Journal of Constructional Steel Research 114 (2015) 204–216

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Experimental investigation of RCS connections performance using self-consolidated concrete

Saeid Alizadeh [a], Nader K.A. Attari [b,*], Mohammad Taghi Kazemi [a]

[a] Department of Civil Engineering, Sharif University of Technology, Azadi Avenue, Tehran, Iran
[b] Department of Structural Engineering, Building & Housing Research Center, Sheikh Fazlollah Noori Highway, Tehran, Iran

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 29 July 2015
Accepted 30 July 2015
Available online xxxx

Keywords:
Composite structures
RCS connections
Additional bearing plates
Self-consolidating concrete
Earthquake resistant structures

ABSTRACT

The cyclic behavior of RCS connection consisted of Reinforced Concrete (RC) columns and Steel (S) beams is studied in this paper. Two interior connections are investigated experimentally. The joint of the first specimen is designed according to ASCE 1994 guideline, while the second specimen has a new proposed joint detail. Self-consolidating concrete is used in both specimens. Self-consolidating concrete could improve constructability of the congested joint of RCS frames. The specimens detail include steel band plates, face bearing plates, L-shaped joint stirrups, and steel doubler plate for the panel zone. The proposed joint detail consists of additional bearing plates, which cause an increase in bearing & joint shear strength. Based on the experimental results, the behavior of both specimens was ductile and maintained their strength at high story drifts. This means that, RCS frames can be used in high seismic zones. By comparing the performance of two specimens, it is observed that using additional bearing plates, increases bearing and shear strength of the joint. Additionally, the inelastic force-deformation response of both specimens is simulated using the OpenSees software by taking into consideration the joint shear and bearing distortions. A modified method for modeling this type of connection is introduced and verified with experimental results.

1. Introduction

Within the past few decades, researchers and designers have become more interested in utilizing the hybrid structures consisting of reinforced concrete and steel members. One of these systems is the RCS moment frame, which consists of Reinforced Concrete (RC) columns and Steel (S) beams. Using concrete columns causes an increase in stiffness and damping and a decrease in material cost. Using steel beams raises the energy dissipation capacity of the structure and reduces the dead load. As illustrated in Fig. 1, there are two main categories in RCS connections, which are beam-through type & column-through type. The beam-through type is widely used, because of its more ductile behavior. In addition, the column-through type needs cover plates or diaphragm plates for connecting steel beams to concrete columns, which requires more workmanship and control during construction to assure required ductility and strength capacity.

Using RCS moment frames in the USA started in the late 70's and early 80's. In these structures, using concrete columns instead of steel columns causes a decrease in material cost [1]. In high-rise buildings, stiffness is the main concern for the designers; therefore, using of concrete columns, which are stiffer leads to design that is more economical. In Japan, the use of RCS moment frames has already been incorporated into low-rise buildings in high seismic regions. Their purpose of using such systems was to develop a design with wider spans to provide larger column-free spaces [2].

One of the most conclusive experimental programs on RCS connections was conducted in 1987 at Texas University by Sheikh [3]. In his research program nine 2/3 scale interior RCS connections were tested. According to their results, two types of joint failure modes were identified as shear failure and bearing failure of panel zone. The experimental study of Sheikh at Texas University was continued, with testing of eight interior RCS connections, by Deierlein [4]. Based on those experimental results and related analytical study, some equations were proposed, for estimating the strength of RCS joint. These equations, with some modifications, were adopted in ASCE design recommendations for beam-column moment connections in composite frames [5]. In 1993, 19 RCS connections have been tested by Kanno [6] at Cornell University. The main variables that were investigated included joint failure modes, use of high strength concrete in the connection, joint aspect ratio and effect of column axial load in joint response. In the late 90's, an analytical and experimental program was conducted by Parra and Wight [7] at the University of Michigan. The experimental part consisted of nine exterior RCS connections with different joint aspect ratios and various

* Corresponding author.
E-mail addresses: alizadeh144@alum.sharif.edu (S. Alizadeh), n.attari@bhrc.ac.ir (N.K.A. Attari), kazemi@sharif.edu (M.T. Kazemi).

http://dx.doi.org/10.1016/j.jcsr.2015.07.026
0143-974X/© 2015 Elsevier Ltd. All rights reserved.

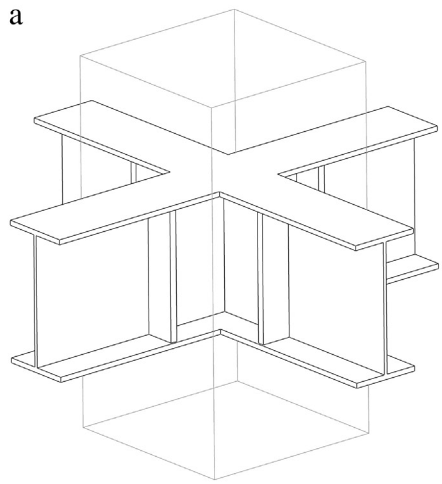

Fig. 1. RCS connections categories. (a) Beam-through type. (b) Column-through type.

joint details. In the analytical program of this research, some suggestions were made for estimating the shear strength of interior and exterior RCS connections [8]. In 2003, Parra and Wight [9] proposed deformation-based capacity approach for design of RCS connections in high seismic risk zones to control joint distortions and damage. Li et al. [10] reviewed the studies that have done on this type of composite structures. They also studied the influence of different parameters on the behavior of composite frame structures by nonlinear finite element analysis [11]. Some parameters, such as distribution of minimum principal stress and the contribution of different elements to joint shear capacity were investigated using nonlinear finite element analyses on exterior RCS connections [12]. Farahmand Azar et al. [13] studied the seismic performance of the RCS frames with consideration of joint deformations using OpenSees software. Alizadeh et al. [14] investigated several joint models with different details. Lateral load-drift response, bearing stress intensity, joint shear internal forces at steel and concrete parts, and axial stresses in the joint stirrups were studied for those models. Some other studies on the behavior of these connections were performed by researchers such as Bugeja et al. [15], Liang [16], Cordova et al. [17], Noguchi et al. [18], Luis et al. [19], and Chou and Chen [20].

Self-Consolidating Concrete (SCC) was first introduced in Japan in the middle of the 80's. The general goal of using this type of concrete is making durable concrete structures, reduction in the number of skilled workers and use in the structural members with high percentage of reinforcement. The fundamental investigations on the workability of SCC were conducted by Ozawa et al. [21]. One of the recent research programs on the structural behavior of beam column joints using SCC was conducted by Maghsoudi [22]. This research was included twelve beam column connections with different percentage of reinforcement. Many other researchers studied the performance and the structural behavior of this type of concrete such as Ouchi et al. [23], Su et al. [24] and Burak [25].

2. Research objectives

The main problems of RCS moment frames are as the following: joint Rigid Body Rotation (RBR) & constructability. Concrete crushing happens at the column edges in the top and bottom of steel beam after several loading cycles, because of high bearing stresses, leading to the joint RBR. This phenomenon decreases energy dissipation capacity of the system and increases total story drifts.

In RCS frames, the ratio of steel to concrete volume at joint region is too high due to existence of continuous steel beams, longitudinal reinforcements and joint stirrups. It causes some complication in construction and does not allow the concrete to fill the formwork properly [26].

In this research program, two interior RCS connections are tested under quasi-static reversed cyclic loading. The main objectives of this research are improving structural performance and using SCC to facilitate the constructability of this type of composite system. A new joint detail consisted of Additional Bearing Plates (ABP), which are attached to steel beam flange is proposed in this research. In addition, a new simplified method for the numerical simulating of this type of connection is proposed.

3. Test specimens

The test specimens were two 3/4-scale beam-through type interior RCS connections. Both of specimens consisted of 3000 mm-long concrete column with 400×400 mm^2 cross section, which was reinforced with sixteen Φ18 bars. This amount of longitudinal reinforcement represents 2.54% of the column gross area. Φ10 bars were used for column and joint stirrups. The SCC was used in both specimens.

IPE 300 steel beam with 3900 mm length was used in both specimens. Fig. 2 shows the specimens' details. In both connections, L-shaped stirrups were used, which were passed through holes ($D = 12$ mm) in the steel beams web. The ratio of stirrups volume to joint

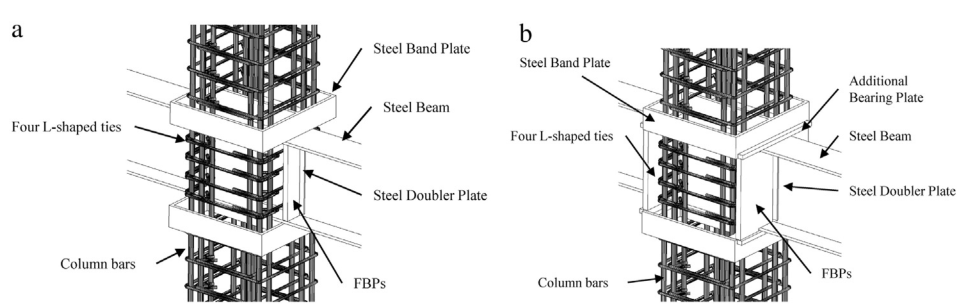

Fig. 2. Details of specimens 1 & 2. (a) Specimen 1. (b) Specimen 2.