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Effect of transverse reinforcement on hysteretic behavior of slender diagonally reinforced coupling beams

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ABSTRACT

Coupled shear wall systems are efficient in resisting lateral forces. Recently coupling beams are comparatively slender due to limitations in story height and the use of high strength concrete. The objective of this study is to investigate the effect of transverse reinforcement on the hysteretic behavior of slender diagonally reinforced coupling beams. Three coupling beam specimens were made and tested subjected to cyclic loading. Standard specimen was designed and detailed according to ACI 318-14. Other specimens were designed as the standard specimen except for the amount of transverse reinforcement. The test results show that the hysteretic behavior of coupling beams was strongly affected by the amount of transverse reinforcement.

1. INTRODUCTION

Coupled shear wall systems, one of the lateral load resisting system, are usually used as the primary structural components in high-rise buildings and efficient in resisting lateral forces such as wind and earthquake loads. Paulay (1974) developed diagonally reinforced concrete coupling beams to prevent the sliding shear failure.

Most experimental studies have been conducted on deep coupling beam and reported that diagonally reinforced concrete coupling beams did not occur sliding shear failure and had higher seismic performance. (Pauly 1974, Barney 1980, Tassios 1996, Fortney 2005) In particular, test results show that shear strength is larger than that calculated by shear strength equation in ACI 318-14 (2014) because only the effect of diagonal reinforcement is considered in shear strength equation of diagonally reinforced concrete coupling beam in ACI 318-14.

The objective of this study is to (1) evaluate the seismic performance of slender diagonally reinforced concrete coupling beam designed and detailed according to ACI 318-14, (2) investigate the effect of transverse reinforcement in slender diagonally reinforced concrete coupling beam. For this purpose, three coupling beam specimens were made and tested subjected to cyclic loading.

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2. DETAILS OF DIAGONALLY REINFORCED CONCRETE COUPLING BEAMS

Diagonal reinforcement should be placed in coupling beams with an aspect ratio (l_n / h) less than 2.0 and the average shear stress larger than $0.33\lambda\sqrt{f'_c}$ MPa (Fig. 1), where l_n is clear span length, h is overall height of the beam, λ is the modification factor for lightweight concrete and f'_c is the compressive strength of concrete. If the aspect ratio is between 2 and 4, reinforcement details with diagonal bars or conventional beam reinforcement details for special moment frames in ACI 318-14 are permitted.

$$V_n = 2A_{vd} f_y \sin\alpha \leq 0.83\sqrt{f'_c} A_{cw} \quad (1)$$

Eq. (1) is the shear strength equation of diagonally reinforced concrete coupling beam specified in ACI 318-14, where A_{vd} is the total area of reinforcement in each group of diagonal bars, f_y is yield strength of diagonal reinforcement, α is the angle between the diagonal bars and the longitudinal axis of the coupling beam, f_c' is the compressive strength of concrete, A_{cw} is area of concrete section of coupling beam resisting shear. Since only the effect of diagonal reinforcement is considered in Eq. (1), diagonally reinforced concrete coupling beam with the same diagonal reinforcement have the same shear strength.

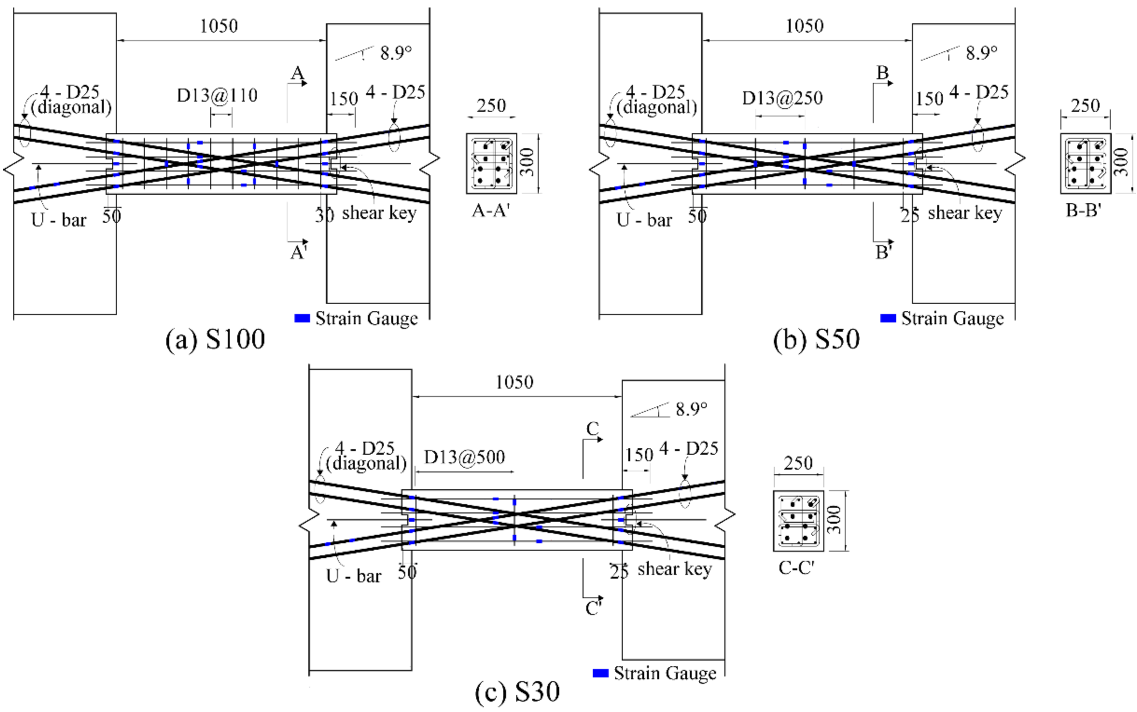

Fig. 1 Reinforcement details and strain gauge layout for the specimens

3. EXPERIMENTAL PROGRAM

Three coupling beam specimens were made with an aspect ratio of 3.5. The amount of transverse reinforcement was the test variable. Fig. 1 shows reinforcement details of each specimen. For all three specimens, the width (b) was 250 mm, overall height (h) was 300 mm and clear span length (l_n) of the coupling beam was 1050 mm. S100 specimen (Fig. 1a) as a standard specimen was designed and detailed according to ACI 318-14. Specimens S50 and S30 were designed as the standard specimen except that the amount of transverse reinforcement was reduced to 50% and 30%, respectively (Fig. 1b, c). Quasi-static displacement-controlled cyclic loading is used. The drift ratio (θ) is defined as a lateral drift divided by the span length of the beam.

4. EXPERIMENTAL TEST RESULT

Fig. 2 indicates the hysteretic curves of three specimens tested subjected to cyclic loadings with increasing amplitude. Standard specimen (S100) showed stable hysteretic behavior and maximum strength was 504 kN (Fig. 2a), which is about 67% higher than the calculated strength according to Eq. (1). The maximum drift ratio was 9.8%, it is measured when strength was reduced to 20%. When drift ratio was 10.0%, a sudden strength drop was observed which was considered as failure of specimen. Thus, slender concrete diagonally reinforced concrete coupling beam detailed according to the full confinement beam section option specified in ACI 318-14 exhibited excellent hysteretic behavior.

Specimen S50 (Fig. 2b) showed stable hysteretic behavior until the drift ratio of 4.0%. The maximum strength was 376 kN, which is about 25% higher than the calculated strength according to Eq. (1). The maximum drift ratio was 4.8%, which is larger than 4.0% required for SMF beams in ASCE 41-13. The specimen failure at the drift ratio of 6.0%.

Fig 5c shows the hysteretic curve of S30 specimen. The maximum strength was 290 kN, which is about 4% lower than the calculated strength according to Eq. (1). The maximum drift ratio was 3.0% and the specimen failure at the drift ratio of 3.5%.

In this experiment, it is observed that hysteretic behavior was significantly affected

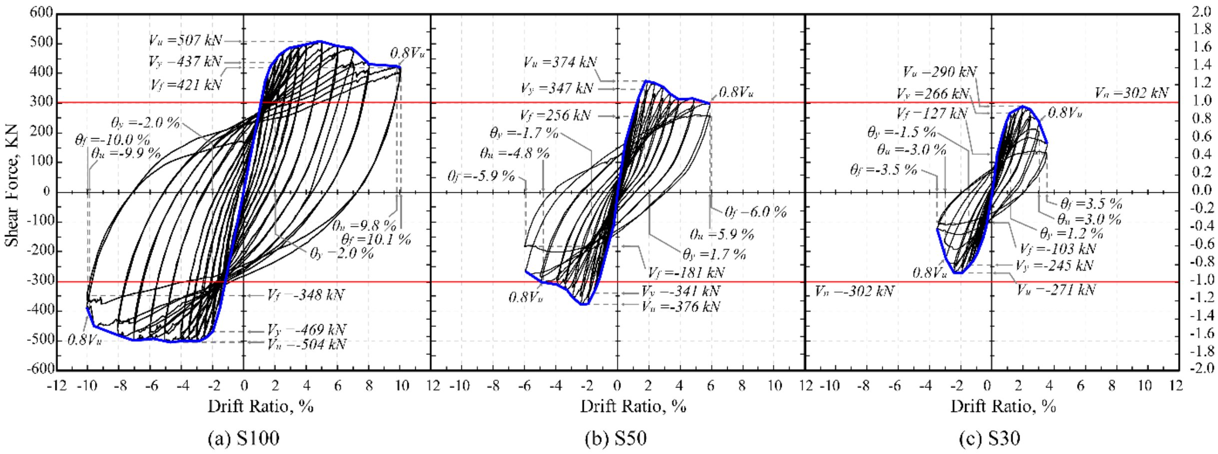

Fig. 2 Hysteretic curves of the specimens

by amount of transverse reinforcement. In particular, the maximum strengths of S100, S50, and S30 were 504 kN, 376 kN, and 290 kN, respectively, even though the calculated strength according to Eq. (1) were all 302 kN. This means that the Eq. (1) only considers the effect of diagonal reinforcement, but the test result shows that shear strength are influenced by the amount of transverse reinforcement. Thus, when calculating the shear strength, not only the effect of diagonal reinforcement but also transverse reinforcement has to be considered.

5. CONCLUSIONS

Experimental tests were conducted using three slender diagonally reinforced coupling beams with different amount of transverse reinforcement to investigate the effect of the amount of transverse reinforcement on the cyclic behavior of coupling beams. Standard specimen, S100 exhibited excellent hysteretic behavior. This specimen sustained cyclic loads up to a drift ratio of 10%, and had shear strength larger than that calculated using the ACI 318-14 strength equation.

It is observed that the shear strength and deformation capacity of slender coupling beams were varied according to the amount of transverse reinforcement. All the specimens were expected to have the same strength according to ACI 318-14 because the strength of the coupling beams use calculated only considering the amount of diagonal reinforcement irrespective of the amount of transverse reinforcement. Test result revealed that shear strength of the coupling beams significantly varied with respect to the amount of transverse reinforcement.

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