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Moment-connection between continuous steel beams and reinforced concrete column under cyclic loading

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ABSTRACT

This paper suggests a new moment connection between steel beams and a reinforced concrete column (RCS). In this proposed connection, two parallel beams pass from both sides of the column and are welded to the cover plates surrounding the concrete column in the joint area. This detail provides two main advantages compared with previous constructions: first, both the beam and column are continuous in the joint area, which provides more reliable performance, and second, the force transfer occurs in such a manner that the cover plates are loaded in-plane and stress concentration is prevented in the connection components. Bar shear connectors were installed between the steel and concrete inside the cover plates to restrict sliding. The force transfer mechanisms and design procedure are described, and the seismic behavior of the proposed connection is studied in two experimental tests under cyclic loading. The test results showed that both specimens sustained 8% story drift with stable hysteretic loops and that the proposed connection is acceptable as a special moment connection. In addition, the test results demonstrated that the proposed design relationships were arranged properly such that the cover plates were maintained in the elastic phase, only slight cracks appeared in the column, and plastic hinges were formed in the beams in the vicinity of the column. Furthermore, to clarify the behavior and shear capacity of bar shear connectors embedded in a confined concrete, two push-out specimens were tested under monotonic loading.

1. Introduction

An optimum combination of steel and concrete and efficient usage of material features renders RCS structures more efficient and economical than traditional concrete and steel frames. Using an experimental test on a specimen with improved composite RCS joint details, Men et al. [1] indicated that the displacement ductility coefficient of RCS frames is much larger than that of conventional reinforced concrete and steel moment frames. Despite these advantages, identification of a beam-to-column connection with proper seismic performance and an explicit force transfer mechanism is essential. Extensive researches have been conducted since 1987 and several details have been proposed to effectively transfer induced forces from steel beam to reinforced concrete column. The investigated details fall into two main types including the beam-through-type and the column-through-type [2].

To enhance the shear transfer in the panel zone, the following details were employed in the beam-through-type connections: face bearing plate welded to the beam at the column face, extended face bearing plate, steel column attached to beam flanges and shear studs welded to the beam flanges to mobilize concrete compression field inside and outside the beam flange [3], steel band plates embedded around the column to prevent bearing failure [3–5], and cover plates and dowel bars [4]. These details were suggested to provide new load paths to reduce stress concentration thereby enhancing the strength and stiffness of the connection. Beam-through-type connections with continuous beam eliminate failure concerns in the beam to column connections where maximum moment exists. By not interrupting the beam at the point of maximum moment at the column face, the beam-through-type details avoid the fracture-critical joints that are of concern in conventional structural construction [6]. However, continuous beam interrupts the column reinforcing bars arrangement and concrete continuity by continuously passing through the joint area.

For seismic design of RCS connections, ASCE 1994 [7] is referenced by the AISC Seismic Provisions (2002) as the recommended design guidelines. ASCE 1994 focuses on the beam-through-type connections and contains a wide variety of joint details. Alizadeh et al. [8,9] tested four interior beam-through-type connections with standard detailing and with additional bearing plate, using normal and self-consolidating concrete. The comparison of the test results showed that all specimens performed in a ductile manner and they maintained their strength with little decrease of stiffness. Zhang et al. [10] conducted five experimental tests to evaluate the seismic behavior of confined reinforced concrete column and composite beam joints with weakening extent of flanges. Furthermore, some experimental and analytical studies have

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been carried out on the behavior of RCS frames with beam-through type connections [11–14].

Column-through-type connections, using diaphragms [15] or cover plates and horizontal stiffeners [16], may simplify construction process; however, additional research is required to improve the strength and ductility of the connection. According to the review by Li et al. [17], the research conducted by Iizuka et al. revealed that the hysteretic loops of the column-through-type connections were more plentiful than the beam-through-type connections; however the through-column type joint was designed stiffer than the through-beam type joint. Therefore, column-through-type connection showed better seismic performance. Li et al. [18] tested three full scale bolted endplate connections to steel beam and reinforced concrete column. Experimental results showed that specimens without slab exhibited good ductility and energy-dissipating capacity; however the specimen with floor slab fractured at the weld between the bottom flange of the beam and the endplate.

Furthermore, various details for other types of composite connections have been studied as well. Li et al. [19] conducted finite element analyses of rebar-penetrated connection between gangue concrete filled steel tubular column and reinforced gangue concrete beam to investigate the failure modes and force transferring mechanism. The seismic behavior of bolted endplate connections for concrete filled circular steel tube (CFT) column to steel beam was investigated by Li et al. [20] and Sheet et al. [21].

In order to improve the performance of steel beam to concrete column connections, this paper proposes a seismic moment connection with proper features of both beam-through-type and column-through-type connections. In the proposed connection, two parallel beams are placed outside the column and are welded to the steel cover plates that surround the concrete column in the joint area. Passing the beams outside the column provides the advantages of a continuous beam and column connections without disturbing the column in the joint area. Two relatively similar specimens of the proposed connection were experimentally studied. In the first specimen, as depicted in Fig. 1, the flanges of the channel-section beams are longitudinally welded to the parallel cover plates (referred to as the side plates), and the beam web is directly welded to the edges of the side plate. In the second specimen, two continuous beams are located on the protruding sections of the cover plates (referred to as the front plates) as vertical supports located perpendicular to the beam web (Fig. 2). To provide sufficient connection, the top and bottom flanges of the I-section beams are welded to the beveled edges of the protruding sections of the front plates. In addition, the beam web is connected to the front plate vertical edges via continuity plates. In both specimens, bar shear connectors are used inside the cover plates to minimize slippage at the steel–concrete interfaces. Studies conducted by MacRae et al. [22] showed that the connection between a steel plate and the concrete column with ribs (with similar behavior to bar shear connectors) were more effective in transferring force than the other types of the studied connection tools. Also it was revealed that slip deformations between the steel and concrete were insufficient to fully activate flexible shear studs in the joint area.

However, the possibility of the proposed connection using bolts also exists in the form depicted in Fig. 3, and this structure can be accurately evaluated through further research. In the connection method that uses bolts, a rectangular connecting plate on one side is connected to the protruding section of the front plates by penetration groove welds, and is bolted to the beam flange on the other side.

According to the configuration of the suggested connection, some advantages are expected including: more resistance against gravity and seismic loads because of continuity of the beams, simultaneous transfer of the shear force and bending moment to the column, in-plane loading of the connection components, more plastic rotation capacity by using two beams with less depth, increase in the capacity of the column in the connection region, possibility of repair in the case of shear yielding, more reliable performance by locating the panel-zone out of the column [23] and appropriate arrangement of reinforcement bars and continuous access inside the column.

In this research program, two interior RCS connections were tested under cyclic loading. The objective of this research is to describe the load transfer mechanisms, design method and seismic behavior of the proposed connection. Furthermore, two push-out specimens were tested under monotonic loading to estimate the shear capacity of a bar shear connector embedded in a confined concrete block.

2. Force transfer mechanisms

2.1. First specimen (SPU)

The moment (M_{pb}) and shear force (V_b) that result from formation of plastic hinges are transferred to the side plates, which are located parallel to the beam web via the weld connection of the beam flanges and web (Fig. 4). These induced forces tend to cause in-plane rotation in the side plates that is resisted by three mechanisms, including the torsional resistance of the side plates and the in-plane and out-of-plane resistance of the front plates. The torsional resistance of the side plates is provided by shear connectors that are welded on the side plates and mobilize the concrete through torsional deformation.

As depicted in Fig. 5, the in-plane mechanism of the front plate produces two sets of in-plane forces along the front plate edges, and the out-of-plane mechanism creates a force distribution perpendicular to the column face. The in-plane resistance of the front plates is provided by the shear resistance of the shear connectors that are welded on the front plates inside the column (Fig. 6). The out-of-plane forces apply

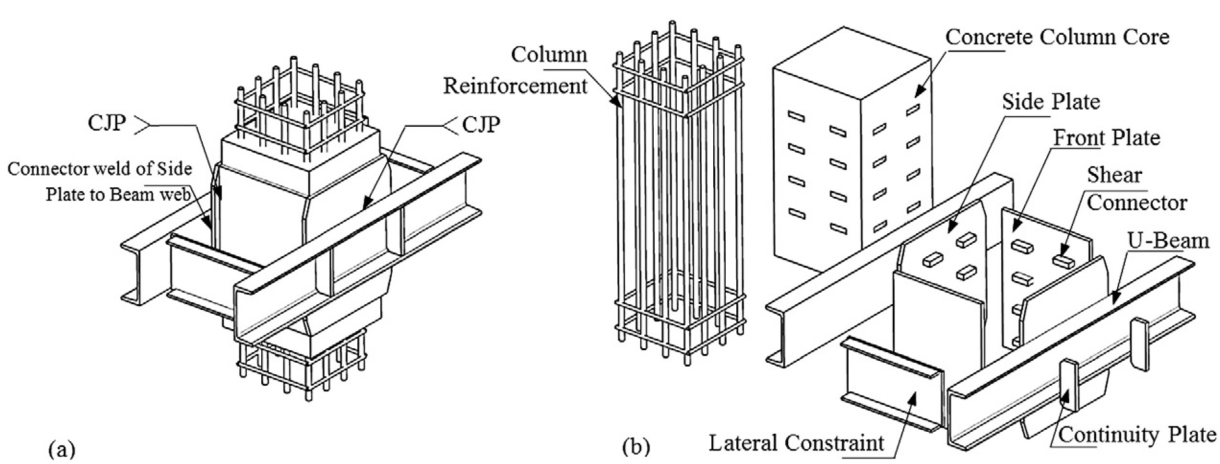

Fig. 1. The first specimen (SPU): (a) Connection configuration, (b) connection assembly.