Contemporary Engineering Sciences, Vol. 10, 2017, no. 3, 103 - 111
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2017.610170

The Structural Performance of RC Coupling Beam Using Cold-Formed Steel Channel Sections for Alternative Detail

Yi-Hyun Nam

Department of Convergence Systems Eng., Chungnam National University
99 Daehak-ro Yuseong-gu, Daejeon, 305-764, Republic of Korea

Young-Il Jang

Department of Construction Eng. Education, Chungnam National University
99 Daehak-ro Yuseong-gu, Daejeon, 305-764, Republic of Korea

Wan-Shin Park

Department of Construction Eng. Education, Chungnam National University
99 Daehak-ro Yuseong-gu, Daejeon, 305-764
Republic of Korea
Corresponding author

Sun-Woong Kim

Department of Convergence Systems Eng., Chungnam National University
99 Daehak-ro Yuseong-gu, Daejeon, 305-764, Republic of Korea

Hyun-Do Yun

Department of Architectural Engineering, Chungnam National University
99 Daehak-ro, Yuseong-gu, Daejeon, 305-764, Republic of Korea
Corresponding author

Sun-Woo Kim

Department of Construction Eng. Education, Chungnam National University
99 Daehak-ro Yuseong-gu, Daejeon, 305-764, Republic of Korea

Abstract

Coupling beams are well known as essential structural element in aseismic design. This paper reports experimental studies to investigate the structural performance of reinforced concrete coupling beams using cold-formed steel channel sections for alternative detail. To investigate the structural performance of coupling beams, experiments were conducted for three coupling beams. The first specimen was made in accordance with the code of ACI-318(11). The other specimens were made with alternative detail using cold-formed steel channel sections. The test results show that the maximum strengths and dissipated energy of coupling beam made in accordance with the code of ACI-318 were higher than those of other specimens made with alternative detail using cold-formed steel channel sections. In addition, the maximum strengths were higher when spacing of stirrup in coupling beam were closer.

Keywords: Coupling Beam, Alternative Detail, Cold-Formed Steel Channel

1 Introduction

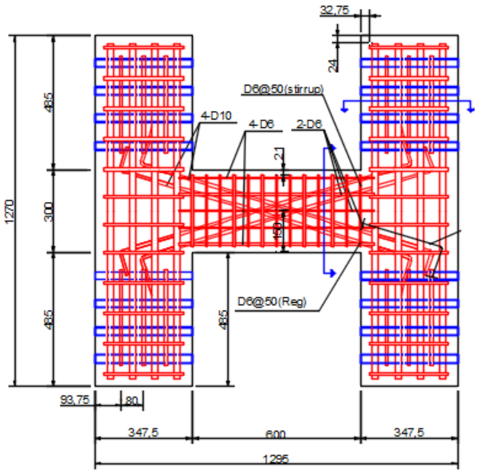
The recent Ulsan earthquake (2016) in the Korea peninsula awakened people to the dangers of earthquake. The earthquakes came concerns that the Korea is no longer safety zone from the earthquake events. Therefore, the importance of seismic design is being emphasized. Coupled wall system with reinforced concrete (RC) coupling beam component containing diagonal oriented reinforcement is one of the lateral load resisting systems for tall buildings [1]. Therefore, coupling beams have been studied by many researchers. Zhao and Kwan. (2003) evaluated the nonlinear behavior of deep reinforced concrete coupling beams [2]. Canbolat et al. (2005) conducted experimental studies of high-performance fiber-reinforced cement composite coupling beams [3]. Park and Yun. (2006) conducted research work to determine bearing strength of steel coupling beam-reinforced concrete [4]. However, the construction of RC coupling beam need to satisfy the detailing requirements for diagonally RC coupling beams with corresponding to ACI 318-11 Building Code [5]. Such details requirements involve facing difficult works for construction. In this study, experimental study was conducted to investigate structural performance of RC coupling beam using cold-formed steel channel sections for alterative detail to solve the problems of detailing requirements for diagonally RC coupling beams.

2 Experimental Programs

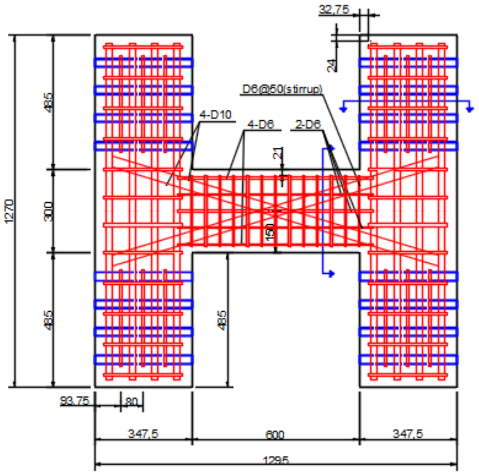
Table 1 and Figure 1 show the variables of test specimens and details of specimens. These three test specimens have same dimensions and different diagonal reinforcement details and/or spacing of stirrups. Test variables of this study are methods of diagonal reinforcement, spacing of stirrup in reinforced concrete coupling beam [6, 7]. Figure 2(a) shows the compressive stress of concrete used for each of the three specimens and Figure 2(b) shows the tensile stress of steel reinforcement and cold-formed steel channel used for each of three specimens. The compressive strength of concrete was 34MPa at 28days and yield strengths of D5 steel, D10 steel and cold-formed steel channel was 285 MPa, 500 MPa and 264 MPa respectively. In addition, Tensile strengths of D5 steel, D10 steel and cold-formed steel channel was 363 MPa, 576 MPa and 361 MPa respectively.

Table. 1 Variables of test specimens

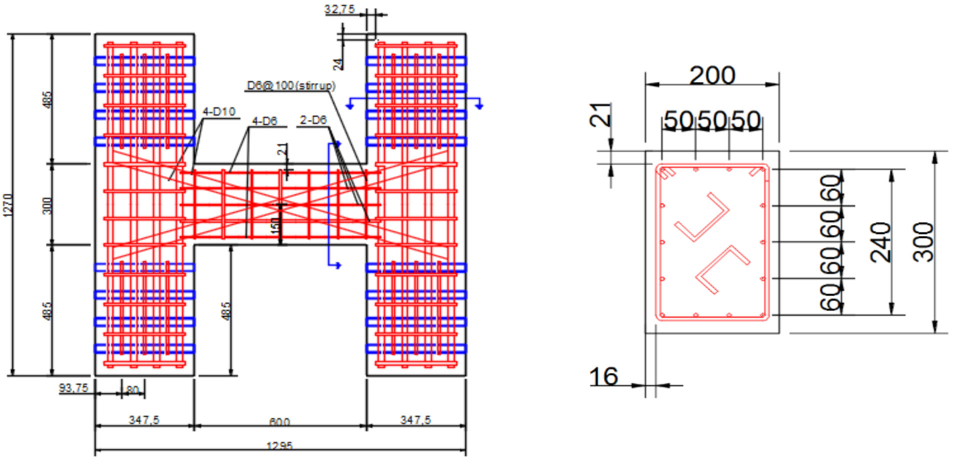
Specimen name	Reinforcement method	Material	Longitudinal reinforcement	Stirrup	Diagonal reinforcement
CB1	Diagonal oriented reinforcement	Concrete	D6-12	D6@50	D10-8
CB2	Alternative details reinforcement				Channel (60x60x6t)
CB3				D6@100	



(a) CB1 specimen

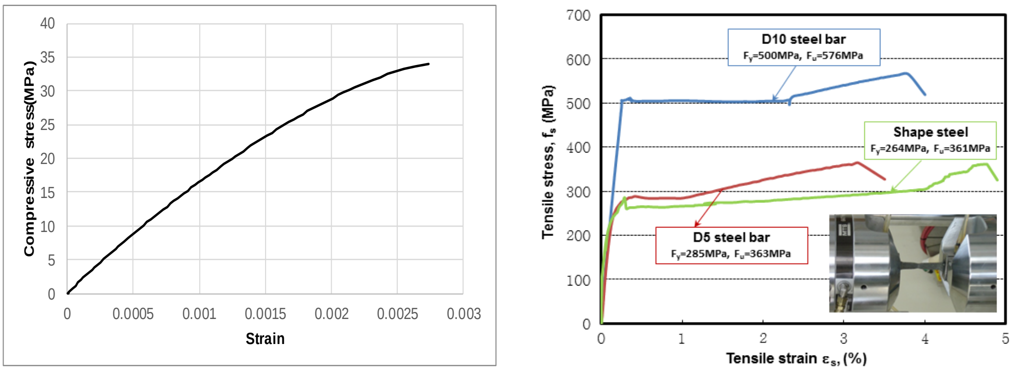


(b) CB2 specimen



(c) CB3 specimen (d) Cross section for CB2 & CB3

Fig. 1 Details of specimens



(a) Compressive stress of concrete at 28days

(b) Tensile stress of steels

Fig. 2 Mechanical properties

Figure 3 shows the test setup of coupling beam. The test specimens were loaded by hydraulic actuator with a capacity of 1,000 kN. The actuator is able to apply forces onto the top steel frame in both positive and negative directions. The Instrumentation was provided to measure the displacement, load, and strain at critical locations. Loading histories of the specimens was operated to loading step and follow same displacement step with gradually increasing amplitude.

The data acquisition system is composed of 20 to 36 internal controls and recording channels. It is possible to obtain data, such as the displacement, load and strain at critical locations. Figure 4 shows the testing procedure including load-controlled and displacement-controlled cycles.

Fig. 3 Test set-up

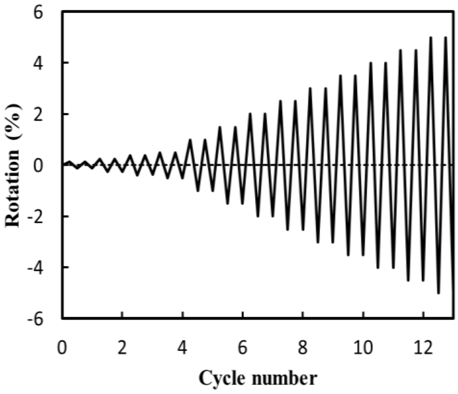


Fig. 4 Loading History

3 Experimental Results

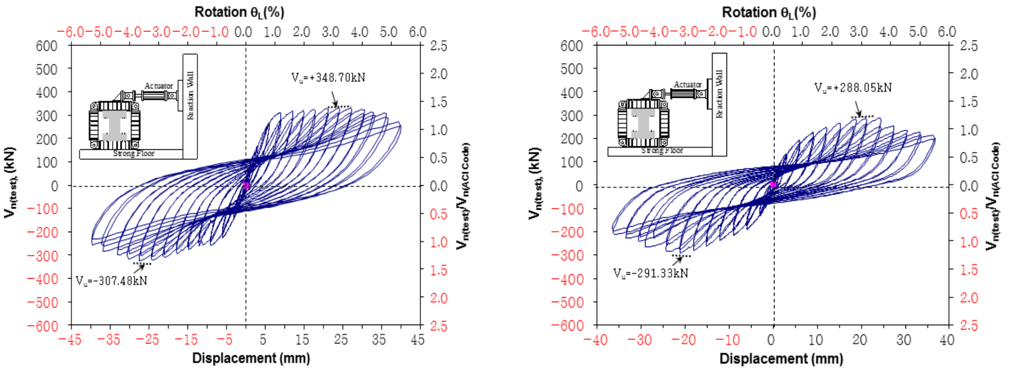
The maximum strengths of test specimens listed in Table 2. As listed in Table 2, the peak loads of specimen CB1 were measured at 348.70kN in the positive loading direction and 307.48kN in the negative loading direction. In particular, maximum strengths of specimen CB1 were higher than those of other specimens in both positive loading and negative loading direction. The peak loads of specimen CB2 were measured at 288.05Kn in the positive loading direction and 291.33kN in the negative loading direction. Maximum strengths of specimen CB2 were second highest of all the specimens in both positive loading and negative loading direction. The peak loads of specimen CB3 were measured at 281.19kN in the positive loading direction and 267.2kN in the negative loading direction. Maximum strengths of specimen CB3 were lower than those of other specimens in positive loading and negative loading direction. In addition, the average maximum strengths of specimens CB1, CB2 and CB3 were 328.09kN, 289.69kN and 274.20kN respectively. It shows that coupling beam made in accordance with the code of ACI-318 had higher maximum strengths than made with alternative detail using channel. This is because the bond area of coupling beam using channel is smaller than coupling beam using bundled bars so there is more slipping at interface with concrete and steel. Moreover, according to the test results of CB2 and CB3, the maximum strengths got higher when spacing of stirrup in coupling beams got closer. This is because the more stirrups could control the cracks of concrete occurred by lateral loads.

Figure 5 (a) to (c) show the hysteresis loops plotted against the displacement. First of all, the hysteresis loops of specimen CB1 were stable and the rate of strength degradation beyond the maximum load was slow comparing with those of other specimens and test was finished at 5.5% rotation angle. Secondly, hysteresis loops of specimen CB2 were variable before the maximum load and the rate of strength degradation beyond the maximum load was fast comparing with the specimen CB1 and test was finished at 5.5% rotation angle. Lastly, the hysteresis loops of specimen CB3 were also variable before the maximum load and the rate of strength degradation beyond the maximum load was fast comparing with the specimen CB1 and test was finished at 4.5% rotation angle. Generally, the hysteresis loops of specimen CB1 were more stable than those of specimens CB2 and CB3. This is because the bond area of coupling beam using channel is smaller than coupling beam using bundled bars so there is more slipping at interface with concrete and steel.

Figure 6 shows the dissipated energy of specimens CB1, CB2 and CB3. At a cycle 1 (0.5% rotational angle), values of cumulative dissipated energy for specimens CB1, CB2 and CB3 were 2.23 kNxm, 1.94 kNxm and 2.06 kNxm, respectively. At a cycle 12 (5.0% rotational angle), values of cumulative dissipated energy for specimens CB1, CB2 and CB3 were 162.06 kNxm, 119.75 kNxm and 120.87 kNxm, respectively. In particular, dissipated energy of specimens CB2 and CB3 show similar tendency. In addition, there is a wide gap between CB1 and either CB2 or CB3.

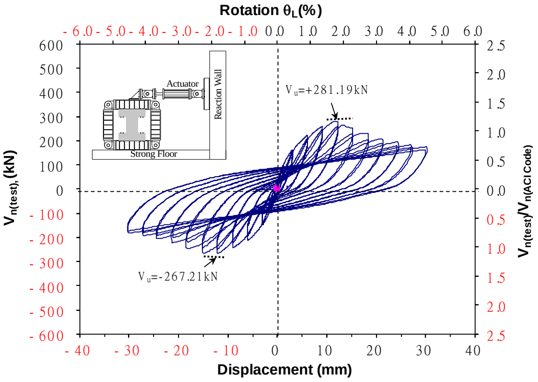
Table. 2 Maximum strength

Specimen	Maximum strength		
	Positive loading	Negative loading	Average maximum strength
CB1	348.70kN	307.48kN	328.09kN
CB2	288.05kN	291.33kN	289.69kN
CB3	281.19kN	267.21kN	274.20kN



(a) Specimen CB1

(b) Specimen CB2



(c) Specimen CB3

Fig. 5 Hysteretic loop

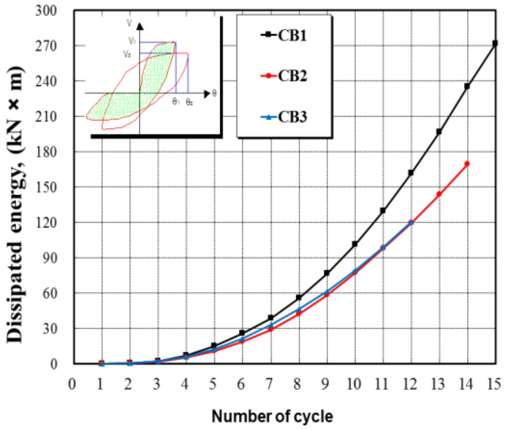


Fig. 6 Dissipated energy

4. Conclusion

Based on the experimental results, first of all, the average maximum strengths of test specimens CB1, CB2 and CB3 were 328.09kN, 289.69kN and 274.20N respectively. In addition, the average maximum strength of CB1 specimen is 1.13 and 1.20 times higher than those of specimens CB2 and CB3 respectively. secondly, the hysteresis loops of specimen CB1 were more stable and the rate of strength degradation beyond the maximum load was slower than those of specimens CB2 and CB3. Lastly, dissipated energy of specimen CB1 was higher than those of other specimens. In particular, dissipated energy of specimens CB2 and CB3 show similar tendency

Acknowledgements. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2014R1A1A2057931)

References

[1] W. S. Park and H. D. Yun, Seismic behaviour of steel coupling beams linking reinforced concrete shear walls, *Engineering Structures*, **27** (2005), no. 7, 1024-1039. https://doi.org/10.1016/j.engstruct.2005.02.013

[2] Z. Z. Zhao and A. K. H. Kwan, Nonlinear behavior of deep reinforced concrete coupling beams, *Structural Engineering and Mechanics*, **15** (2003), no. 2, 181-198. https://doi.org/10.12989/sem.2003.15.2.181

[3] B. A. Canbolat, G. J. Parra-Montesinos and J. K. Wight, Experimental Study on Seismic Behavior of High-Performance Fiber-Reinforced Cement Composite Coupling Beams, *Structural Journal*, **102** (2005), no. 1, 159-166. https://doi.org/10.14359/13541

[4] Wan-Shin Park, Hyun-Do Yun, The bearing strength of steel coupling beam-reinforced concrete shear wall connections, *Nuclear Engineering and Design*, **236** (2006), no. 1, 77-93. https://doi.org/10.1016/j.nucengdes.2005.06.005

[5] ACI Committee 318, Editor, American Concrete Institute, (2011).

[6] S. W. Kim, et al., The Behavior Characteristics of Link Beam with Alternation of Reinforcement Details, *Journal of KCI Proceeding*, **28** (2016), no. 1, 107-108.

[7] S. W. Kim, et al., The Failure Mode of Link Beam with Angle of Reinforcement Details, *Journal of KSMI Proceeding*, (2016), 143-144.

Received: November 12, 2016; Published: January 3, 2017