Engineering Structures 111 (2016) 333–344

Contents lists available at ScienceDirect

Engineering Structures

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

Behavior of interior RC wide and conventional beam-column roof joints under cyclic load

Sara Mirzabagheri, Abbas Ali Tasnimi *, Masoud Soltani Mohammadi

Structural Engineering Division, Faculty of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran

A R T I C L E I N F O

Article history:
Received 3 March 2015
Revised 2 December 2015
Accepted 13 December 2015
Available online 6 January 2016

Keywords:
Roof wide beam-column joint
Roof conventional beam-column joint
Hysteresis response
Shear strength
Bond behavior
Quasi-static cyclic loading
Energy dissipation capacity

A B S T R A C T

Performance of RC interior beam-column joints at roof level is defined as the area needing research by ACI 352R-02. Because of a lack of research data on performance of this type of joints, two half scale interior beam-column connections with discontinuous column were designed in accordance with ACI 318-11 and ACI 352R-02 provisions. One of the specimens had wide beams and the other had conventional beams to compare their behavior. These specimens were tested under quasi-static cyclic loading. It became clear by the experiments that roof wide beam-column joint had lower strength compared to that of roof conventional beam-column joint. Both of the specimens had almost equal energy dissipation capacity. The conventional beam-column joint reached its expected capacity but wide beam-column joint did not reach its capacity. Moreover, wide beam-column joint had sufficient joint shear strength unlike conventional one. Therefore, joint shear requirements could be relaxed for roof wide beam-column joint. This relaxation must be reapproved by more tests to be advisable for design purposes.

1. Introduction

One of the main portions in reinforced concrete moment resisting frames under seismic excitation is beam-column connection. Based on ACI 318-11 design code, joint failure should not occur. The beam-column joints must be strong enough and failure should occur in the beams or columns [1]. Two types of RC beams are used in the buildings i.e. conventional beam and wide beam. In the case of conventional beams, influence of many parameters affecting the joint behavior have been investigated experimentally or numerically under seismic loads extensively [2–5]. Moreover, various rehabilitation methods have been tested to enhance joint behavior [6,7]. Using wide beams has several advantages such as reduction in the amount of formwork, providing simplicity for repetition, lower story height and faster construction. In past, it was seen that RC moment resisting frames with wide beams had low lateral stiffness. Moreover, transmission of bending moments from wide beams to the columns was not sufficient and energy dissipation capacity of this system was low. Thus, using this structural system was banned as lateral-load resisting system and it could be used as gravity-load resisting system in non-seismic regions [8]. Various researches were performed on seismic behavior of wide beam-column joints and they resulted in some provisions for design codes to allow using wide beam system as lateral-load resisting system in seismic regions. From 1995, ACI 318 has permitted use of wide beam-column connections in earthquake resistant design [1,9–12]. ACI 318-11 limits beam width to minimum amount between $b_c + 1.5h_c$ and $3b_c$ [1].

In 1991, Hatamoto et al. tested two series of beam-column joints to determine the maximum effective beam width and the maximum amount of beam reinforcement not placed in the joint core [13]. Popov et al. also tested interior narrow and wide beam-column joints and the role of beam bars passing outside the column core was evaluated [14]. In 1992, four exterior 3/4-scale wide beam-column joints were tested at the structural engineering laboratory of University of Michigan. It was found that wide beam-column joints performed well if design parameters were carefully controlled. The main parameters in this investigation were beam to column width ratio and amount of beam reinforcement not placed in the joint core [15]. Researches on wide beam-column joints were continued at University of Michigan by experimental researches on three exterior and three interior wide beam-column joints. It was reported that these joints when properly designed, possessed adequate strength and deformation capacity [16,17]. Moreover, other researchers evaluated these types of joints and they proposed a new detailing strategy for interior wide beam-column joints and concluded that no limitation was required for beam to column width ratio if this detailing

* Corresponding author.

http://dx.doi.org/10.1016/j.engstruct.2015.12.011
0141-0296/© 2016 Published by Elsevier Ltd.

Nomenclature

b_b	beam width
b_c	column width
b_j	effective width of joint transverse to the direction of shear
BI	bond index
d	effective height of beam
d_b	beam bar diameter
d_c	column bar diameter
f_c	compressive strength of concrete
f_t	tensile strength of concrete
f_u	ultimate strength of reinforcement steel
f_y	yield strength of reinforcement steel
h_b	full depth of beam
h_c	full depth of column
l_b	total length of beam
l_c	total height of column
M_n	nominal design bending capacity
M_{pbj}	maximum attainable bending moments of the beam limited by the shear failure of the joint
M_{pcj}	maximum attainable bending moments of the column limited by the shear failure of the joint
M_V	ultimate bending moments limited by nominal shear strength
T_{cr}	cracking torque of transverse beam in wide beam specimen
u_b	maximum bond stress of beam bar
V_c	nominal shear strength provided by concrete
V_{nhj}	nominal shear strength of the joint under horizontal shear
V_{nvj}	nominal shear strength of the joint under vertical shear
V_{uhj}	design shear force of the joint under horizontal shear
V	nominal shear strength
z_b	internal moment arm of beam
z_c	internal moment arm of column
γ	shear strength factor
ρ	percentage of reinforcement

regime was adopted [18,19]. Another investigation was performed on full-scale exterior and interior wide beam-column joints in 2009 and 2010. It was also concluded, this flooring system could perform well and could be used as lateral load resisting system if it was designed with suitable parameters [20,21]. Elsouri and Harajli investigated on exterior wide beam-narrow column joints and they observed by improving reinforcement detailing, joints performed considerably better [22]. Recent experimental investigation on four full-scale wide and conventional exterior and interior beam-column connections with continuous column was carried out by authors and their colleagues under quasi-static loading. Results showed that the hysteresis response and total energy dissipation capacity of the wide beams were better than those of conventional beams [23]. Besides, Benavent-Climent et al. conducted a wide range of investigations on seismic behavior of wide beam-column joints designed according to past construction in Spain. These wide beam-column joints were designed to use as gravity load resisting systems [24–26]. Because of poor behavior of knee joints in the Loma Prieta earthquake, Wallace et al. tested this type of joints under quasi-static loading. These joints had conventional beams and they did not include transverse beams. It was concluded that knee joints were not capable of achieving a joint shear level of $12\sqrt{f_c}$. The maximum shear stress obtained ranged from 7.4 to $9.2\sqrt{f_c}$. Therefore $8\sqrt{f_c}$ was proposed for this parameter [27,28]. Beam-column joints experienced joint shear failure, were considered by Kim and LaFave. They concluded for estimating failure of connection correctly, joint shear strength factor proposed by ACI 352R-02 should be adjusted [29].

ACI 352R-02 identified some areas needing research. One of these areas is roof joints that have continuous beams but they have discontinuous column as opposed to knee joints [30]. Moreover, no specific data is available for joints with discontinuous column effectively confined on all four vertical faces or on three vertical faces. Thereby, the value of shear strength factor, γ, for this type of joints was proposed based on the judgment of relevant committee and not on the basis of experimental investigation. Also, shear strength factor for joints with wide beam or conventional beam is the same [30]. Hence, in this research program seismic behavior of RC joints with discontinuous column that effectively confined on all four vertical faces with wide or conventional beams is evaluated. The specimens are subjected to quasi-static reversal loading and overall seismic performance of the connections is clarified.

2. Experimental investigation

2.1. Description of prototype buildings

In order to investigate the behavior of roof interior beam-column connections, two residential moment resisting frame buildings were considered in high seismic region (D category of ACI 318-11) based on the Iranian code of practice for seismic resistant design of buildings (Standard 2800). The design dead and live load were 7 and 2 kN/m^2, respectively. Because of limited height of buildings, equivalent lateral force procedure was considered for the analysis. All the structural elements of two buildings were designed in accordance with ACI 318-11 code provisions.

One of these buildings had conventional beams in both directions. The other had wide beams in the interior frames and conventional beams in the exterior frames to have the benefits of both systems. In this building, low depth of wide beams reduces the whole building height with no reduction in clear height of the story and conventional beams in exterior frames increase stiffness of the structure. Both of the buildings had six stories and four spans in each direction. The height of each story in the building with conventional beams was 3 m and in the building with wide beams was 2.8 m. Floor system of prototype buildings was one-way joist slabs. One interior joint was selected from the roof level of each building (named as RIWBC and RICBC for wide beam and conventional beam-column joints, respectively). These joints were terminated approximately at mid-span of the beams and mid-height of the column. No axial load was applied on top of the column to have the critical condition of the joint. Fig. 1 represents prototype structure. The design yield stress of the reinforcement was 300 MPa for Φ8 and Φ10 and 400 MPa for Φ12. The design concrete compressive strength was assumed 30 MPa.

2.2. Dimensions of test specimens

The specimens were designed based on ACI 318-11 and ACI 352R-02 provisions with scale factor of 1:2. Overall dimensions of the specimens RIWBC and RICBC are shown in Figs. 2 and 3, respectively. Both of the specimens had columns with cross section of 200 × 200 mm. In RIWBC specimen, beam cross section was 400 × 150 mm led to beam width to column width ratio of 2. This ratio is lower than ACI 318-11 code provision for width ratio which