Simulation of Cyclic Behavior for Diagonally Reinforced Concrete Coupling Beams using Accurate Analytical Model

Conference Paper · August 2017

3 authors:

Sang Whan Han
Hanyang University

Hyeyoung Koh
University of Wisconsin–Madison

Chang Seok Lee
Hanging University

The 2017 World Congress on
Advances in Structural Engineering and Mechanics (ASEM17)
28 August - 1 September, 2017, Ilsan(Seoul), Korea

Simulation of Cyclic Behavior for Diagonally Reinforced Concrete Coupling Beams using Accurate Analytical Model

Sang Whan Han[1)], *Hyeyoung Koh[2)] and Chang Seok Lee[3)]

[1), 2), 3)] *Department of Architectural Engineering, Hanyang University, Seoul, Korea*
[1)] swhan82@gmail.com

ABSTRACT

Coupled shear wall system is an efficient structural system for tall buildings in view of excellent ductility and energy dissipation properties. The objective of this study is to simulate the cyclic curve of coupling beams using an accurate analytical model that can properly account for cyclic deteriorations in strength and stiffness. For this purpose, a phenomenological model is used as a base model in this study. Parameters for the analytical model was determined using the test results of coupling beams. The analytical model with the values of the parameters is verified by comparing the cyclic curves obtained from analyses and experimental tests.

1. INTRODUCTION

Coupled shear wall system is an efficient structural system for tall buildings in view of excellent ductility and energy dissipation properties. In particular, coupling beams which connecting shear walls behave as seismic fuse elements that can dissipate substantial amount of energy and take large deformation relative to adjacent walls. Therefore, a properly designed coupling beam is needed to improve ductility and energy dissipation capacity in the overall structural system. However, coupling beams with conventional reinforcement may suffer sliding shear failure and diagonal shear failure. To prevent such brittle failure, Paulay (1971) first proposed diagonally reinforced coupling beam (DRCB). The capacity of DRCBs for ductility and energy dissipation was proven throughout experiments (Naish 2013, Han 2015)

Under cyclic loading tests of DRCBs, structural damage such as concrete spalling or steel buckling occurred in the specimen. The damage appeared in cyclic curves as pinching or cyclic deteriorations, which can lead the collapse of structural systems. Therefore, It is important to consider pinching and cyclic deterioration when predicting cyclic behavior of RC components. The objective of this study is to simulate the cyclic curve of DRCB using an accurate analytical model that can properly account for pinching, cyclic deteriorations in strength and stiffness. This paper provides a procedure of calibration to predict the cyclic behavior of DRCBs.

[1)] Professor, Corresponding author
[2), 3)] Graduate Student

2. Modeling parameters

In order to simulate the cyclic behavior of DRCBs, this study used the Pinching4 material model (Lowes 2003) provided in the OpenSees. The Pinching4 model can present hysteretic characteristics including pinching, cyclic deteriorations in strength and stiffness. In the Pinching4 model, the values for the constituent parameters of cyclic deteriorations and pinching should be assigned with respect to a pre-defined quad-linear monotonic backbone. It is important to decide proper parameters based on test data to obtain accurate simulation result of DRCBs.

2.1 Monotonic quad-linear backbone curves

The Pinching4 model uses a quad-linear backbone curve. The parameters for backbone curve can be represented by yield, capping, ultimate and residual points (Fig.1a). This study constructed monotonic backbone based on cyclic curve (Lignos and Krawinkler 2011). Capping point ($\theta_c.V_c$) is the point where maximum strength is observed. Yield point ($\theta_y.V_y$) is an intersection of two lines with slopes yield stiffness (k_y) and capping stiffness (k_c). k_y is defined as a secant slope where a drift ratio is 1%. k_c is a slope of line between V_c and another peak strength in the previous loading cycle for V_c. Ultimate point ($\theta_u.V_u$) is determined as the drift ratio at failure and shear strength at V_c. Lastly, residual point is set to have very small value for V_r and $1.1\theta_u$ for θ_r.

2.2 Pinching Parameters

Pinching is determined by three parameters, $rDisp, rForce, uForce$ (Fig. 1b). The proper values for the three pinching parameters are determined to simulate pinching behavior observed from test data.

2.3 Deterioration Parameters

The amount of cyclic deteriorations in strength and stiffness are estimated with the damage index (δ_i) (Lowes 2003). δ_i is calculated using Eq. (1) modified version of the equation proposed by (Park and Ang 1985)

$$\delta_i = \alpha_2 \left(\frac{E_i}{\alpha_5 E_c}\right) \quad (1)$$

where E_i is cumulated hysteretic energy up to loading cycle i, E_c is an area under monotonic backbone curve, α_2 is deterioration parameter calibrated to match the actual deterioration measured from test results, and α_5 is the calibration factor for E_c.

It is important to properly determine α_2 to simulate deterioration behavior. For this purpose, Eq. (2) is used to calculate actual deteriorations in strength and stiffness. Eq.(2) is modified version of the equation proposed by Lowes (2003)

$$\delta_{i,test} = 1 - \frac{x_i}{x_{0,i}} \tag{2}$$

where x_i can be shear strength (V_i), reloading stiffness ($k_{r,i}$) or unloading stiffness ($k_{u,i}$) obtained from test data at loading cycle i, and $x_{0,i}$ is a corresponding value in monotonic backbone.

In the Pinching4 model, once pinching and strength deterioration are implemented in the model, reloading stiffness deterioration is dependently generated. Additionally, the value of unloading stiffness deterioration parameters for three test data had almost same value as those of strength deterioration parameters. In this study, therefore, deterioration in reloading stiffness is ignored and same parameters are used for deteriorations in strength and unloading stiffness.

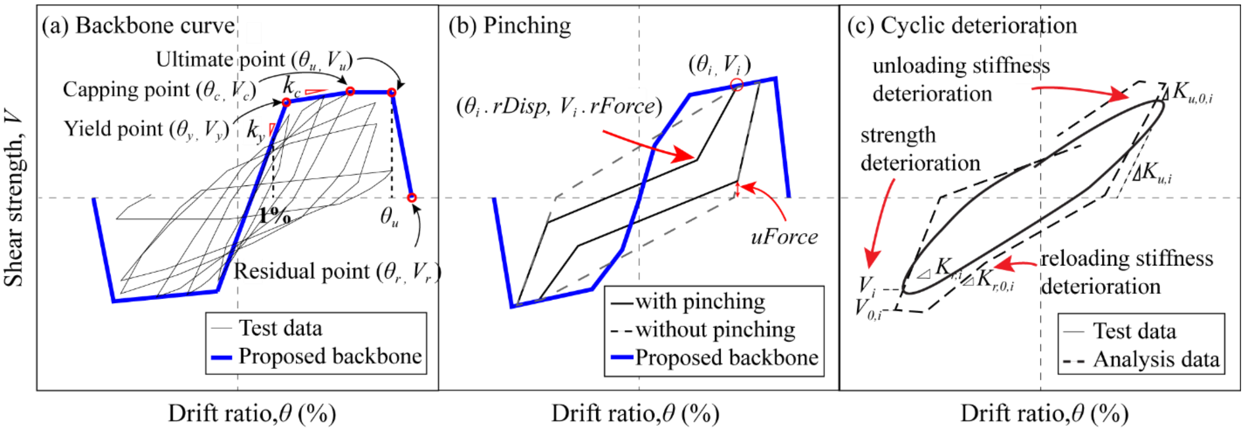

Fig. 1 Summary of Pinching4 model

3. Verification

To verify the accuracy of calibrated parameters in Pinching4 model, three DRCB specimens (CB24F, SD-2.0, SD-3.5, Naish 2013; Han 2014) are considered. Physical properties and input parameters of three specimens are summarized in Table 1 and Table 2. Fig. 2 compares cyclic curves between test and analysis results. It is observed that the calibrated parameters of backbone, pinching and cyclic deterioration can simulate test data for DRCBs with great accuracy.

Table 1. Specimen properties

Specimen	b (mm)	h (mm)	l_n (mm)	l_n / h	α (°)	f_c' (MPa)	f_{yd} (MPa)	f_{yl} (MPa)	f_{yt} (MPa)
CB24F	305	457	1524	2.4	15.7	47.2	483	483	483
SD-2.0	250	525	1050	2.0	20.4	44.0	438	483	506
SD-3.5	250	300	1050	3.5	8.9	44.0	442	506	506

b: width of beam section, h : height of beam section, l_n :length of clear span, l_n / h:aspect ratio, α:angle of diagonal reinforcement, f_c':compressive strength of concrete, f_{yd} :yield strength of diagonal reinforcement, $f_{yl}(f_{yt})$:yield strength of longitudinal(transverse) reinforcement

Table 2. Input parameters

Specimen	θ_y	V_y	θ_c	V_c	θ_u	*rDisp*	*rForce*	*uForce*	α_2
CB24F	1.12	722.48	3.00	761.13	12.22	0.99	0.99	0.05	13.28
SD-2.0	1.62	1061.68	2.61	1117.25	7.37	0.99	0.99	0.1	10.61
SD-3.5	1.81	475.06	5.16	507.34	10.53	0.99	0.99	-0.1	6.88

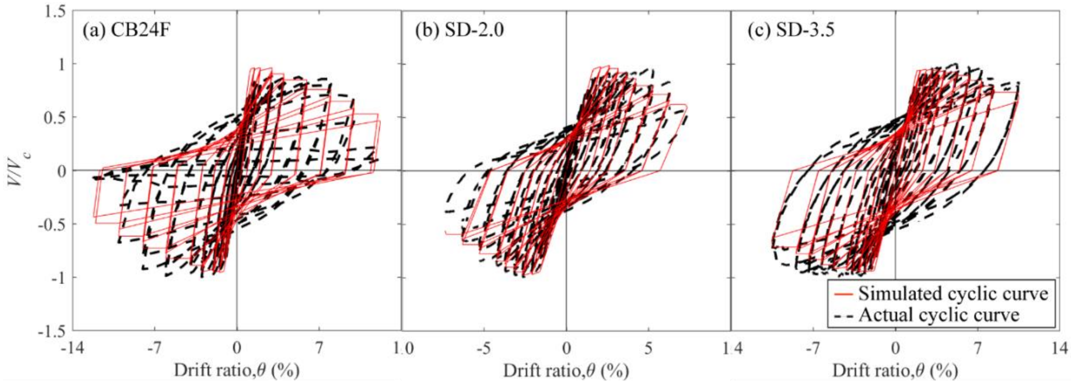

Fig. 2 Verification of calibrated parameters

4. CONCLUSIONS

In this study, the pinching4 model is used to simulate the cyclic behavior of diagonally reinforced concrete coupling beams. Modeling parameters for backbone, pinching and cyclic deterioration were calibrated to simulate cyclic curves of DRCBs. Three specimens are selected for verification of calibrated parameters. By comparing analytical and test cyclic curves, it was observed that the calibrated parameters predict cyclic behavior of DRCBs accurately. Hysteretic characteristics such as pinching and cyclic deteriorations are properly simulated. The Pinching 4 model with calibrated parameters can be used for nonlinear response history analyses of coupled shear wall systems.

ACKNOWLEDGEMENT

Authors acknowledge the financial supports provided by National research foundation of Korea (NRF-2017R1A2B3008937).

REFERENCES

Han, S.W., Lee, C.S., Shin, M., Lee, K. (2015). Cyclic performance of precast coupling beams with bundled diagonal reinforcement. Engineering Structures, *93*, 142-151.

Lignos, D.G., Putman, C., Zareian, F., and Krawinkler, H. (2011), Seismic evaluation of steel moment frames and shear walls using nonlinear static analysis procedures. Structures Congress, 2011, 2204-2215.

Lowes, L.N., Mitra, N., and Altoontash, A. (2003), A beam-column joint model for simulating the earthquake response of reinforced concrete frames, Pacific Earthquake Engineering Research Center, College of Engineering of California

Naish, D., Fry, A., Klemencic, R., and Wallace, J. (2013), Reinforced concrete coupling beams-Part I: testing. ACI Structural Journal, 110(6), 1057.

Paulay, T. (1971). Coupling beams of reinforced concrete shear walls. Journal of the Structural Division, 97(3), 843-862.