Engineering Structures 132 (2017) 1–13

Contents lists available at ScienceDirect

Engineering Structures

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

Structural behavior of a new moment-resisting DfD concrete connection

Jianzhuang Xiao [a,b,*], Tao Ding [a,*], Qingtian Zhang [a]

[a] *Department of Structural Engineering, Tongji University, Shanghai 200092, China*
[b] *State Key Lab. for Disaster Reduction in Civil Eng., Tongji University, Shanghai 200092, China*

ARTICLE INFO

Article history:
Received 19 November 2015
Revised 6 November 2016
Accepted 8 November 2016

Keywords:
Design for deconstruction (DfD)
Concrete connection
Structural behavior
Moment-resisting
Natural aggregate concrete (NAC)
Recycled aggregate concrete (RAC)

ABSTRACT

Design for deconstruction (DfD) is a burgeoning concept in civil engineering. DfD building components have the possibility to be reused as a second life at the end of the building's first service life. A simple moment-resisting DfD concrete connection for concrete frame joints was proposed in this study. Five full-scale specimens were tested to explore the effectiveness and limitations of the new developed DfD concrete connections. Both static and cyclic flexural loading tests were conducted. Beams made of natural aggregate concrete (NAC) or recycled aggregate concrete (RAC) were extended from column faces. Test results confirmed that the achievement of reinforcement continuity significantly improved the structural behavior of DfD concrete connections. The proposed DfD concrete connections, made of NAC and RAC demonstrated favorable ductility under static and cyclic loadings respectively. In addition, mechanical removal process was easy during the deconstruction stage on account of little post-cast concrete.

1. Introduction

The sustainability of concrete industry is imperative to the global environment and human development. The environmental issues associated with CO_2 emission and construction and demolition (C&D) waste generation of concrete industry play a leading role in the sustainable development of the world [1]. During past several years, techniques on recycling of waste concrete have achieved great progress from mechanical properties of recycled aggregate concrete (RAC) [2–6] to structural performance of RAC structures [7–10]. In addition to waste concrete recycling, reuse of concrete components is also a hot topic among the research area in recent years and has achieved certain progress.

Design for deconstruction (DfD) is a burgeoning concept in civil engineering beyond precast structures [11,12], which initially comes from the field of design for disassembly in mechanical industries [13]. For DfD structures, disassembly building elements have the possibility to be reused as a second life at the end of the building's initial service life. Traditional architectures such as timber structures in ancient China and modern steel frame structures are typical examples of DfD structures. In recent years, methods and tools like life cycle assessment (LCA) and building information modeling (BIM) [14] have been adopted to assess the economic and environmental benefits of DfD applications in civil engineering.

In fact, the DfD concept has been applied to building structures for more than 10 years. In the year around 2000, the CIB (*International Council for Research and Innovation in Building and Construction*) Task Group 39 (Deconstruction) released series reports to state the status of deconstruction in a variety of countries at that time [15,16]. The DfD cases in countries like Australia, Germany, Israel, Japan, Netherlands, Norway, the UK and the US were presented and discussed in these reports. Addis and Schouten [17] and Crowther [18] also defined several principles for DfD applications. According to their suggestions, the connections between structural components are essential and important when applying DfD purpose in civil engineering. That is, the design of connections and connectors of structures should withstand repeated applications.

Generally speaking, it is found that the application of DfD purpose in the case of concrete structures is more challenging than any other types of structures. Due to the requirements of monolithic connections between structural components, abundant cast-in-situ concrete is usually incorporated in the connection area which leads to difficulties in subsequent disassembly. Even so, there are still a number of experimental researches focusing on the concrete components connection to pursue an opportunity of demountability.

From the point view of DfD concrete connections, those dry concrete connections without or with very little cast-in-situ concrete construction, is regarded as suitable for DfD purpose. Some novel connection designs for frame structures, such as dowel connections [19–23], pre-stressed connections [24–27] and

---

* Corresponding author at: Department of Structural Engineering, Tongji University, Shanghai 200092, China.

E-mail addresses: jzx@tongji.edu.cn (J. Xiao), 1130461@tongji.edu.cn (T. Ding).

http://dx.doi.org/10.1016/j.engstruct.2016.11.019
0141-0296/

hybrid-steel connections [28–32] which possess a certain degree of demountability have been studied in past years. It is found that only low-rise buildings can be designed employing the pinned dowel connections because this kind of connection cannot withstand bending moment during earthquake actions. The prestressed connections and hybrid-steel connections usually exhibit the desired structural performance. The capacity and energy dissipation characteristics of specimens with these connections are adequate compared to monolithic specimens. However, disadvantages such as complicated construction, additional equipment and technology limit the application of these connections. In addition, no intended research directly for DfD concrete connections has yet been found for these types of connections.

Particularly, due to the possible continuity of reinforcements in the joint area and avoidance of the inherent plastic hinging region, beam-to-beam concrete connection is deemed as the best way to pursue DfD purpose for concrete frame structures. Investigators [33,34] found that the beam-to-beam connection is feasible as a replication of cast-in-situ concrete moment-resisting frames, as the crack propagate, failure pattern and the ductile behavior performs similarly. In addition, the frame with beam-to-beam connection allows the formation of plastic hinges located at the beam-end regions. However, for the purpose of DfD, only one pioneer research was found to verify the structural behavior of beam-to-beam concrete connections after deconstruction and reconstruction [35]. They proposed a DfD moment-resisting beam-to-beam connection for application in typical multi-storey reinforced concrete (RC) apartment blocks. For this type of beam-to-beam connection, the bolted end plate steel connection was selected as the basis for the proposed DfD moment-resisting connection. However, it was stated by their own investigations that mechanical demolition work during deconstruction may damage the connection resulting in much clamor and debris.

As a result, to the best knowledge of the authors, the amount of performed tests on the structural behavior of DfD concrete connection is still insufficient. It is well known that, for long span frame structures, the structural behavior of the frame system is expected to be governed by flexure rather than by shear. It is important that DfD concrete connection can transfer the flexure which is externally applied through the beams to the columns. Therefore, the present study proposes a moment-resisting DfD concrete connection by welding the steel at both ends of the reinforced concrete beam. Experiments were carried out to evaluate the structural behavior and demountable flexibility of DfD ductile connections proposed in this study. A total of five full-scale concrete specimens were designed and tested to failure under both static and cyclic flexural loadings.

2. Experimental program

2.1. Design and details of specimens

Reuse flexibility is the major issue that needs to be addressed for DfD structures. The layout of the original building is very likely to differ from the new one. As a result, the DfD specimen in this study was mainly focused on beam components. Moreover, in order to avoid complicated construction process and high economic cost, the welding method was adopted for the proposed DfD ductile connection in this study. Fig. 1 shows the prototype of the DfD concrete frame system and Fig. 2 displays the details of the proposed DfD concrete beam to be tested in this study. The construction detail consisted of a middle precast beam, which was placed on a short protruding beam. The short protruding beam was extended from the column of a frame structure. More importantly, by moving the connections away from the column face, the coinciding condition between the inherent plastic hinge locations and the connection regions could be avoided. It is expected that this arrangement will greatly enhance the structural safety of the proposed DfD system.

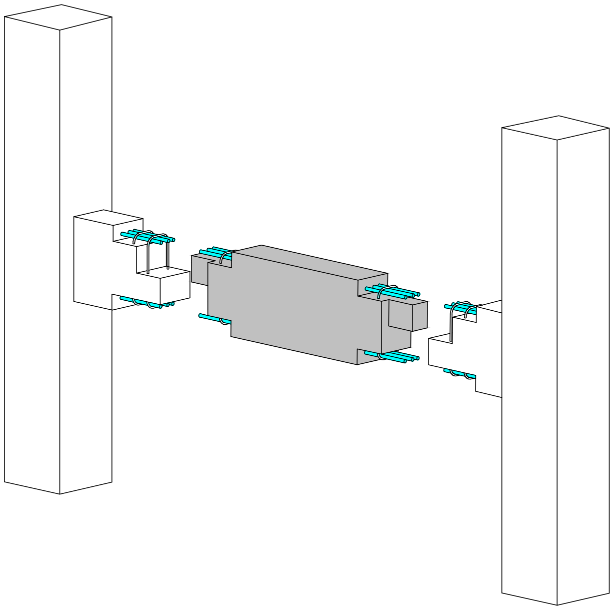
Fig. 1. Prototype of the DfD concrete structure.

Within the connection region, the main reinforcements in both the top and bottom of the beam were welded to the main reinforcements of the frame columns. Elaborate design on the position and dimension of the steel should be carefully taken into account to provide feasible connection assembly on-site in the future. Once the middle precast beam was located on the column and reinforcement connection was achieved, only a very small amount of cast-in-situ concrete was placed for the convenience in future deconstruction. The post cast-in-situ concrete only provided the compression stress transfer and played a role in providing protection for steel bars against possible corrosion and fire during their service life.

During the deconstruction process, the post cast-in-situ concrete was dismantled and the welding reinforcement was cut off by mechanical tools. It is predictable that only minimal damage would be brought due to the small quantity of post cast-in-situ concrete. Conceptually, with proper reinforcement design of new frame columns, the middle beam can be reused as a second life, achieving the DfD purpose and the sustainability.

In order to obtain a comprehensive understanding on the structural behavior of the proposed DfD concrete connections, both static and cyclic flexural loadings were applied to the specimens in this study. In consideration of possibilities that RAC could also be applied for sustainable purpose, specimens made of RAC were also casted and evaluated.

During the static loading tests, three specimens were completed and studied. They were monolithic natural aggregate concrete (NAC) specimen (MNS), DfD NAC specimen (DNS) and DfD RAC specimen (DRS-1). Specimen MNS was designed as a reference specimen. It did not contain any DfD connection. Specimen DNS was designed and constructed with a DfD ductile connection which was proposed in this study. For specimen DRS-1, the reinforcement and design method was a replication of DNS except for casting with RAC. For the sake of reflecting the behavior under earthquake actions, another two specimens including monolithic RAC specimen (MRS) and DfD RAC specimen (DRS-2) were tested under the cyclic loading. Specimen MRS was taken as a reference