Construction and Building Materials 151 (2017) 258–278

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Development and testing of hybrid precast concrete beam-to-column connections under cyclic loading

Haider Hamad Ghayeb *, Hashim Abdul Razak *, N.H. Ramli Sulong

StrucHMRS Group, Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

HIGHLIGHTS

- Study on hybrid connections of precast concrete.
- Steel bars yielding of PC beams were not achieved in the critical section.
- The performance of PC2 significantly improved due to stiffening of the steel angles.
- RC and PC2 specimens failed in flexural and PC1 failed at the steel plate yielding.
- Concrete crushed did not occur in the PC specimens.

ARTICLE INFO

Article history:
Received 5 April 2017
Received in revised form 11 June 2017
Accepted 13 June 2017

Keywords:
Beam-to-column connection
Precast concrete
Reinforced concrete connection
Seismic load
Steel plate connection

ABSTRACT

In general, precast concrete structure has insufficient ductility to resist seismic load. Detailed understanding on the behaviour of precast concrete connections are limited and current researches are focused addressing this. In this study, two precast and two monolithic concrete joints for exterior beam-to-column connection were tested under cyclic loading. The installation of precast specimens was prepared using dry type method while the monolithic joints were casted in-situ. The evaluation of seismic performance of the joints was conducted by applying hysteretic reverse cyclic loading until failure. Information regarding the strength, ductility and stiffness properties of the connection were recorded and analysed. Based on the test results and damage condition, the initial design of the joint was improved. Consequently, a new joint was constructed and tested, which exhibited a better performance. Precast concrete connections showed stable load–displacement cycles and dissipated a higher energy. The structural drift obtained was up to 9.0%. Pinching and deterioration were attained at a drift ratio of 4.5%. Also, there was improvement in the tested precast joints based on deflection, plastic hinges, crack pattern and shear deformation. Thus, the precast joints had a satisfactory resistance to seismic loads.

1. Introduction

Precast connections appear to be the most critical members in the structural building. This is due to the significant role they have in controlling the behaviour of the structure in seismic zones. Generally, the commonly used beam-to-column connections type are monolithic, dry pinned, emulative, and bolted. Moreover, studies based on the behaviour and design of different connections has been done by Park et al. [1] and Fib [2]. Also, welded steel sections has been developed and used with precast concrete buildings [3,4].

Generally, strong dry connection is achievable by using steel billets, steel plates, and steel angles. These systems could be considered as semi-rigid connections [6–8]. Past study on a dry precast concrete joint used two steel plates embedded at the top and bottom of the main concrete beam to test the joint under cyclic loading. The two steel plates were connected to column brackets by welding [5]. The design of this connection was subsequently improved by the addition of plates at the sides of the beam. The energy dissipation, joint strength, and toughness of the connection with the side plate element had a similar performance with the monolithic connection. However, applying such specification on site was problematic to a certain extent, and necessitates a cautious quality control mechanism [5].

Another study used a steel plate in precast connections to accomplish an appropriate seismic performance [6]. However, in the connection region, lap splicing was used to continue the upper reinforcement. The lower reinforcement was sustained by welding both steel plates together and anchoring them to the bottom of the

* Corresponding authors.
E-mail addresses: eng_hhg@yahoo.com, phd.haider@siswa.um.edu.my (H.H. Ghayeb), hashim@um.edu.my (H.A. Razak).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.073
0950-0618/

middle cantilever beam as depicted in Fig. 1. The continuity helped to prevent substantial waste of connection resistance. The difficulty related to anchorage was solved by joining the top steel through welding. Even though the performance of the connections was satisfactory, the specifications necessitated welding of the column reinforcement and beam that could lead to difficulties on the construction site. In addition, high seismic performance could not be achievable by employing this type of connection [6]. Nevertheless, the thickness of the connection plate is vital to the dissipation energy and the ability of the connection to deflect [7].

Meanwhile, the strength and ductility of any connection can be improved by the continuity of such connection. This is achievable in several ways such as, using steel plate, stiffening with steel angles, utilizing external embedded rod in the joint, an adequate embedded bar length and appropriate splicing length of the steel bars. For instance, a lap splicing length of 15 times bar diameter (d_b) is adequate to achieve higher connection strength. Thus, the strength of such connection increased up to 9% higher than the expected ultimate connection strength [8]. Additionally, an embedment length of $12d_b$ or longer can improve the strength ratio more than 1.25 in the grouted dowel connection and significantly increased the connection ductility [9].

Furthermore, the load capacity, hysteresis behaviour, ductility and energy dissipation were studied for two kinds of dry precast beam-to-column connections using cleat angles without stiffener and J-Bolt. The connection using J-Bolt was capable of dissipating more energy and providing higher ductility compared to related monolithic connection, and connection using cleat angle without stiffener [10]. In addition, the connection of the steel cleat angles with double stiffener has a better performance than the single stiffener or J-Bolt connections in terms of ductility and energy dissipation under cyclic load. Hence, this suggests that the behaviour of precast connection is satisfactory compared to a monolithic connection [11].

Ertas et al. [12], carried out a study using four varieties of ductile moment-resisting precast concrete frame connections and one monolithic concrete connection. The best performance in terms of ductility, energy dissipation, and strength, as well as ease and speed of construction, was obtained using a modified bolted connection. Three of the hybrid connection frames used in the study were capable of withstanding up to 3.5% story drift [12]. On the other hand, the ductility of a connection for a precast frame system is provided by the ductile connectors. It takes advantage of the disconnected nature of concrete in the precast systems. Moreover, ductile hoops of precast frame system, which eliminates the necessity of corbels, has a rod that functions at specific strength. The rod limits the effective load from being transferred to the weak ductile elements of the frame system [13]. Meanwhile, a new precast connection was tested under cyclic loading in order to develop the moment resistance frame in the study conducted by Guan et al. [14]. The flexural strength of the connection, and its stiffness with higher energy dissipation improved when compared to the monolithic connection [14]. Additionally, Xue and Yang [15] tested four full-scale of precast concrete connections. The beam-to -column connections in their study was built in full-scale to represent an interior connection, an exterior connection, a knee connection, and a T-connection. The aim of their study was to improve the performance of connection as moment resisting frame [15].

Furthermore, precast connections were tested to develop plastic hinges for various beam-column connections by French et al. [16,17], whereby the plastic hinge was developed outside the connection region. Also, the study concluded that threading of the steel reinforcement bar joints with tapering and threaded splices are the best promising solution based on applicability, economy, and fabrication [16,17]. It is crucial to note that most of the damages to the precast buildings, exposed to an earthquake, occur in the connection zones between beams and columns [18,19]. For instance, the lack of mechanical connectors between precast elements was recognized to be the most common failure of the precast structural buildings after the 2012 Emilia earthquake in Northern Italy [20,21]. Massive damage and catastrophic failures of precast concrete structures in high-magnitude earthquakes can be attributed to failure of beam- to -column connections as well as insufficient ductility [6,22–24]. This indicates the significance of ductile connections in precast structures.

On the other hand, several open and closed stirrups has been used as shear reinforcement in reinforce concrete (RC) beams [25]. The study of Varney et al. [26] studied the effect of hoop anchorage on the shear strength of RC beams. They reported that the reinforcement anchorage has no significant influence on RC beams shear capacity [26]. Meanwhile, quite a few studies revealed that the cracking strength and shear characteristics of the RC beams could be substantially enhanced by reducing the stirrup spacing and/or by means of utilizing closed-stirrups [27].

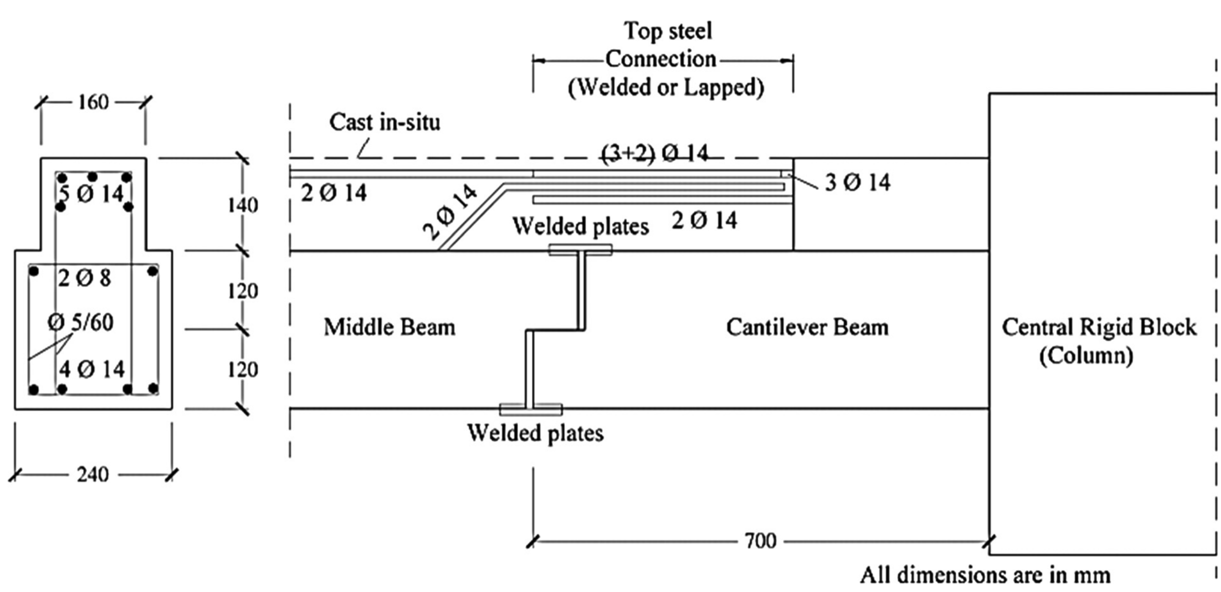

Fig. 1. Reinforcement and dimensions of a plate connection [6].