Code investigation and Experimental study of wide beam-column connections

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ABSTRACT

In this paper, seismic behavior of wide beams was investigated. First, code provisions and results of previous tests on reinforcement concrete wide beam-column connections were reviewed. After precise investigation of previous test results and in order to detailed study of behavior of wide joints, 4 specimens of exterior wide beam-column connections in scale of 3:5 were casted and tested under constant axial and cyclic lateral loads. The specimens were designed and detailed in accordance with ACI 318-14 and ACI 352R-02. In tested specimens, different geometries for columns (square, rectangular or circular) and spandrel beams (wide or conventional) were considered. During the tests, formation of full-width flexural plastic hinge of wide beams was observed in all the specimens without any shear or torsional failure. Energy absorption of specimens was relatively high and that is because of using stirrups at the joint area and axial loads applied to columns. The width of spandrel beam and geometry of columns influenced the seismic performance of tested specimens. A comparison between experimental results and ACI provisions showed that dimensional limitations of ACI 318 on wide beams can be violated. Also, in wide joints with axial load ratio greater than 15%, the bond performance of column longitudinal bars is improved and ACI 352R provisions in this context can be relaxed.

KEYWORDS

Wide beam, Exterior beam-column connection, spandrel beam, seismic performance, reinforcement detailing

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1. Introduction

Wide beam frames are efficient gravity and lateral systems in which the beam is wider than the column, and some of the wide beam bars are anchored in spandrel beam. Many codes of practice prior to 1995 prohibited the use of these frames in highly seismic regions [1]. But recent research in the last two decades has revealed that the performance of wide frames when subjected to lateral excitation may be acceptable [2,3]. The key parameter in the seismic behavior of wide beams as earthquake-resistant structures is the reinforcement detailing, especially at the joint region [4,5]. The torsional failure observed in many wide connections tested in the literature can be avoided by providing adequate transverse and longitudinal reinforcement at spandrel beam [6,7].

However, there are still some concerns about the seismic performance of wide beam-column connections. The ductility, stiffness and energy dissipation capacity of wide joints are usually lower than those of conventional ones [8,9]. Generally, the codes do not have comprehensively distinct provisions for seismic designing of wide beams. Most of them only impose a restriction on the dimensional parameters of wide beam-column connections [10–12]. The correct implementation of reinforcement details at the joint area seems to be vague and practically difficult.

In the current study, the seismic behavior of wide beams was investigated. The study focused on the reinforcement detailing at the joint region.

2. Methodology

The paper is based on an experimental program conducted in the structural laboratory of Tehran University. Four 3:5 scale exterior wide beam-column connections were tested under constant axial and quasi-static lateral loads. The test setup is shown in Figure 1.

The test specimens were derived from a five-story prototype building. Different spandrel beam types, namely conventional and wide beams, and various column geometries, including square, rectangular and circular, were used in the specimens.

All the specimens were designed according to rules and regulations of ACI 318-14 and ACI 352R-02 [13,14]. Some violations from the code requirements were considered to facilitate the construction of the connections. The amount of stirrups used in wide beams was significantly relaxed compared with that provided by ACI 318-14. The anchorage ratio of column longitudinal bars (the ratio of beam height to the diameter of column bars) was lower than the minimum value suggested by ACI 352R-02. Some dimensional restrictions of the beam width in ACI 318 were violated, too.

The spandrel beams were designed to resist against the torsional demand in accordance with ACI 352R-02. The transverse reinforcement of wide beams was continued at the joint region in conforming to ACI 318-14. This detailing was not thoroughly used in previous studies, maybe because of difficulties in the execution.

The axial load of specimens was $0.15A_g f_c$ (A_g is the column area and f_c is the compressive strength of concrete). The lateral loading pattern was obtained from ACI 374.2R13 [15] and is shown in Figure 2.

3. Results and Discussion

Figure 3 shows the lateral response of wide beam-column connections studied in this research. The specimens had the lateral drift capacity near 6.0%. The hysteresis loops shown in Figure 3 are relatively fat, which means that behavior of specimens in terms of energy dissipation was fine. Full flexural hinges developed in test specimens and no sign of immature shear or toraion failure was observed in the tests.

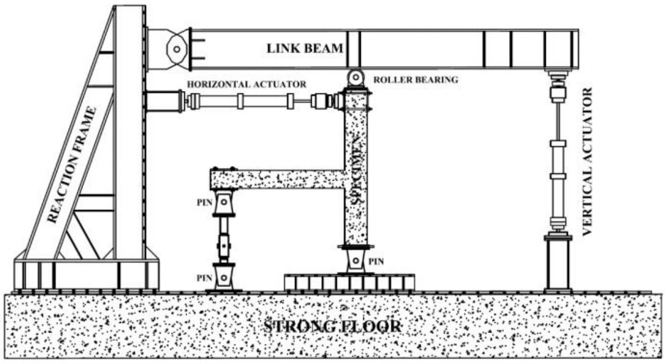


Figure 1. Test setup

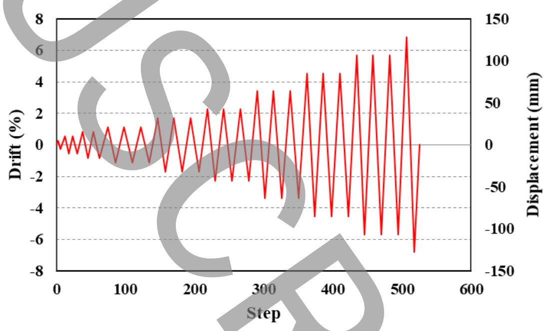
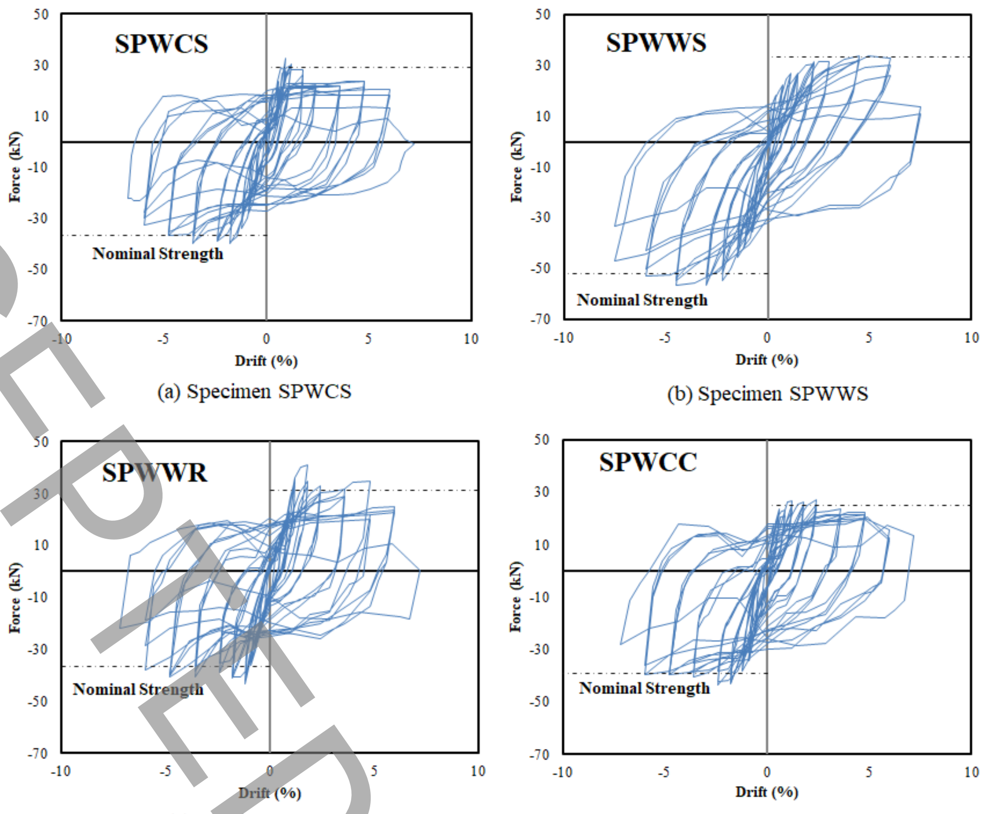


Figure 2. Lateral Loading protocol



(a) Specimen SPWCS

(b) Specimen SPWWS

(c) Specimen SPWWR

(d) Specimen SPWCC

Figure 3. Force-displacement hysteresis response of specimens

In specimens with conventional spandrel beam, the plastic hinge formation observed at the intersection of wide beam and column, while in specimens with wide spandrel beam the plastic mechanism occurred at the intersection of wide and spandrel beam, far from the column face. The specimen with circular column had lower energy dissipation and greater ductility in comparison with that with square column.

Although some of the code requirements were neglected in test specimens, the overall performance of tested connections was satisfactory in terms of ductility, stiffness and energy dissipation.

4. Conclusion

The wide beam-column connections investigated in this study, had good seismic performances. The acceptable seismic behavior of these specimens mainly can be attributed to fine reinforcement detailing at the joint region. Violating some of requirements in test specimens did not disturb the overall performance of the connections.

5. References

[1] I. Fadwa, T.A. Ali, E. Nazih, M. Sara, Reinforced concrete wide and conventional beam–column connections subjected to lateral load, Engineering Structures, 76 (2014) 34-48

[2] H. Behnam, J.S. Kuang, R.Y.C. Huang, Exterior RC wide beam-column connections: Effect of beam width ratio on seismic behaviour, Engineering Structures, 147 (2017) 27-44.

[3] A. Pakzad, M. Khanmohammadi, Experimental cyclic behavior of code-conforming exterior wide beam-column connections, Engineering Structures, 214 (2020) 110613.

[4] A.M. Elsouri, M.H. Harajli, Seismic response of exterior RC wide beam–narrow column joints: Earthquake-resistant versus as-built joints. Eng Struct 2013;57:394–405

[5] A.M. Elsouri, M.H. Harajli, Interior RC wide beam-narrow column joints: Potential for improving seismic resistance, Engineering Structures, 99 (2015) 42-55.

[6] J.M. LaFave, J.K. Wight, Reinforced concrete exterior wide beam-column-slab connections subjected to lateral earthquake loading, Structural Journal, 96(4) (1999) 577-585.

[7] C.G. Quintero-Febres, J.K. Wight, Experimental study of reinforced concrete interior wide beam-column connections subjected to lateral loading, ACI Structural Journal, 98(4) (2001) 572-582.

[8] T.R. Gentry, Reinforced Concrete Wide Beam-column Connections Under Earthquake-type Loading, University of Michigan., 1992.

[9] J.M. LaFave, Behavior of reinforced concrete exterior wide beam-column-slab connections subjected to lateral earthquake loading, University of Michigan, 1997.

[10] ACI 318-19: Building Code Requirements for Structural Concrete and Commentary. 2019.

[11] Eurocode 8: Design of structures for earthquake resistance. Part 2005;1:1991–8.

[12] NZS 3101. The design of concrete structures. Standards New Zealand Wellington; 2006.

[13] ACI 318-14: Building Code Requirements for Structural Concrete and Commentary. 2014.

[14] ACI352R-02: Recommendations for Design of Beam-Column Connections in Monolithic Reinforced Concrete Structures 2002.

[15] A.C. Institute, Guide for testing reinforced concrete structural elements under slowly applied simulated seismic loads (ACI 374.2 R13), in, 2013.