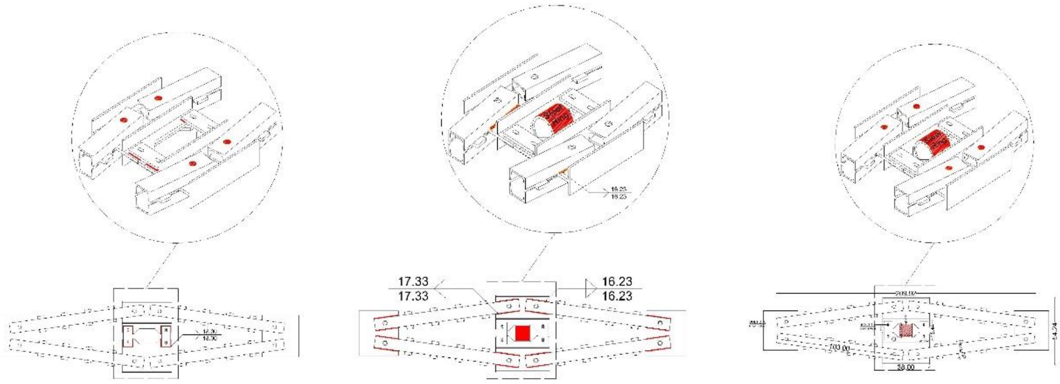


Fig. 1. Dimensions of components used in the bracing system.



(a) Semi-rigid model (b) Rigid model (C) Pinned model

Fig. 2. Comparative illustration of rigid, semi-rigid, and pinned models.

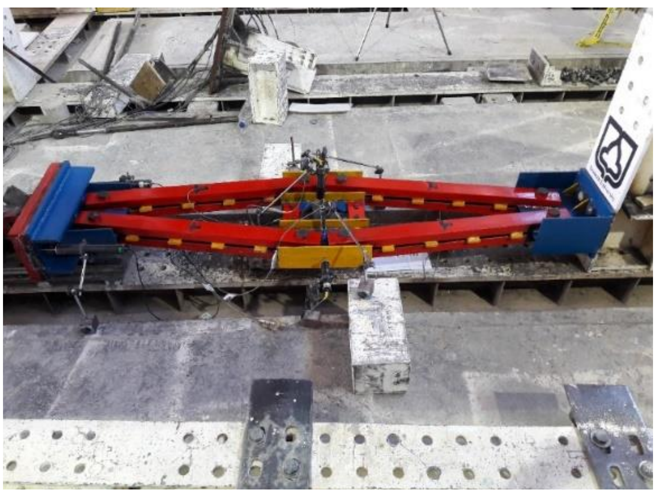


Fig. 3. General view of proposed bracing system.

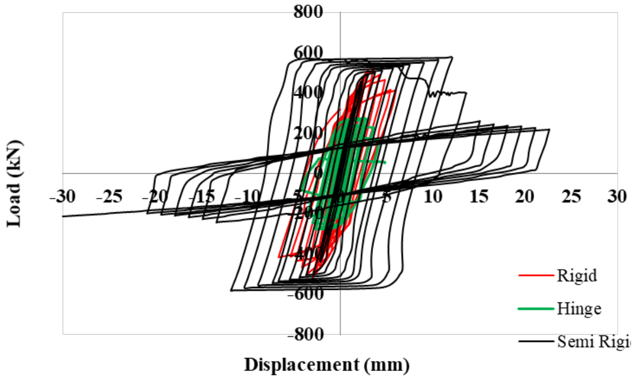


Fig. 4. Comparison of load-carrying capacity in a direction perpendicular to that of loading

Table 1. Summary of analysis results for the direction perpendicular to that of loading.

	Hinge	Semi Rigid	Rigid
Max Load (kN)	264.0	623.5	517.7
Max Displacement (mm)	5.3	7.1	6.3
Energy Dissipation (kN-mm)	9939.4	43859.5	21393.9
Stiffness (kN/mm)	55.5	87.9	82.1
Yielding Stress (kN)	156.37	236.76	199.11
Ultimate Stress (kN)	263.98	623.53	517.70
Ductility	4.9	4.2	4.41

3- Results and Discussion

To better understand how the bracing system behaves, hysteretic curves of them for the direction perpendicular to that of loading have been presented. As presented in Fig. 4 and Table 1, the semi-rigid model possesses the lowest energy absorption and ductility due to the welded areas around the bean-shaped plate. However, in the rigid and pinned models, opening and closing the steel ring dissipates the induced energy and thus, a higher rate of energy absorption is achieved. It is noteworthy that displacement in the transverse direction of the bracing system indicates the rate of opening and closing of the steel ring as given in Table 1.

- The stress-strain curves of all three models were extracted based on the cyclic tests and then, energy absorption, maximum applied load, and stiffness were computed. The results approved the sufficient performance and applicability of the proposed system.

- Comparison of the three developed systems, indicated that the pinned model has provided the best performance given its failure mode in which the damper has yielded and the other components of the system have remained elastic. On this basis, the pinned model was introduced as the final selected model of the proposed bracing scheme.

- On the contrary to the other systems previously developed in the literature, in the pinned system proposed herein, the ring and diagonals act in parallel. Hence, the damper capacity is not only utilized maximally but also in the case of damper failure, the system is still able to withstand the induced loads, and failure of the steel ring does not lead to disrupting the performance of the whole system.

- Among the three models, the type of connections in the pinned model, provided a great ability to repair or replace the steel ring.

- Comparison between the numerical and experimental results indicated an acceptable agreement based on which, it can be concluded that the proposed bracing system is capable of being reasonably simulated in the numerical programs. Thus, as a subject for further research, the proposed system can be developed by assessing its performance against different loading conditions.

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