13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 3046

EFFECT OF CONFINEMENT ON THE BEHAVIOR OF DIAGONALLY REINFORCED COUPLING BEAMS

Riyadh HINDI[1] and Midhat HASSAN[2]

SUMMARY

This paper summarizes a theoretical model to predict the monotonic load-deformation behavior of diagonally reinforced coupling beams. The model assumes all load is resisted by diagonal tension and compression. The diagonal compression is carried by the diagonal reinforcement and the concrete core surrounded by the diagonal bars in that direction, while the diagonal tension is carried only by the diagonal reinforcement. Either rupture of the diagonal reinforcement or crushing of the concrete core defines the end point of the behavior (failure) of the coupling beam. The strain hardening of the reinforcing steel is considered in this study, which is an important source of strength at high deformation. The model is applied and compared to 13 specimens that were experimentally tested by other investigators. The specimens vary in terms of dimensions, reinforcement and material properties. The model gave good results compared to the test results.

INTRODUCTION

Many reinforced concrete high-rise buildings have coupled shear walls to resist lateral loads due to earthquakes. The system is designed with the shear walls coupled by beams (the coupling beams) that are the weak ductile links to dissipate energy from earthquakes. Coupling beams are an essential structural elements in seismic design due to their great ability to considerably reduce the bending moment at bottom of the coupled shear walls (stiffness of these walls are usually much larger than those of the coupling beams so under lateral loading the walls imposed equal rotations at the built-in ends of the beam), as well as their energy dissipation capacity. Those beams are usually designed to sustain large displacement and they must be proportioned with sufficient strength and deformation capacity to ensure proper force transfer between the connected structural walls. Coupling beams are subjected to constant shear and asymmetric curvature as shown in Figure 1. Diagonally reinforced coupling beams are usually recommended since they show better hysteretic response than the conventionally reinforced coupling beams. The monotonic load-deformation behavior of diagonally reinforced coupling beams is needed to predict the response of a coupled shear wall system under seismic loading.

[1] Assistant Professor, Bradley University, Peoria, Illinois, USA. Email: hindi@bradley.edu
[2] Graduate Student, Bradley University, Peoria, Illinois, USA. Email: mhassan@bradley.edu

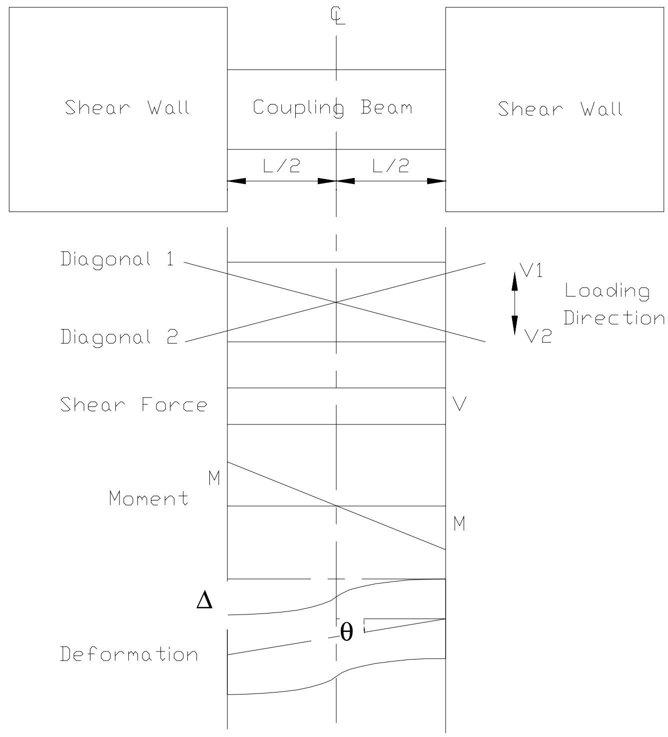


Figure 1. Forces and Deformations

The results obtained from the test conducted by Paulay [1] on conventionally reinforced coupling beams acquired more research to improve the behavior of the coupling beams. Those conventionally reinforced coupling beams presented dominant shear behavior, given their low span-to-depth ratios of 1.02 and 1.29. It was concluded that conventionally reinforced squat coupling beams did not have the desired structural properties for seismic loading. Failure mechanisms such as diagonal tension or sliding shear were encountered during the tests. These types of failures are not adequate for seismic performance, given that they are brittle failures and there is considerable loss of strength and stiffness even after a few cycles into the inelastic range.

To improve the ductility of concrete coupling beams and particularly to suppress the shear mode of failure many studies have been carried out through last decades (Paulay [2], Tassios [3], Galano [4], and Adebar [5]). Most of these studies have focused experimentally on determining the behavior of concrete coupling beams with different reinforcement amount and arrangement, dimensions and material properties in terms of strength and ductility. These experimental studies revealed that coupling beams, when they are diagonally reinforced with enough confinement to provide adequate stability, provide excellent ductility and energy dissipation.

Paulay [2] theoretically predicted the ultimate shear capacity of diagonally reinforced coupling beams using a simple model that assumes all load is resisted by diagonal compression and tension carried by the diagonal reinforcement after yielding. This assumption can be conservative if the concrete core surrounded by the diagonal reinforcement in each direction can contribute in resisting diagonal compression (Figure 2). This is more true when the diagonal bars in each direction are well confined by ties as current seismic design standards recommend.

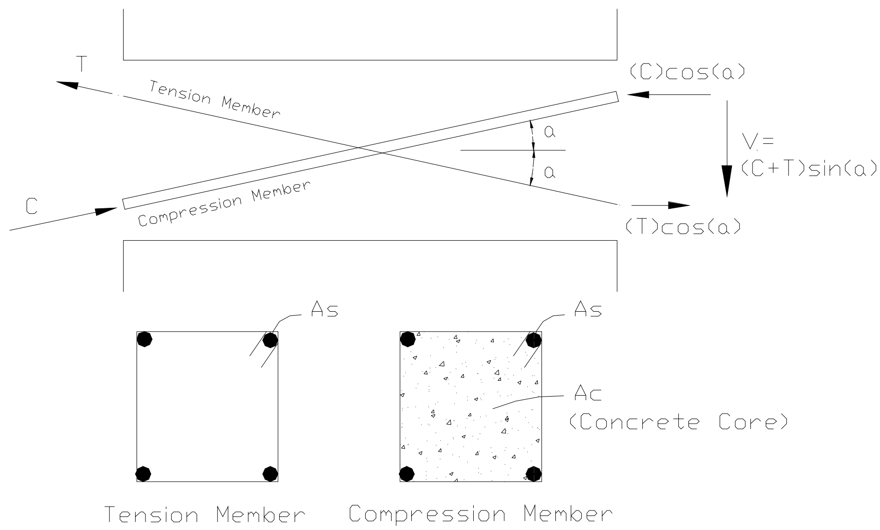


Figure 2. Truss Model.

The objective of this study is to develop a theoretical model to predict not only the ultimate shear strength of diagonally reinforced coupling beams but also the nonlinear monotonic load-deformation behavior up to failure. Such a behavior is needed to predict the behavior of the coupled shear walls system.

NONLINEAR LOAD-DEFORMATION MODEL

A simple truss model to predict the monotonic force-displacement response of diagonally reinforced coupling beams is introduced in this section. The model assumes that all load (shear force and bending moment) is resisted by a combination of diagonal tension and compression as assumed by Paulay [2]. In order to consider the contribution of the concrete core surrounded by the diagonal bars in each direction, it is assumed that the diagonal compression is carried by both the diagonal reinforcement and concrete core within the diagonal reinforcement (compression member) as shown in Figure 2. However, the diagonal tension is assumed to be carried only by the diagonal reinforcement (tension member) as illustrated in Figure 2.

As the concrete walls on both sides of the coupling beam remain parallel (under lateral loading the walls imposed equal rotations at the built-in ends of the beam) and the coupling beam is restrained axially by the slab on top of it,; therefore, the strains along the two diagonals in the coupling beam are assumed to be equal in magnitude (ε) and opposite in direction at a certain deformation. The diagonal tensile force (T) and the diagonal compressive force (C), as shown in Figure 2, at any diagonal strain (ε) can now be expressed as,

$$\begin{aligned} T &= A_s f_s^+ = A_s f(\varepsilon_s^+), \\ C &= A_s f_s^- + A_c f_c^- = A_s f(\varepsilon_s^-) + A_c f(\varepsilon_c^-) \end{aligned} \tag{1}$$

Where A_c is the area of the concrete core within the diagonal compression reinforcement, f_c and f_s are the concrete and steel stresses, respectively; and ε_c and ε_s (where $\varepsilon_c = \varepsilon_s = \varepsilon$ as assumed) are the concrete and steel strains along the diagonal directions, respectively. The positive and negative superscripts refer to tension and compression, respectively.

As shown in Figure 2, the total shear force resisted by the coupling beam at a diagonal strain (ε) is given by,

$$V = (T + C)\sin\alpha \tag{2}$$

where α is the angle of the diagonal reinforcement as shown in Figure 2.

Since the diagonal compression (C) can be larger than the diagonal tension (T), the difference between the horizontal components of the diagonal compression and tension [$(C - T)\cos\alpha$] is assumed to be carried by the provided longitudinal reinforcement in the coupling beam and the slab on top of it.

The displacement of the coupling beam (D), as shown in Figure 1, at any diagonal strain (ε) can now be determined using simple transformation and assuming that the coupling beam is axially restrained,

$$\Delta = \varepsilon \frac{L}{\cos\alpha \sin\alpha} \tag{3}$$

where L is the length of the coupling beam.

Therefore, by assuming a diagonal strain value (ε), the displacement (Δ) and the shear force (V) can be calculated from equations 1, 2 and 3. This requires that the stress-strain relationships for concrete and steel be available to calculate the stresses in the diagonal steel bars (f_s) and concrete core (f_c) from their strains ε_s and ε_c, respectively. This is repeated for different values of strains (from zero to failure) to come up with the monotonic force-displacement response of a diagonally reinforced coupling beam. The end point (failure) of the response is defined by either crushing of the concrete core or rupture of the diagonal reinforcement. Crushing of the concrete will eventually lead to buckling of the diagonal compression bars.

In this paper, the two diagonal directions (diagonal members) are numbered as 1 and 2. If the two diagonal members have different compressive stiffness because of the different concrete core area and/or diagonal reinforcement, then member 1 always refers to the stronger diagonal member in compression. These numbers also refer to the loading directions, where loading direction 1 always resists more shear as shown in Figure 1.

MATERIALS BEHAVIOR

After a careful review of existing concrete stress-strain models (Hassan [6]), the concrete stress-strain model suggested by Chang [7] is adopted in this study. The concrete core within the diagonal reinforcement is treated as confined or unconfined depending on the confinement reinforcement (ties) surrounding the diagonal bars. The confinement model suggested by Mander [8] is adopted herein.

The strain hardening of the reinforcing steel is considered in this study since it can be an important source of strength for such elements (Paulay [2] and Galano [4]). The stress-strain model for reinforcing steel suggested by Mander [9] is adopted in this study. The model includes linear elastic region up to yield, elastic-perfect-plastic region, and strain hardening region. The strain and stress limits of these regions are obtained from the experimental test data and material properties.

APPLICATION AND COMPARISON

The model proposed in this paper was applied to 13 diagonally reinforced coupling beams tested by several investigators (Paulay [2], Tassios [3], Galano [4] and Adebar [5]) to predict their monotonic force-displacement behaviors. A comparison between the theoretical and experimental results of the considered specimens is presented in this section. The proposed ultimate shear strength is also compared to the shear strength as suggested by Paulay [2]. Tables 1 and 2 show the experimental and theoretical ultimate shear strength of the considered specimens for loading directions 1 and 2, respectively. The predicted shear strength without considering the steel hardening is also presented in Tables 1 and 2. More details about the proposed model and its application can be found in Hassan [6].

Tests by Paulay and Binney

Paulay [2] tested four coupling beam specimens. Three of them were diagonally reinforced. The diagonal reinforcements of two specimens were surrounded with ties (confined, specimens 317 and 396), while the other specimen (316) was diagonally reinforced without ties (unconfined). The failure mechanism for the specimens was buckling of the compression diagonal reinforcement after the surrounding concrete had broken away. The specimens with closely spaced ties surrounding the diagonal reinforcement were more ductile compared to the specimen without such ties. This can be explained by noting that the ties confine the concrete inside the steel cage, providing the section with better stability or anti-buckling properties. Table 3 summarizes the material and geometrical properties for these tests.

The diagonal reinforcements of these specimens are not symmetric as shown in Table 3; therefore, unsymmetrical responses are expected for the two loading directions 1 and 2. The complete experimental results were not available electronically; therefore, only the theoretical results are shown here. Complete experimental results can be found in Paulay [2]. Figure 3 shows the predicted results for the three specimens 316, 317 and 395. Specimen 316 (diagonal bars without ties) had an experimental ultimate shear force of 600 kN in direction 1 and 535 kN in direction 2 as shown in Tables 3 and 4. The Paulay model predicted the ultimate shear capacity of this specimen to be 475.5 kN as shown in Figure 3a. The proposed model gave ultimate shear force of 550 kN in direction 1 and 475 kN in direction 2 since diagonal compression is carried only by the diagonal reinforcement in direction 2. Some of the shear force was carried by the unconfined concrete core within the diagonal bars in direction 1; however, this strength was soon lost after the concrete core crushed and the shear force was carried only by the reinforcement. The proposed model gave a small ultimate displacement (15 mm) because of the early crushing of the unconfined concrete core surrounded by the diagonal bars.

The main differences between specimens 317 and 395 (with confined diagonal bars in direction 1 only, since diagonal 2 had only one layer of three bars) are the section depth and concrete strength as shown in Table 3. Figure 3b shows the theoretical results of specimen 317. The test gave an ultimate shear force of almost 600 kN in direction 1 and 535 kN in direction 2. The Paulay model gave ultimate shear capacity of 462 kN for the two directions. Paulay model underestimated the capacity because it does not consider the steel hardening and the concrete core contribution. The proposed model gave a maximum shear force of about 610 kN for direction 1 and ultimate displacement of 42 mm, while it gave ultimate force of 462 kN for direction 2 since no concrete core existed in this direction.

Figure 3c shows the results of specimen 395. The test gave an ultimate shear force of almost 650 kN in direction 1 and 535 kN direction 2. The Paulay model predicted a maximum shear capacity of 532 kN for the two directions. The proposed model showed a maximum shear force of about 780 kN for direction 1 and ultimate displacement of 55 mm as shown in Figure 3c.

Table 1. Ultimate Shear Capacity in Direction 1 (kN)

Specimen	Experimental	Paulay	Proposed With Steel Hardening	Shear Ratio Prop/Exp.	Proposed W/O Steel Hardening	Shear Ratio Prop/Exp.
Adebar et al	900	555	865	0.96	840	0.93
Galano P05	239	156	236	0.99	236	0.99
Galano P06	241	156	249	1.03	249	1.03
Galano P07	238	156	267	1.12	267	1.12
Galano P08	238	156	265	1.11	265	1.11
Galano P10	241	156	250	1.04	250	1.04
Galano P11	239	156	236	0.99	236	0.99
Galano P12	240	156	239	1.00	239	1.00
Tassios 2A	283	202	295	1.04	240	0.85
Tassios 2B	170	123	182	1.07	145	0.85
Paualy 316	600	475	550	0.92	550	0.92
Paualy 317	600	462	610	1.02	580	0.97
Paulay 395	650	532	780	1.20	630	0.97
			Average	1.04		0.98
			ST Deviation	0.08		0.08

Table 2. Ultimate Shear Capacity in Direction 2 (kN)

Specimen	Experimental	Paulay	Proposed With Steel Hardening	Shear Ratio Prop/Exp.	Proposed W/O Steel Hardening	Shear Ratio Prop/Exp.
Adebar et al	900	555	865	0.96	840	0.93
Galano P05		156	236		236	
Galano P06		156	249		249	
Galano P07	230	156	267	1.16	267	1.16
Galano P08	220	156	265	1.21	265	1.21
Galano P10		156	250		250	
Galano P11	230	156	236	1.02	236	1.02
Galano P12	237	156	239	1.01	239	1.01
Tassios 2A	235	202	295	1.26	240	1.02
Tassios 2B	143	123	182	1.27	145	1.01
Paualy 316	535	475	475	0.89	475	0.89
Paualy 317	535	462	462	0.86	462	0.86
Paulay 395	535	532	532	0.99	532	0.99
			Average	1.06		1.01
			ST Deviation	0.15		0.11

Table 3. Specimens Properties (Paulay and Binney, Tassios et al, and Adebar et al)

	Paulay and Binney			Tassios et al		Adebar et al
Specimen	**316**	**317**	**395**	**CB-2A**	**CB-2B**	**-**
$f`_c$ (MPa)	33.3	50.7	35.5	28.5	26.3	35.6
fy (diagonal reinf) (MPa)	288	270-306	260-289	504	504	464
fu (diagonal reinf) (MPa)	-	-	-	764	764	663
fy (ties) (MPa)	288	288	288	281	281	400
fy (long reinf) (MPa)	288	288	288	281	281	400
L (beam length) (mm)	1016	1016	1016	500	500	1220
b (beam width) (mm)	152	152	152	130	130	305
h (beam height) (mm)	787	787	991	500	300	445
Diagonal Bars (direction 1)	4 ϕ 22	4 ϕ 22	4 ϕ 22	4 ϕ 10	4 ϕ 10	4 – 30M
Diagonal Bars (direction 2)	3 ϕ 25	3 ϕ 25	3 ϕ 25	4 ϕ 10	4 ϕ 10	4 – 30M
Dimensions of Diagonal Member 1 (mm)	76 x 76	76 x 76	76 x 76	44 x 44	44 x 44	216 x 140
Dimensions of Diagonal Member 2 (mm)	-	-	-	44 x 44	44 x 44	115 x 140
Ties (diagonal members)	-	ϕ 6 @ 100	ϕ 6 @ 100	ϕ 6 @ 50	ϕ 6 @ 50	10M @ 100
Longitudinal Bars	4 ϕ 16	4 ϕ 16	4 ϕ 16	8 ϕ 6	8 ϕ 6	4 – 10M
α (degree)	33	33	41	39	23	12.34
Shear Span-Depth Ratio	0.645	0.645	0.513	0.5	0.834	1.37

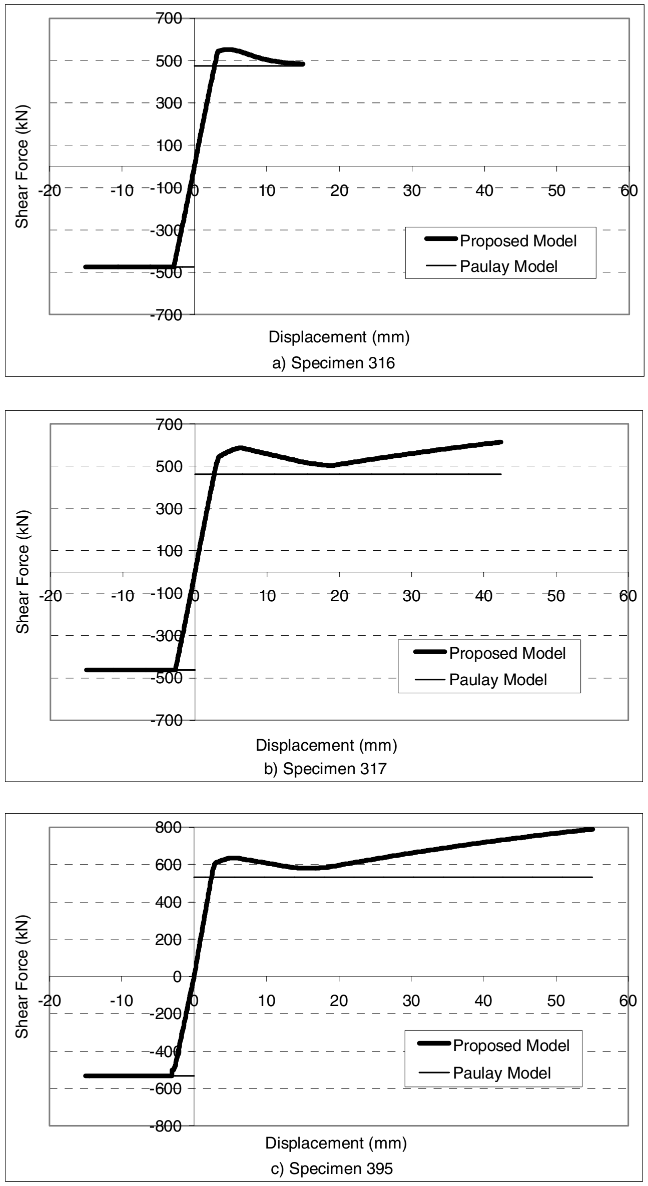


Figure 3. Results of Specimens 316, 317, and 395 (Paulay and Binney)

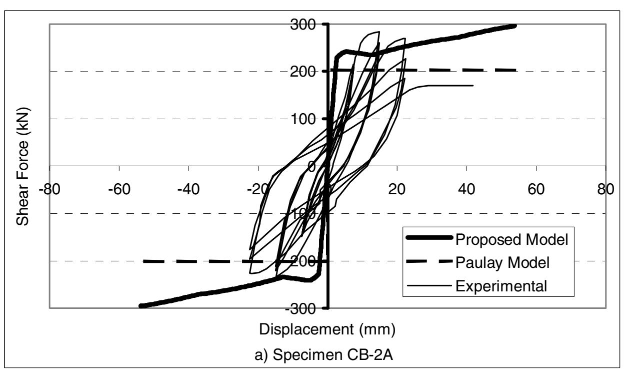
As shown in Figure 3, the confinement helped specimens 317 and 395 increase their ductility and strength. After yielding they both lost some shear strength due to the descending region of the concrete behavior, but they gained some strength soon after due to the hardening of steel.

Tests by Tassios, Moretti and Bezas

Tassios [3] studied the effect of various layouts of reinforcement on the hysteretic response of short and medium coupling beams. They observed that the pinching effect diminished when diagonal reinforcement was used. The crack pattern as well as the mode of failure of the specimens differed according to the arrangement of reinforcement and the value of the shear ratio. It was confirmed that beams with diagonal reinforcement perform better than other reinforcement arrangements. Only two diagonally reinforced specimens were tested (CB-2A and CB-2B). Table 3 shows the material and geometrical properties of the two specimens considered in this study.

Figure 4 shows the results of the two specimens (CB-2A and CB-2B) tested by Tassios [3]. These specimens had symmetric diagonal reinforcement in direction 1 and 2 as shown in Table 3. The only difference between the two specimens was the section depth, which led to different diagonal angles (a). Figure 4a shows the results of specimen CB-2A. The experimental ultimate shear was about 283 kN in direction 1. The loading stopped at about 40 mm of displacement after losing significant shear strength due to cycling. Paulay model gave an ultimate shear capacity of 202 kN. The proposed model predicted ultimate shear strength of 295 kN for both direction because of symmetry. The proposed ultimate displacement was about 53 mm. Figure 4b shows the results of specimen CB-2B. The experimental ultimate shear was about 170 kN for both directions. The loading stopped at about 43 mm of displacement after losing significant shear strength due to cycling. Paulay model gave an ultimate shear capacity of 123 kN. The proposed model predicted ultimate shear strength of 182 kN and ultimate displacement of about 75 mm.

Theoretically, the two specimens (CB-2A and CB-2B) showed only a small reduction in shear strength after yielding. This is because of the good confinement of the diagonal reinforcement, which helped maintain the diagonal compression strength. The proposed ultimate displacements for the two specimens seem to be overestimated. It was assumed that the beams were axially restrained when calculating the displacement; however, the specimens were not restrained axially during the tests. The assumed axial restrain allowed for more displacement to accommodate deformation in the diagonal members.



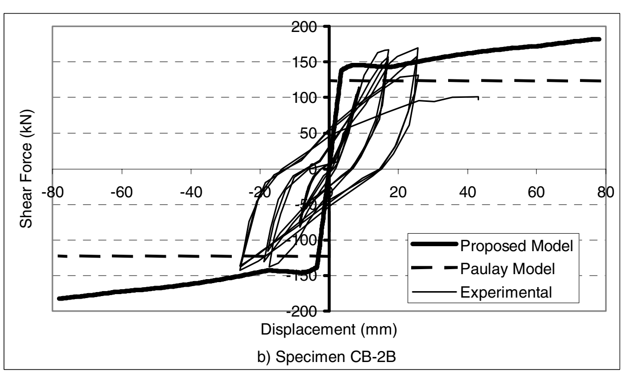


Figure 4. Results of Specimens CB-2A and CB-2B (Tassios, Moretti and Bezas)

Tests by Galano and Vignoli

Galano [4] conducted an experimental program in which 15 short coupling beams with four different reinforcement layouts were tested under monotonic and cyclic shear loading. These specimens were axially restrained using rollers at the end of the shear walls. Seven specimens were diagonally reinforced: four of them have no ties surrounding the diagonal bars (P05, P06, P07, and P08), while the other three (P10, P11, and P12) are confined by ties. All specimens were characterized by a shear span-depth ratio of 0.75. Monotonic and cyclic tests were conducted depending on the loading procedures. Table 4 shows the material and geometrical properties of the seven specimens considered in this study.

Figures 5 and 6 show the results of the specimens tested by Galano [4]. Experimental results of specimen P06 were not available to the authors. Specimen P05, P06, P07 and P08 had no ties around the diagonal bars (unconfined diagonal bars). Their experimental shear strength was about 240 kN as shown in Figure 5 and Table 1. The proposed model predicted average ultimate shear strength of about 250 kN. There is a small difference in the shear capacities of the specimens (Tables 1 and 2) due to the difference in the concrete strength as shown in Table 4. As shown in Figure 5, the theoretical shear strength was quickly reduced after yielding to 156 kN, which is the same strength given by the Paulay model, due to loosing the concrete core strength. The ultimate displacements of these specimens seem to be significantly less than the experimental results. This is believed due to ignoring the confinement that is provided to the concrete core within the diagonal members by the longitudinal and transverse reinforcement in the coupling beam.

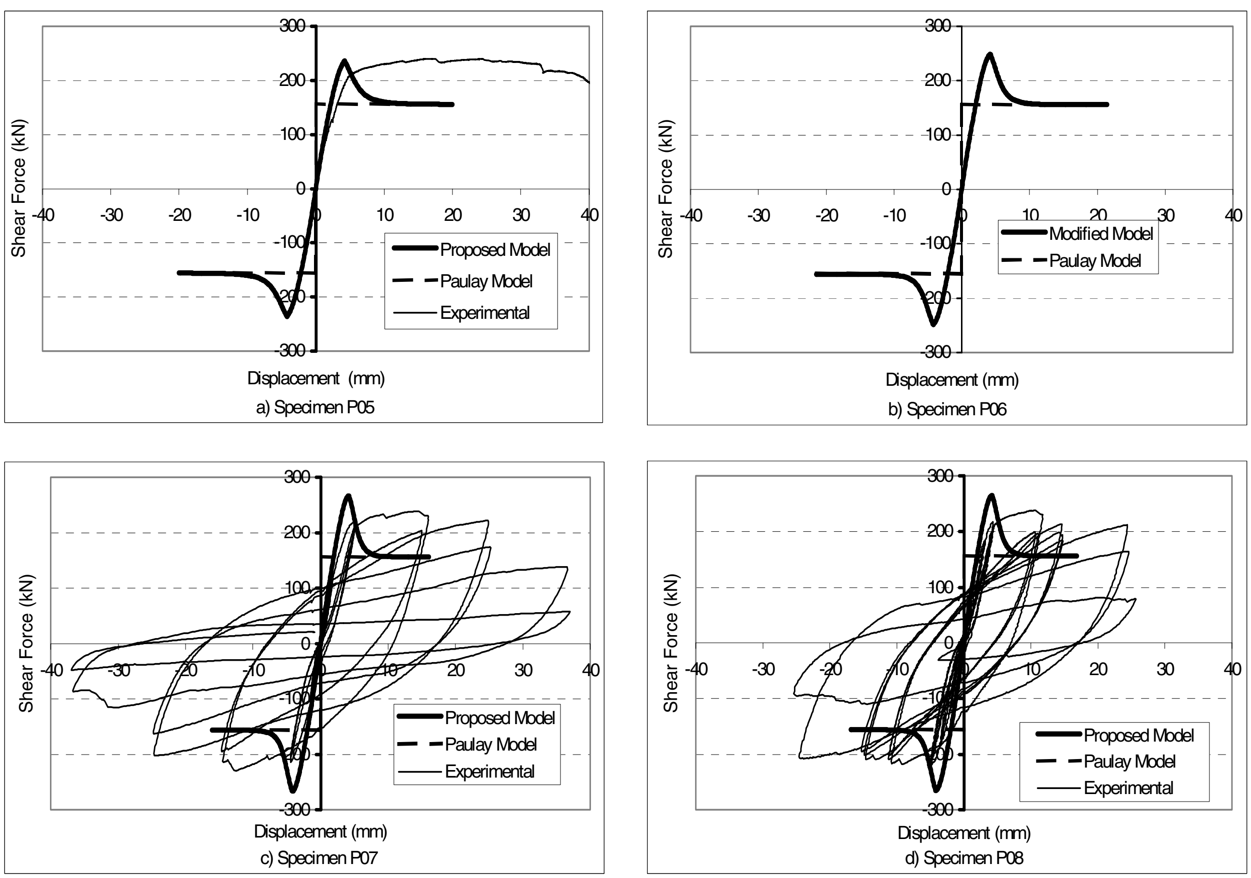


Figure 5. Results of Specimens P05, P06, P07 and P08 (Galano and Vignoli)

Table 4. Specimens Properties (Galano and Vignoli)

Specimen	P05	P06	P07	P08	P10	P11	P12
f'_c (MPa)	39.9	46.0	54.0	53.4	46.8	39.9	41.6
fy (diagonal reinf) (MPa)	567	567	567	567	567	567	567
fu (diagonal reinf) (MPa)	660	660	660	660	660	660	660
fy (ties) (MPa)	-	-	-	-	567	567	567
fy (long reinf) (MPa)	567	567	567	567	567	567	567
L (beam length) (mm)	600	600	600	600	600	600	600
b (beam width) (mm)	150	150	150	150	150	150	150
h (beam height) (mm)	400	400	400	400	400	400	400
Diagonal Bars (direction 1)	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10
Diagonal Bars (direction 2)	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10	4 ϕ 10
Dimensions of Diagonal Member 1 (mm)	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74
Dimensions of Diagonal Member 2 (mm)	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74	74 x 74
Ties (diagonal members)	-	-	-	-	ϕ 6 @ 100	ϕ 6 @ 100	ϕ 6 @ 100
Longitudinal Bars	6 ϕ 6	6 ϕ 6	6 ϕ 6	6 ϕ 6	6 ϕ 6	6 ϕ 6	6 ϕ 6
α (degree)	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Shear Span-Depth Ratio	0.75	0.75	0.75	0.75	0.75	0.75	0.75

Figure 6 shows the results of specimens P10, P11, and P12. These specimens had ties around their diagonal members; therefore, they theoretically showed higher ultimate displacements compared to specimens P05, P06, P07 and P08. Their experimental shear strength was about 240 kN. The proposed model predicted average ultimate shear strength of 250 kN. As shown in Figure 6, the shear strength was slowly reduced after yielding to about 175 kN. The strength was then increased to about 200 kN due to the hardening of the steel. Paulay predicted maximum shear strength of 156 kN. The experimental ultimate displacement of specimen P10 reasonably compared to the proposed model as shown in Figure 6a.

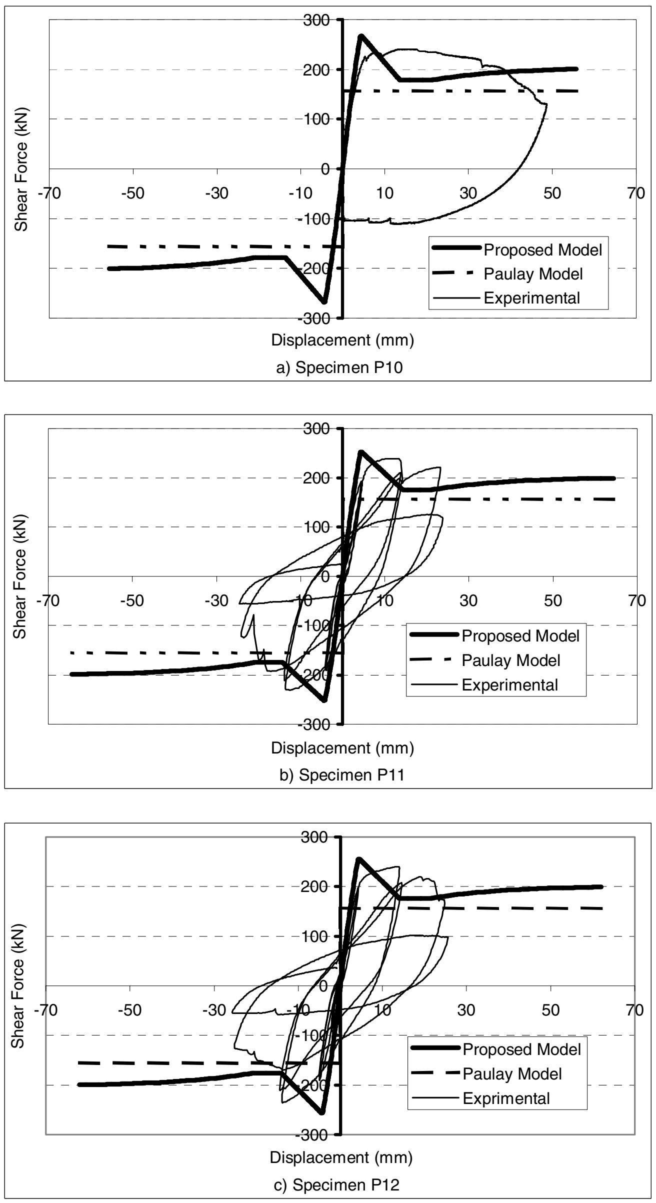


Figure 6. Results of Specimens P10, P11, and P12 (Galano and Vignoli)

Test by Adebar, Hindi and Gonzales

Adebar [5] tested only one full scale diagonally reinforced coupling beam. The specimen was axially restrained using high strength Dywidag bars to simulate the concrete slab on top of the beam in a high-rise building. The shear span-depth ratio was 1.37. The diagonal bars were well confined according to the Canadian Concrete Code CSA-A23.3 [10]. It was concluded that even though the span-depth ratio was high (shallow coupling beam) the specimen showed good ductility and hysteretic behavior. The failure mode was crushing of the concrete core and buckling of the diagonal reinforcement. Table 3 shows the material and geometrical properties of the considered specimen

Figure 7 shows the results of the specimen tested by Adebar [5]. The only difference between the two diagonal directions is the area of the concrete core surrounded by the diagonal reinforcement as shown in Table 3. This specimen showed very good agreement between the proposed model and the experimental results throughout the loading history because of the good confinement and effective axial restrain that the Dywidag bars provided. The test showed ultimate shear strength of about 900 kN in direction 1 and 980 kN in direction 2. Then, the strength in direction 2 significantly reduced to 830 kN after few cycles as shown in Figure 7. Paulay model predicted maximum shear capacity of 555 kN. The proposed model gave ultimate shear strength of 865 kN and ultimate displacement of 160 mm in direction 1. The test showed ultimate displacement of about 156 mm as shown in Figure 7.

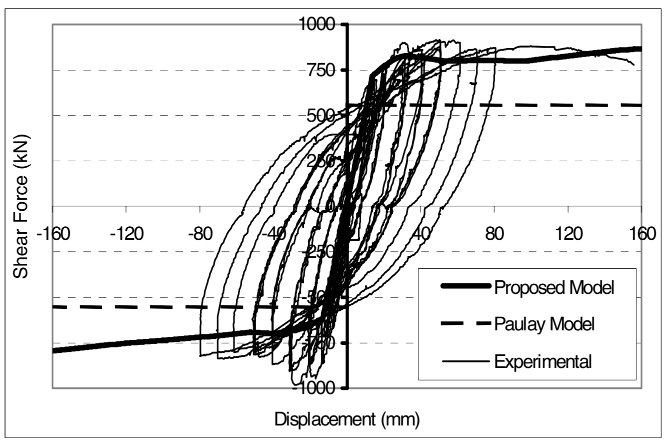


Figure 7. Results of Specimen tested by Adebar, Hindi and Gonzales

The theoretical failure mode of all the 13 specimens considered in this study was crushing of the concrete, which leads to buckling of the diagonal bars due to loosing stability. This agreed with the experimental observations.

CONCLUSIONS

The following was concluded from the application of the proposed model to the 13 specimens of diagonally reinforced coupling beams;

1. The proposed model gave good results in terms of shear capacity. The mean value of the proposed to the experimental shear strength for loading direction 1 is found to be 1.04, with a standard deviation of 0.08, while the mean for loading direction 2 is 1.06, with a standard deviation of 0.15. The mean value of the proposed to the experimental shear strength for both loading directions 1 and 2 is found to be 1.05, with a standard deviation of 0.11.

2. The proposed model gave reasonable results in terms of deformation when the specimens were axially restrained, as it is the case in real coupling beams in high-rise buildings.

3. In general, the proposed model underestimated the deformation of the considered specimens. This may be improved if the confinement that is provided to the concrete core (within of the diagonal bars) by the longitudinal and transverse reinforcement in the coupling beam is considered.

4. The theoretical failure mode of all considered specimens was crushing of the concrete, which leads to buckling of the diagonal bars due to loosing stability. This agreed with the experimental observations.

ACKNOWLEDGEMENT

This research was supported by the Graduate Research Assistant Sponsored Project at Bradley University. This support is gratefully acknowledged. The authors would like to thank Drs. Galano, Vignoli, Tassios and Moretti for their help in providing the experimental data. A special thank goes to Dr. Paulay for his time and effort to answering some requests.

REFERENCES

1. Paulay, T., (1971), "Coupling beams of reinforced concrete shear walls", Journal of Structural Engineering, ASCE, V. 97, No. 3, March, 843-862.
2. Paulay, T., and Binney, J.R. (1974), "Diagonally reinforced coupling beams of shear walls", Shear in Reinforced Concrete, SP-42, American Concrete Institute, Farmington Hills, MI, 579-598.
3. Tassios, T.P., Moretti, M., and Bezas, A., (1996), "On the behavior and ductility of reinforced concrete coupling beams of shear walls", ACI Structural Journal, V. 93, No. 6, November-December, 711-720.
4. Galano, L., and Vignoli, A. (2000), "Seismic behavior of short coupling beams with different reinforcement layouts", ACI Structural Journal, V. 97, No. 6, November-December, 876-885.
5. Adebar, P., Hindi, R. A., and Gonzalez, E, (2001), "Seismic behavior of a full-scale diagonally reinforced slender coupling beam", Technical Report, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.
6. Hassan, M. A., (2003), "Nonlinear behavior of diagonally reinforced coupling beams", Master Thesis, In Preparation, Department of Civil Engineering and Construction, Bradley University, Peoria, IL, USA.
7. Chang, G.A. and Mander, J.B., (1994), "Seismic energy based fatigue damage Analysis of bridge columns", NCEER Report No. 94-0006, State University of New York at Buffalo, NY.
8. Mander, J. B, Priestley, M.J.N., and Park R., (1988), "Theoretical stress-strain model for confined concrete", Journal of Structural Engineering, ASCE, V. 114, No. 8, August, 1804-1826.
9. Mander, J. B, Priestley, M.J.N., and Park R., (1984), "Seismic design of bridge piers", Report No. 84-2, Department of Civil Engineering, University of Canterbury, February, 483.
10. CSA-A23.3, (1994), "Canadian Concrete Code", Canadian Standards Association, Rexdale, Ontario, Canada.