The 2020 World Congress on
Advances in Civil, Environmental, & Materials Research (ACEM20)
25-28, August, 2020, GECE, Seoul, Korea

Investigation of RC coupling beams with different span-depth ratios and their behavior under cyclic loads

*Tse-An Chou[1] and Thomas Kang[2]

[1), 2)] *Department of Architecture & Architectural Engineering, Seoul National University, Seoul, Korea*
[2)] *tkang@snu.ac.kr*

ABSTRACT

Seismic and wind behavior of reinforced concrete coupling beams with different span-depth ratios and reinforcement layouts was investigated. Reinforced concrete coupling beams can form an efficient energy dissipating fuse and force transfer element between reinforced concrete shear walls under seismic or wind action of tall buildings. In order to understand reinforced concrete coupling beams' behavior, this study used the Pivot Hysteretic Model to simulate experimental results from previous researches (Barney et al., 1980; Lim et al., 2016a; Lim et al., 2016b) and compared test results between conventional longitudinal coupling beams and/or diagonal coupling beams with (l_n/h) < 2.0, 2.0 ≤ (l_n/h) ≤ 4.0 and (l_n/h) ≥ 4.0 under cyclic loading. Based on the comparison, the study will be expanded for purpose of proposing a new reinforcement layout and/or design/modeling methodology of reinforced concrete coupling beams with reasonable energy dissipation and constructability.

1. INTRODUCTION

Reinforced concrete coupling beams can form an efficient seismic system between reinforced concrete coupled shear walls for resisting lateral loads in tall buildings. In order to understand reinforced concrete coupling beams' behavior, this study applied the Pivot Hysteretic Model of ETABS to obtain similar hysteretic results to experimental results from previous researches. This was done to better simulate effective flexural stiffness, effective shear stiffness and hysteretic parameters. Modeling and experimental results are compared between longitudinal coupling beams and/or diagonal coupling beams with (l_n/h) < 2.0, 2.0 ≤ (l_n/h) ≤ 4.0 and (l_n/h) ≥ 4.0 under cyclic loading. Specimens C5, C6, C7 and C8 (Barney et al., 1980), CB10-1, CB10-2, CB20-1 and CB20-2 (Lim et al., 2016a), and CB30-C, CB40-C and CB30-DB (Lim et al., 2016b) were investigated in this study.

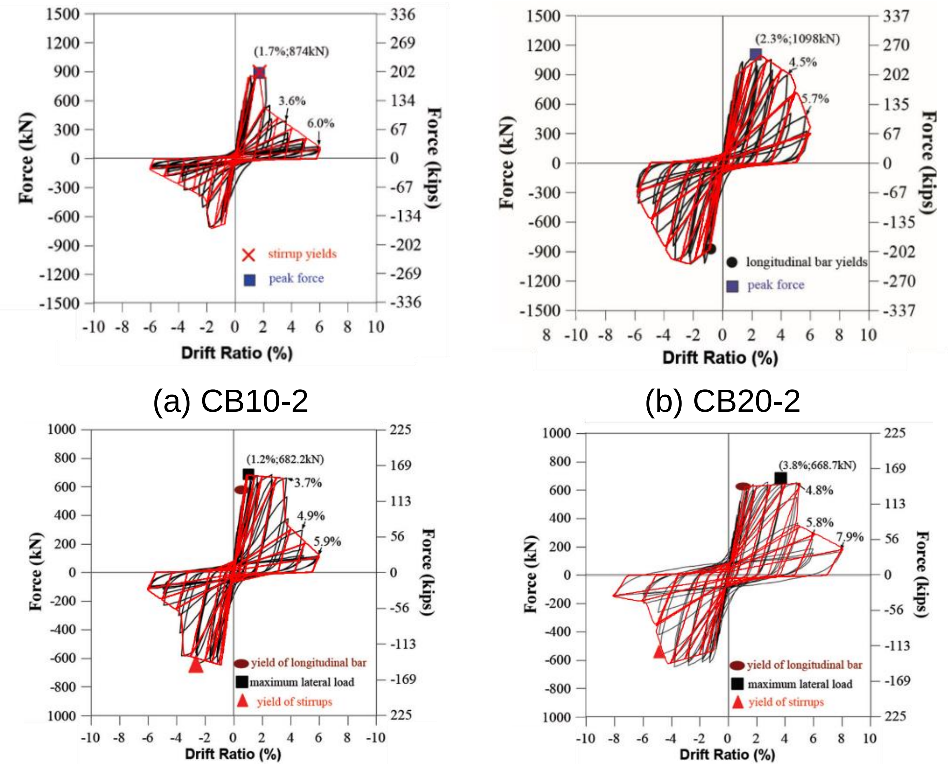
[1)] Graduate Student
[2)] Professor

2. MODELING

For coupling beams, effective flexural stiffness (E_cI_g), effective shear stiffness (E_cA_g), plastic rotation at significant shear strength degradation, and residual strength are important parameters of modeling. In this study, the Pivot Hysteretic Model (Dowell et al., 1998; Sharma et al., 2013) of ETABS was applied for obtaining effective stiffnesses and hysteretic parameters (α, β, etc.) from previous research outcomes. The results are shown in Table 1 and Fig. 1.

Table 1 Parameter values

Specimen	Layout	l_n/h	E_cI_g	E_cA_g	α	β
CB10-2	Longitudinal	1.0	0.07	0.15	10	0.095
CB20-2	Longitudinal	2.0	0.2	0.15	3	0.124
CB30-C	Longitudinal	3.0	0.3	0.15	3	0.123
CB40-C	Longitudinal	4.0	0.3	0.16	3	0.152



(a) CB10-2 (b) CB20-2

(c) CB30-C (d) CB40-C

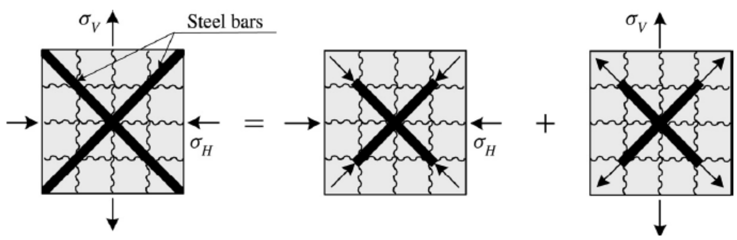
Fig. 1 Hysteretic models for longitudinal coupling beams

In terms of effective stiffness, the following is suggested: 1) FEMA 356 (2000) recommends stiffness values of $0.5E_cI_g$ and $0.4E_cA_g$; 2) ACI 318R-14 (2014) recommends stiffness values of $0.35E_cI_g$ and $1.0E_cA_g$; 3) TBI 2017 (2017) recommends $0.07(l_n/h)E_cI_g$ ($\leq 0.3E_cI_g$) and $0.4E_cA_g$; and 4) PEER/ATC 72-1 (2010) recommends $0.15E_cI_g$ and $0.4E_cA_g$ (for $l_n/h \geq 2.0$) or $0.1E_cA_g$ (for $l_n/h \leq 1.4$), with linear interpolation between $0.4E_cA_g$ and $0.1E_cA_g$ (for $2.0 \geq l_n/h \geq 1.4$). According to the results of longitudinally reinforced coupling beams, the effective flexural stiffness values prescribed by TBI 2017 are closer to obtained values, and the effective shear stiffness values prescribed by FEMA 356, ACI 318R-14, TBI 2017 and PEER/ATC 72-1 are generally higher than obtained values.

3. PINCHING MECHANISM

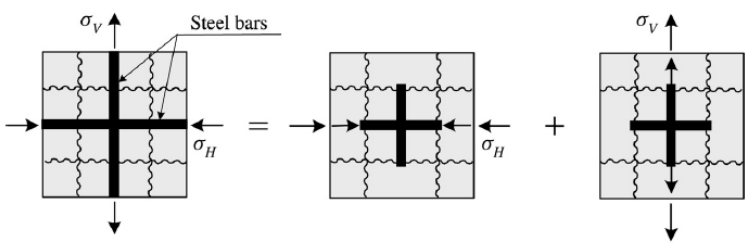
The presence of pinching effect occurred in longitudinally reinforced coupling beams after steel yielding, approaching to the origin in the hysteretic loops (Fig. 1). This phenomenon was mainly due to the opening and closing of concrete cracks under cyclic loading and led to degradation of stiffness, deterioration of strength and the reduction of energy dissipation capacity (Mansour et al., 2005).

The mechanism of pinching is illustrated in Figs. 2 and 3. Since the horizontal shear stress, σ_h, induces a compressive stress in steel bars (Fig. 2(b)), and the vertical tensile shear stress, σ_v, induces a tensile stress in steel bars in the meantime (Fig. 2(c)). These two stresses will cancel each other out and result in tiny shear resistance but with a large shear strain of RC element. However, in case of absence of pinching (Fig. 3), while steel bars are parallel to the horizontal shear stress, σ_h, and the vertical tensile shear stress, σ_v, they will resist these two shear stresses, allowing for an element to have a higher shear stiffness than 45°-rotated steel bars. Therefore, diagonally reinforced coupling beams generally have a better deformation capacity and energy absorption than longitudinally reinforced coupling beams due to its rounded hysteretic loops.



(a) RC element grid (b) Compressive stress (c) Tensile stress

Fig. 2 Cracked RC element grid with 45°-rotated diagonal steel bars



(a) RC element grid (b) Compressive stress (c) Tensile stress

Fig. 3 Cracked RC element grid with grid-type steel bars

4. TEST RESULTS

Test results from previous research show that diagonally reinforced coupling beams can offer higher shear strength and have lager deformation capacity than the counterpart of longitudinally reinforced coupling beams with different span-depth ratios (Table 2). It is notable that diagonally reinforced coupling beams with higher span-depth ratio have a decreasing trend of drift ratio at maximum load capacity as shown in Fig. 4. After the diagonally reinforced coupling beams reached the maximum load, the shear load dropped down much more suddenly, compared to that of the longitudinally reinforced coupling beams.

Table 2 Test results

Specimen	Layout	l_n/h	Shear strength (kN)	Drift ratio (%)	Ultimate drift ratio (%)	Normalized shear strength ($\sqrt{\text{MPa}}$)
C5	Longitudinal	2.5	41.8	3.1	8.4	0.63
C6	Diagonal	2.5	56.6	4.7	5.4	0.86
C7	Longitudinal	5.0	23.1	2.7	6.0	0.35
C8	Diagonal	5.0	33.4	4.5	6.9	0.51
CB10-1	Diagonal	1.0	1443.8	5.8	5.8	2.6
CB10-2	Longitudinal	1.0	873.6	1.7	1.7	1.3
CB20-1	Diagonal	2.0	-1073.0	-2.2	-2.2	1.3
CB20-2	Longitudinal	2.0	1098	2.3	-2.3	1.2
CB30-DB	Diagonal	3.0	728.2	2.7	7.4	0.78
CB30-C	Longitudinal	3.0	682.2	1.2	4.1	0.66
CB40-C	Longitudinal	4.0	668.7	3.8	5.1	0.44

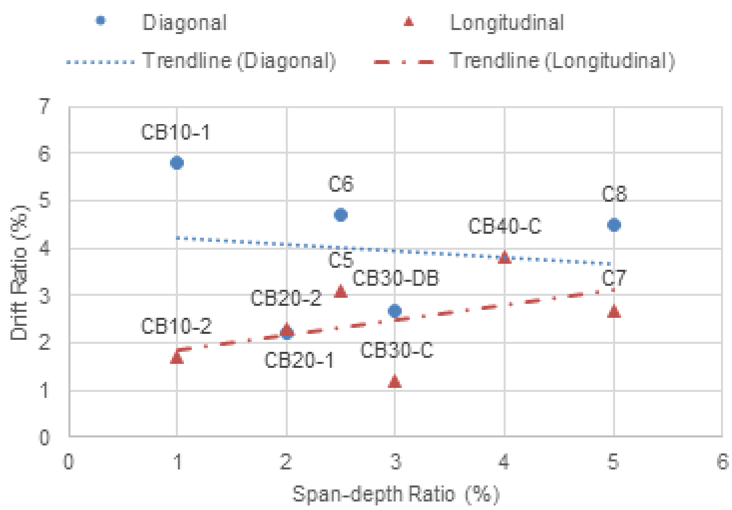


Fig. 4 Span-depth ratio versus drift ratio

5. CONCLUSIONS

Based on the modeling and experimental results of the previous research, two major conclusions can be drawn as follows:

1. In the case of modeling longitudinally reinforced coupling beams (e,g, Lim et al., 2016a; 2016b), the effective flexural stiffness values prescribed by TBI 2017 are closer to the obtained values, while the effective shear stiffness values prescribed by FEMA 356, ACI318R-14, TBI 2017 and PEER/ATC 72-1 are generally higher than the obtained values.
2. Diagonally reinforced coupling beams have better resistance of shear strength, deformation ductility and energy dissipation capacity than longitudinally reinforced coupling beams due to absence of pinching effect; however, there is a potential for the latter to be used for many purposes, particularly for tall coupled shear wall buildings in the regions where high wind force and moderate-to-high seismic force are present.

REFERENCES

ACI Committee 318 (2014), *Building code requirements for structural concrete (ACI 318-14) and commentary (ACI 318R-14)*, American Concrete institute, Farmington Hills, MI, USA.

Barney, G. B., Shiu, K. N., Robbat, B. G., Fiorato, A. E., Rossel, H. G. and Corley, W. G. (1980), “Behavior of coupling beams under load reversals,” *Research and Development Bulletin RD068.01B*, Portland Cement Association, Skokie, IL, 25 pp.

FEMA (2000), *Prestandard and commentary for the seismic rehabilitation of buildings (FEMA 356)*, Federal Emergency Management Agency, Washington, D.C, USA.

Lim, E., Hwang, S.-J., Wang, T.-W. and Chang, Y.-H. (2016a), “An investigation on the seismic behavior of deep reinforced concrete coupling beams,” *ACI Structural Journal*, **113**(2), 1-10.

Lim, E., Hwang, S.-J., Cheng, C.-H. and Lin, P.-Y. (2016b), “Cycling tests of reinforced concrete coupling beams with intermediate span-depth ratio,” *ACI Structural Journal*, **113**(3), 515-524.

Mansour, M.Y., Lee, J.-Y., Hindi, R. (2005), “Analytical prediction of the pinching mechanism of RC elements under cyclic shear using a rotation-angle softened truss model,” *Engineering Structures*, **27**(8), 1138-1150.

PEER/ATC 72-1 (2010), *Modeling and acceptance criteria for seismic design and analysis of tall Buildings (PEER/ATC 72-1)*, Pacific Earthquake Engineering Research Center (PEER)/Applied Technology Council (ATC), Berkeley, CA, USA.

Sharma, A., Eligehausen, R., Reddy, G. R. (2013), “Pivot hysteresis model parameters for reinforced concrete columns, joints, and structures,” *ACI Structural Journal*, **110**(2), 217-228.

TBI/PEER (2017), *Guidelines for performance-based seismic design of tall buildings (TBI 2017)*, Pacific Earthquake Engineering Center, Berkeley, CA, USA.