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BEHAVIOR OF COUPLING BEAM WITH DIFFERENT REINFORCEMENT DETAILS IN BUILDING

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Abstract: This paper describes a non-linear finite element analysis for the coupling beams with different reinforcement details. Three types of reinforcement details are investigated in this study, conventionally reinforced coupling beam (CRCB), Diagonally reinforced coupling beam (DRCB) and Double beam coupling beam (DBCB). Numerical models are generated by using Non-linear Finite element analysis software ABAQUS using a three- dimensional framework to verify the results with available experimental specimens. Parametric Study was conducted on the three different types of reinforcement to investigate the effect of changing the concrete compressive strength between the shear walls and the coupling beam during casting in site, studying the lateral load-displacement curve for the new type of reinforcement (DBCB) comparing between the others and studying the effect of increasing the aspect-ratio for the three types of reinforcement that will be increased about the international limits.

***Index Terms* - Coupling beams, Non-linear Finite Element Analysis.**

1 INTRODUCTION

Nowadays countries are racing to build high rise buildings that indicates the extend of structural and architectural progress. In tall buildings, as the height and number of stories increase, the ability of building to resist the horizontal forces caused by winds and earthquakes will decrease. Reinforced concrete shear walls connected by deep or short beams called link or coupling beams are widely used in medium and high-rise buildings. Reinforced concrete coupled shear walls can provide large stiffness, strength, and energy dissipation under seismic and wind loads; however, the presence of large shear forces combined with reversed-cyclic nonlinear rotation make the design of the coupling beam in challenging. Coupling beam can be constructed by using conventionally reinforcement that contain longitudinal and transverse reinforcement or with diagonally reinforcement especially used with small span to depth ratio. Coupling beams are considered the main factor that dissipate energy in the coupling wall systems because it develops plastic hinges along the height of the coupled wall system, resulting good energy dissipation. Coupled structural wall systems are more efficient than the isolated because it produces larger lateral strength and stiffness than the isolated wall. When the coupled wall system subjected to lateral loads, shear forces will be resisted by the wall units and axial forces will be developed in the base of the wall units resulting from the accumulation of the shear forces in the coupling beams. Overturning moment will be resisted by flexure in the base of the wall and the couple moment from the axial forces, M_1 and M_2 as shown in Fig. 1.1. There are different between the behavior of the conventionally and the diagonally reinforced concrete coupling beam. Experimental investigations showed that the conventionally coupling beams are vulnerable under large lateral load reversal so extensive researches were conducted to improve their performance. This paper is conducted to investigate the effect of different reinforcement details in the lateral load-displacement behavior and the sliding shear behavior.

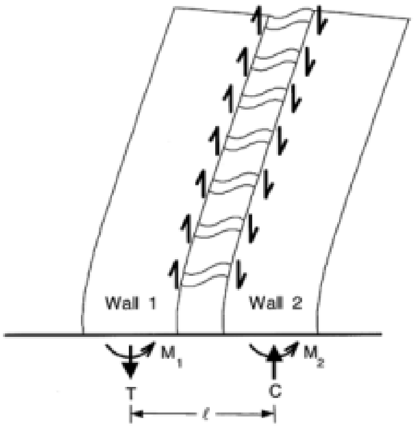


Figure 1.1- Flexural resistance of the coupled shear walls (Canbolat 2004)

2METHODOLOGY

2.1 General

Previously the coupling beams were design by the conventional reinforcement that consist of longitudinal and transverse reinforcement. In this approach, it was assumed that the shear strength was provided by both the concrete mechanism and the truss action with the concrete through the vertical stirrups. When the coupled-wall system subject to lateral loads, the differential movement will occur between the two ends of the coupling beam results from the lateral displacement of the coupled-wall then the coupling beam will undergo shear and flexural deformations. Flexural deformation will make the coupling beam to bend in double-curvature pattern with compression along one half of the coupling beam changing in tension along the other half while the shear deformation causes tension on both bottom and top surfaces along the length of the coupling beam. Paulay and Biney (1974) proposed a new detail for the coupling beam that consist of group of diagonal reinforcement confined with closely transverse reinforcement. The diagonal reinforcement acts similar to steel structure cross-bracing, that provide more stable post-yielding better than the conventionally reinforcement. Tegos and Penelis (1988) proposed a new technique in the reinforcement of the coupling beam as they made an inclination in the main reinforcement to form a rhombic truss to prevent the short coupling beam from the sliding shear failure, the results showed that the coupling beams with the rhombic reinforcement performed similar to the coupling beams with the diagonal reinforcement. Poorya Hajyalikhani and Shih-Ho Chao (2014) conducted a study to simplify the reinforcement of the coupling beam to reduce the congestion of the diagonal reinforcement. A new approach of reinforcement was used in this study as they used Double-Beam coupling beam that was consist of two cages similar to typical beams used for moment special frames. When the large displacement occurs, cracks will appear at the mid span of the DBCB and at the mid height, then it will propagate gradually towards the beam’s ends so the damage zone can easily be predicted that makes the maintenance work easier after the earthquakes. DBCB can also eliminate the sliding shear failure at the wall-beam interface. I. Aziz1 and K. M. Amanat2 (2019) conducted a study by using Hybrid steel coupling beam to investigate its behavior under cyclic loading and to enhance the capability of the post-damage repair. Three-dimensional non-linear finite element model was conducted by using ANSYS to simulate their experimental specimen that consist of shear link acts as a “fuse” that connected two steel beam segments by each other at their ends to improve the seismic resistance of the coupled system. The results showed that the strain of the energy density was concentrated in the fuse. Therefore, the shear link is considered the main key to dissipate the energy of the lateral loads. When any damage occurs in the shear link because of the earthquake, it can be replaced easily that will save the time of recovery and restore the normal capacity for the construction to have the ability to face any latera loads one more time. Hasan Sesli and Metin Husem (2020) tested Conventionally and diagonally reinforcement concrete coupling beams with a new complex setup according to the ACI318-14 to determine its behavior under cyclic loading. The experimental setup simulated real-like beam-wall interaction for crack propagation on the shear walls and beams which showed that the height and length of the wall piers must be three and two times of the coupling beam depth. Diagonally reinforced concrete coupling beam specimen showed higher life safety and higher ductility than the conventionally reinforced concrete coupling beam specimen. The confinement around the diagonal bars retarded the buckling of bars. Especially, ruptured (diagonal tension) or buckling of diagonal bars (diagonal compression).

3 MODELING

3.1 VERIFICATION

Series of experiments were conducted on coupling beams by Hasan Sesli and Metin Husem (2020) to determine its behavior with different reinforcement details under lateral cyclic loading. The tests were conducted on conventionally reinforced concrete coupling beam and diagonally reinforced concrete coupling beam. These beams were with aspect ratio of two. Two specimens were chosen to be verified and modeled for this study. This chapter details the reinforcement and geometrical dimensions for the coupling beams used in this study. Procedures of the finite element analysis and comparison between the finite element and experimental results.

3.2 DESCRIPTION OF THE BEAM'S SPECIMENS

The two specimens were conventionally and diagonally reinforced coupling beam with aspect ratio of 2. CRCCB and DRCCB were 900mm long with 450mm depth. The adjacent wall piers were 1350mm height,750mm width and 200mm thickness. CRCCB was reinforced with four D14 at bottom and top, D12@80 as skin reinforcement and 11-D8@80 were provided as stirrups. DRCCB was reinforced with D12@80 were provided as top, bottom and skin reinforcement with 4D14 were provided as diagonal reinforcement and 11-D8@80 were provided as stirrups. The inclination angle for the diagonally reinforcement was 18.66°. Wall piers were reinforced with 18-D14 as vertical reinforcement and D8@70 as horizontal reinforcement. The summary of material properties and specimen's properties is given in Table 3.1. Reinforcement details and dimensions of CRCCB and DRCCB specimens are illustrated in Fig.3.1.

Table 3.1. Beam specimens and concrete material properties

Specimen	Width b (mm)	Depth h (mm)	Span (mm)	Aspect ratio	Bar inclination angle (°)	Diagonal RFT.		Horizontal RFT.		Transverse RFT.		f_{cu} (MPa)
						Diameter (mm)	No	Diameter (mm)	No	Diameter (mm)	Spacing (mm)	
CRCCB	200	450	900	2	0.00	—	—	12-14	12-8	8	80	39.91
DRCCB	200	450	900	2	18.66	14	8	12	12	8	80	34.94

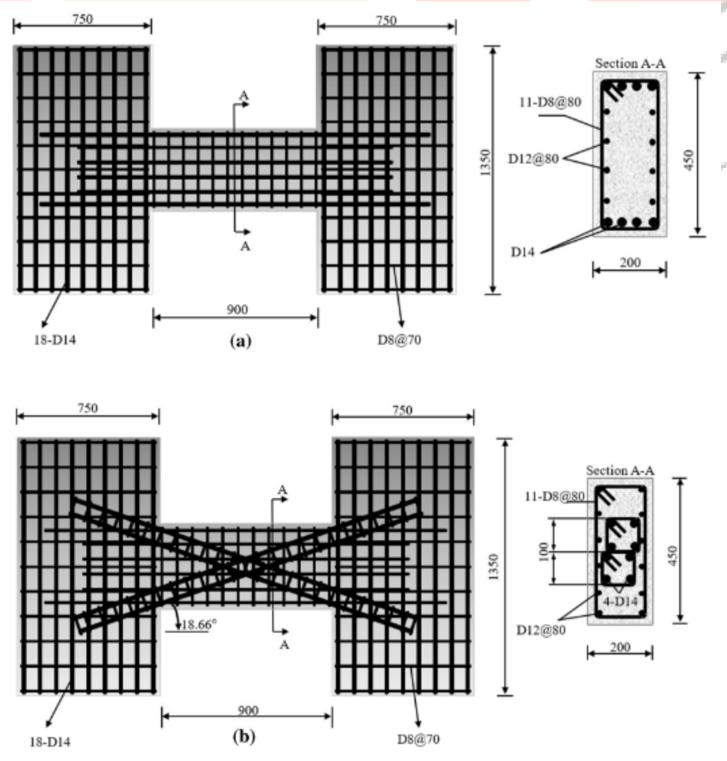
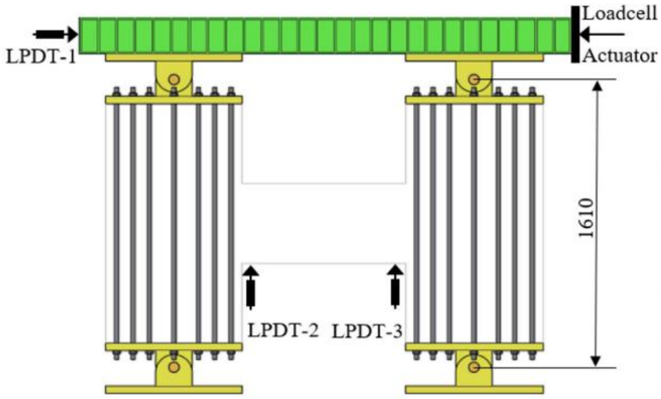


Fig. 3.1. Dimensions and details of the Coupling Beam Specimens (a) CRCCB, (b) DRCCB (Adapted from Hasan Sesli and Metin Husem 2020)

New setup approach was conducted in this study that provide equal double curvature bending, rotation and local deformation at wall-beam joint. The top and the bottom surface of the wall pier were connected to pin assemblies, bottom pen assembly was fixed to the floor. However, the top pen assembly was fixed to stiff beam that was providing axial restraint to simulate the effect of the slabs and in-plane stiffness of the shear walls in the reality condition of the building. 100 KN actuator was used on the stiff beam to transfer the lateral load to the wall piers connected to pen assemblies. Half of this lateral load will transfer to the wall piers as a shear force. The longitudinal and transverse reinforcement of the shear walls were used to satisfy the code recommendation and to reflect the local deformation that will happen at the beam-wall joint. The main different between this approach from other setups is that the stress intensity on the connection zone between pins and shear walls were reduced. Overview of the experimental setup is shown in Fig.3.2.

(a)



(b)

Fig. 3.2. Test setup: (a) fabrication in laboratory (b) installation of instruments
(Adapted from Hasan Sesli and Metin Husem 2020)

Displacement control cyclic loading was applied on the stiff beam and results were measured using linear variable displacement transducers (LVDTs). The loading history that was applied in the experiment as shown in Fig.3.3.

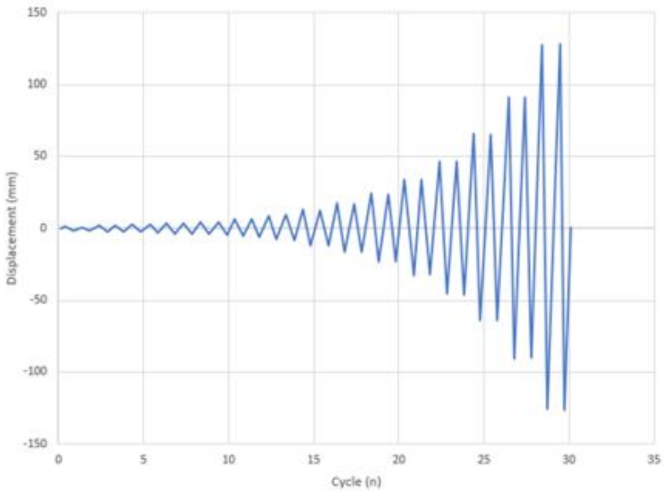


Fig. 3.3. Displacement-controlled cyclic loading history (Adapted from Hasan Sesli and Metin Husem 2020)

3.3 Modeling and Analysis

CRCCB and DRCCB finite element model is generated by using ABAQUS (2020) using a three- dimensional framework. The concrete is modeled as a solid element and the steel is modeled as a wire. The reinforcement is meshed by using truss elements as the bending stiffness is neglectable. To make interaction between the steel and concrete, the reinforcement is embedded into the concrete and was assumed to be perfectly bonded. Stiff loading beam was conducted in ABAQUS to simulate the experimental specimens that have large value of the modulus of elasticity to avoid any deformation or failure during the cyclic loading. Stiff loading beam was rested on steel plate that transfer the lateral loads as a shear load to the wall piers. The model assemblage is as shown in Fig. 3.4.

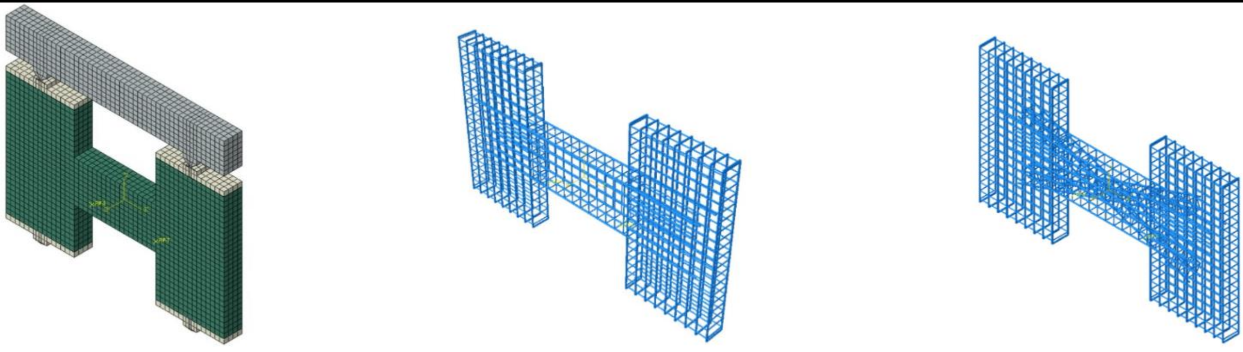


Fig. 3.4. ABAQUS Model Assemblage

The boundary conditions that were applied in the models are shown in Fig.3.5. The end conditions applied in the models were hinged supports at the bottom pin assemblies and at the intersection between the top surface of the stiff loading beam with the top assemblies to transfer the lateral load to the top pin assemblies and roller supports at the center of the top pin assembly. The lateral load was applied on the stiff loading beam as a displacement.

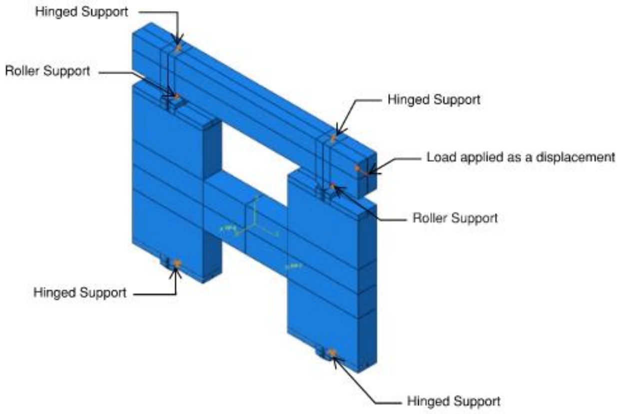


Fig. 3.5 Loading and Boundary Conditions

The mesh size of elements was subsequently generated with size of 50mm. The concrete damaged plasticity model has a high effect to the mesh size, so the mesh was studied up to the point that the change in mesh size did not have an effect on the results. The mesh size of models is shown in Fig. 3.6.

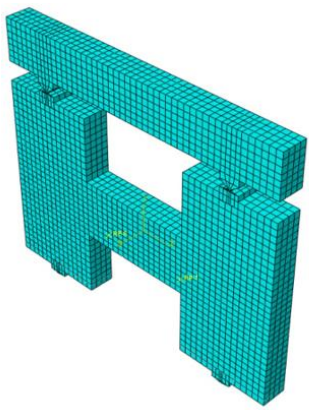
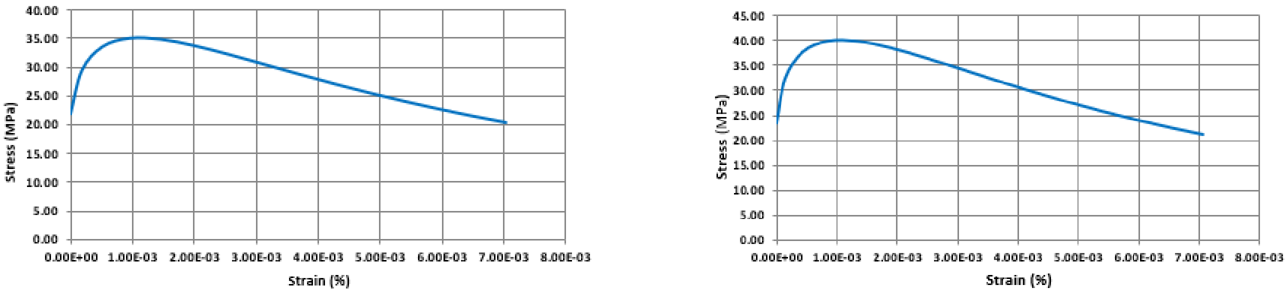


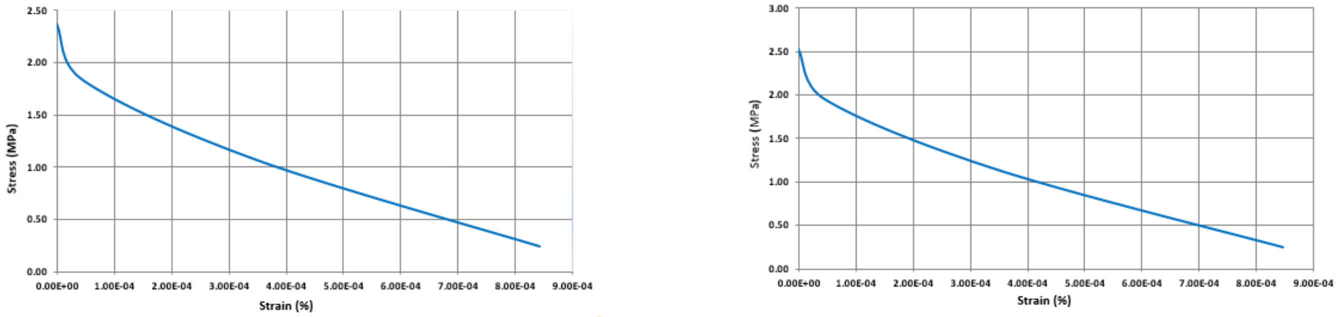
Fig. 3.6. Mesh size from the ABAQUS Model

Concrete damage plasticity parameters used for these models are shown in Table 3.2. The elastic-plastic behavior of the concrete in compression including strain softening for concrete compressive strength 34.94 and 39.91 MPa are shown in Fig.3.7. The concrete tensile behavior for concrete compressive strength 34.94 and 39.91 MPa is shown in Fig 3.8.



(a) (b)

Fig. 3.7. Elastic-Plastic behavior of concrete in compression: (a) f_{cu}=34.94 MPa (b) f_{cu}= 39.91 MPa



(a) (b)

Fig.3.8. Concrete Tensile behavior of concrete: (a) f_{cu}=34.94 MPa (b) f_{cu}= 39.91 MPa

Table 3.2. Damage plasticity parameters used in ABAQUS for CRCCB and DRCCB

Parameters	Value
Dilation Angle	36
Eccentricity	0.1
fb0/fc0	1.16
K	0.667
Viscosity Parameter	0.01

3.4 RESULTS

3.4.1 LATERAL LOAD-DISPLACEMENT BEHAVIOR

The elasto-plastic model is implemented for the reinforcement and the damage plasticity model is implemented for the concrete. The lateral load obtained is now plotted against displacement is shown in Fig. 3.9 and 3.10 for CRCB and DRCB respectively. For the CRCB, the peak lateral load predicted by the model was 447 kN compared to 423 kN as obtained in the experiment and for the DRCB, the peak lateral load predicted by the model was 641 kN compared to 640 kN as obtained in the experiment, and this seems a good match.

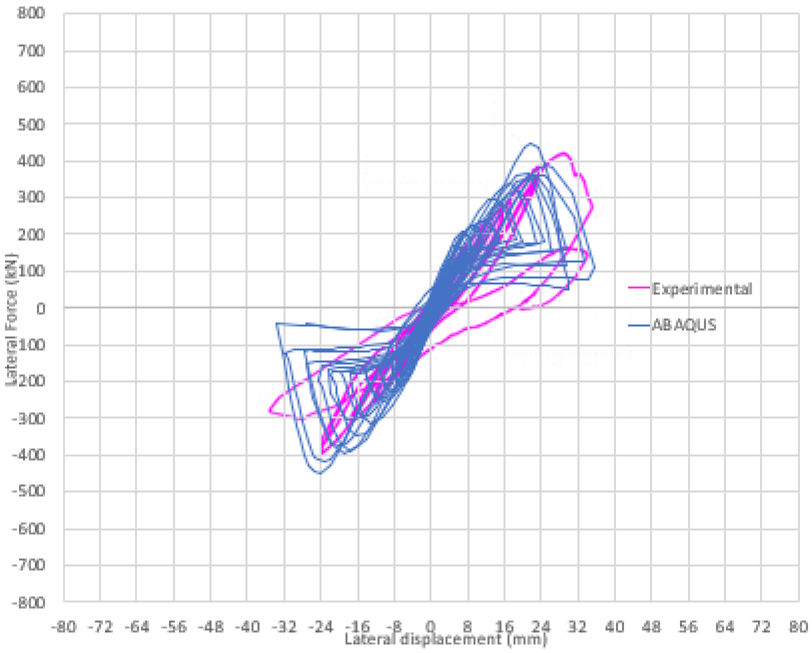


Fig. 3.9. Lateral Load-displacement relationship for CRCB specimen
(Adapted from Hasan Sesli and Metin Husem 2020)

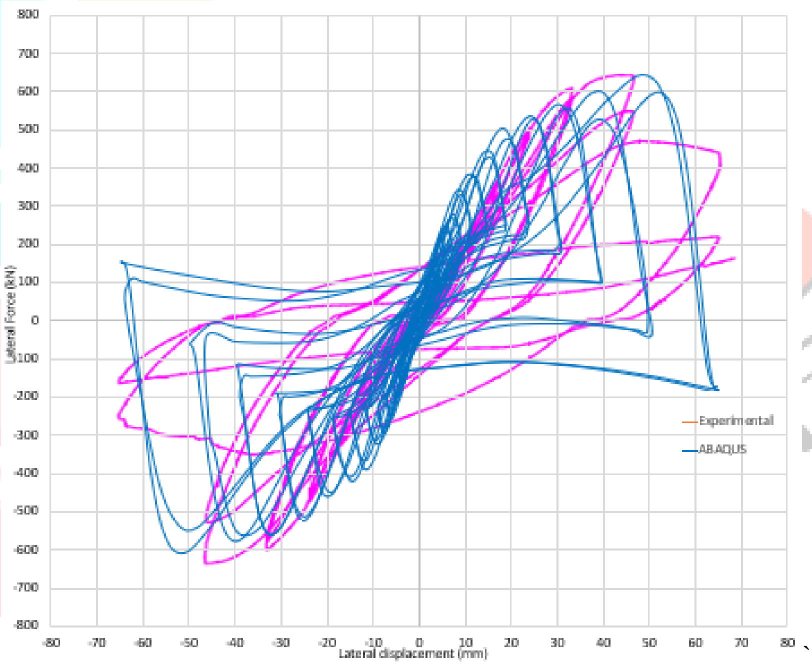
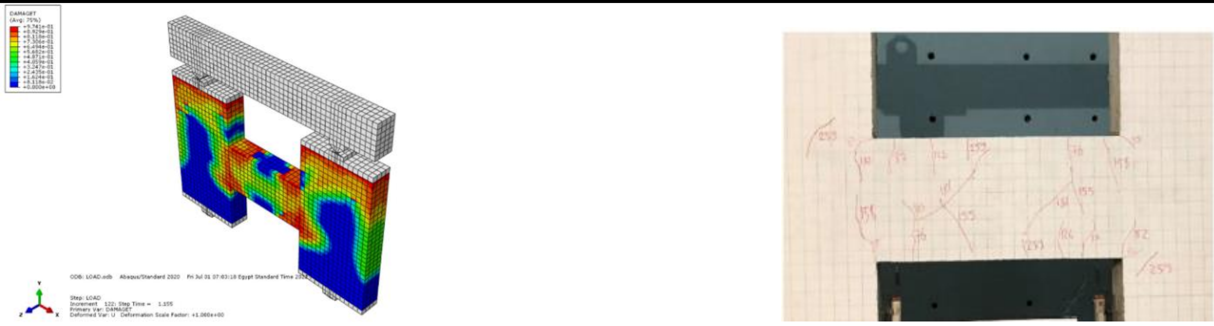


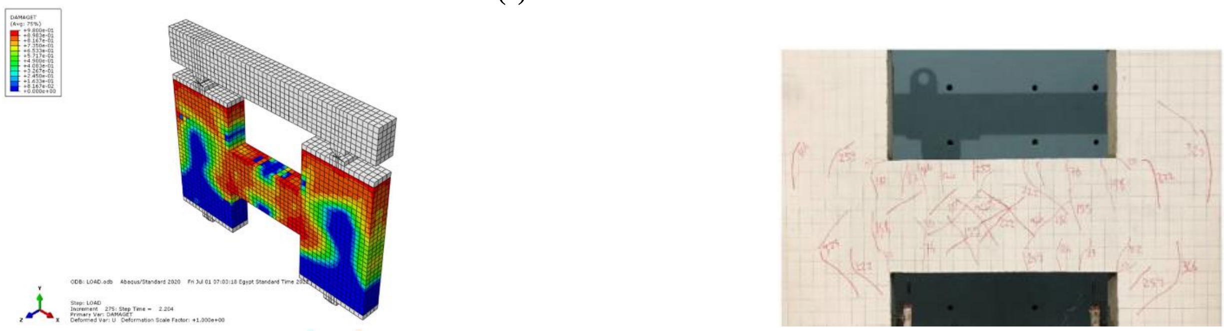
Fig. 3.10. Lateral Load-displacement relationship for DRCB specimen
(Adapted from Hasan Sesli and Metin Husem 2020)

3.4.2 CRACK PROPAGATION FOR THE DRCCB

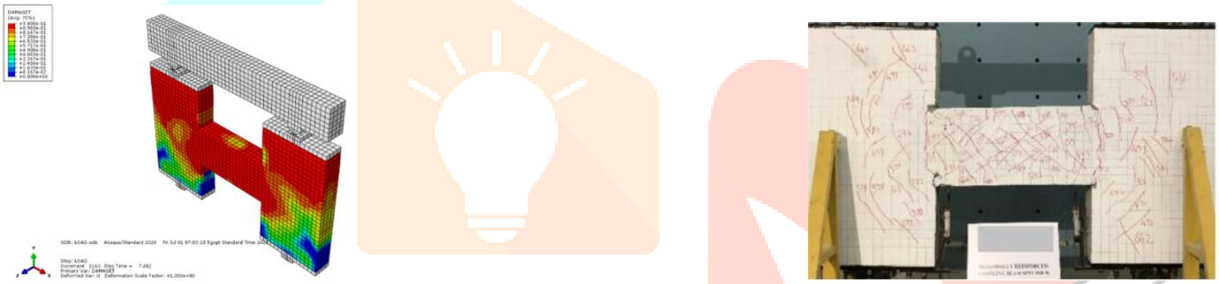
Crack propagation and development on the DRCB (diagonally reinforced coupling beam) specimen was depending on the ratio between the lateral displacement of the stiff loading beam and the vertical distance between the upper and lower pins as a drift ratio. At first, flexural cracks were observed at the corners of the coupling beam then vertical cracks appeared and propagated toward the center of the coupling beam. After that diagonal tension cracks appeared and developed with increasing in inclination after 0.75% as shown in Fig.3.12(a). At drift level of 1%, the diagonal tension cracks were concentrated quietly at the beam center and on the shear walls as shown in Fig.3.12(b). At drift level of 3%, diagonal cracks at the beam center were elongated toward the beam's corners and flexural cracks at the beam-wall interface with propagation of cracks at the shear walls within distance of about the depth of the coupling beams as shown in Fig.3.12(c). Finally, spalling and crushing of the concrete of the corners were occurred.



(a) drift level = 0.75%



(b) drift level = 1.00%



(c) drift level = 3.00%

Fig. 3.12. Crack propagation and failure modes for the DRCB specimen
(Adapted from Hasan Sesli and Metin Husem 2020)

4 PARAMETRIC STUDY

In order to investigate the influence of different variables on the strength and behavior process, a data base of 21 rectangular RC beams with three different reinforcement details were conducted. The PS database is presented in Tables 4.1 to 4.2. 21- RC beams will be studied with an overall length of 900mm and depth of 450mm. The first group included nine specimens of coupling beams to study its behavior when there is no difference between the concrete compressive strength of shear walls and beam and by using different concrete compressive strength between them (SP-01 to SP-09). The second group included 12 specimens of coupling beams with different aspect ratios (SP-10 to SP-18). to study its behavior when using the codes recommendations for the aspect ratio and by exceeding the codes' limits. Table 4.1 gives the RC beam geometry. Table 4.2 describes the bottom and top reinforcement properties and the shear reinforcement properties. Coupling beam's specimens in the PS database are simply supported beams, three types of reinforcement were used that consist of conventionally reinforcement, diagonally reinforcement and double reinforcement that were loaded with cyclic loading. All specimens in this study have a simple statical system. All coupling beams are simply supported. The loading type that is used in this study is cyclic loading as the half of the cyclic loading is concentrated on the upper face of the right wall and the other half of the cyclic loading is concentrated on the upper face of the left wall as shown in Fig. 4.1.

Table 4.1-PS database-Concrete properties of the coupling beam's specimens

	Type of RFT.	Name	$f_{cu\,wall}$ (MPa)	$f_{cu\,beam}$ (MPa)	Beam length (mm)	Beam depth (mm)	beam width (mm)	Wall length (mm)	Wall height (mm)	Wall width (mm)	f_y (MPa)	Aspect ratio
Group 1 (f_{cu})	CRCB	SP-01	50	50	900	450	300	750	1350	300	350	2
	CRCB	SP-02	50	40	900	450	300	750	1350	300	350	2
	CRCB	SP-03	50	30	900	450	300	750	1350	300	350	2
	DRCB	SP-04	50	50	900	450	300	750	1350	300	350	2
	DRCB	SP-05	50	40	900	450	300	750	1350	300	350	2
	DRCB	SP-06	50	30	900	450	300	750	1350	300	350	2
	DBCB	SP-07	50	50	900	450	300	750	1350	300	350	2
	DBCB	SP-08	50	40	900	450	300	750	1350	300	350	2
	DBCB	SP-09	50	30	900	450	300	750	1350	300	350	2
Group 2 (Aspect Ratio)	CRCB	SP-10	40	30	900	360	300	750	1350	300	420	2.5
	CRCB	SP-11	40	40	900	300	300	750	1350	300	420	3
	CRCB	SP-12	40	40	900	220	300	750	1350	300	420	4
	CRCB	SP-13	40	40	900	200	300	750	1350	300	420	4.5
	DRCB	SP-14	40	40	900	360	300	750	1350	300	420	2.5
	DRCB	SP-15	40	40	900	300	300	750	1350	300	420	3
	DRCB	SP-16	40	40	900	220	300	750	1350	300	420	4
	DRCB	SP-17	40	40	900	200	300	750	1350	300	420	4.5
	DBCB	SP-18	40	40	900	360	300	750	1350	300	420	2.5
	DBCB	SP-19	40	40	900	300	300	750	1350	300	420	3
	DBCB	SP-20	40	40	900	220	300	750	1350	300	420	4
	DBCB	SP-21	40	40	900	200	300	750	1350	300	420	4.5

Table 4.2-PS database for all-RC beam specimens' details

Wall main RFT.	Wall transverse RFT.	Beam main RFT.	Beam side bars	Beam stirrups
18-D16	D8@70	4T16	2T12	D8@80

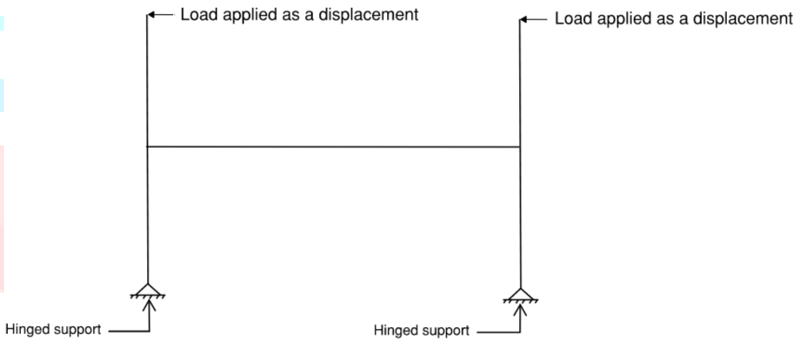
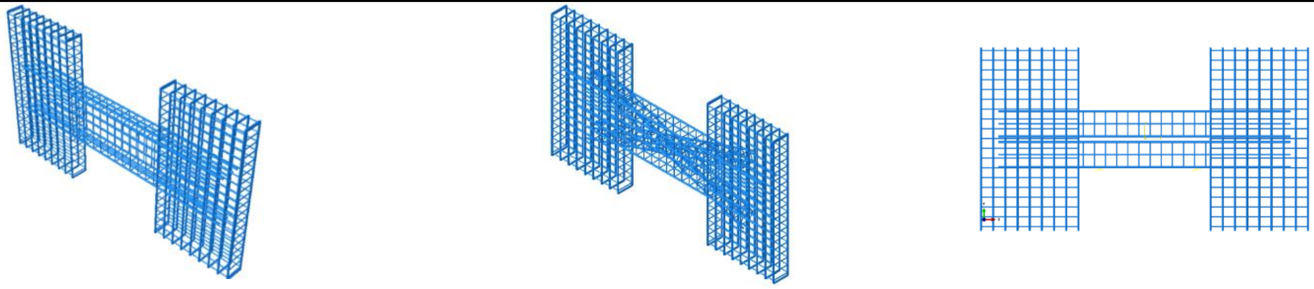


Fig.4.1. Statical system for the coupling beam's specimens

Group 1 includes nine specimens with variable concrete compressive strength (f_{cu}) 50,40 and 30 MPa for the shear walls and beams to study their effect on the strength and the behavior of the coupling beams. Sometimes, shear walls are casted in a different time of casting the coupling beams so we may find that there are different between the concrete compressive strength of shear walls than the coupling beams, therefore group 1 is conducted to investigate the effect of different concrete compressive strength between walls and beams in the behavior of the coupling beams. Specimens from SP-1 to SP-09 are studied in group 1. Group 2 includes twelve specimens with different aspect ratios for the coupling beams. Specimens from SP-10 to SP-21 are studied in group 2. Three different types of reinforcement are used in this study, Conventionally RFT. (CRCB), diagonally RFT. (DRCB) and double RFT. (DBCB). All these 21-specimens have 900mm length,450mm depth and 300mm width. The main reinforcement of the coupling beams for the three different types of reinforcement are 4D16 with side bars of 2T12 and stirrups of D8@80. Shear walls have 750mm length, 1350mm height and 300mm width. The wall main reinforcement is 18D16 with transverse reinforcement of D8@70. Fig. 4.2. describes the details of reinforcement for the specimens with the different three types of reinforcement.

4.1 Numerical Study

Conventionally reinforced concrete coupling beam (CRCB), diagonally reinforced coupling beam (DRCB) and double beam coupling beam (DBCB) finite element models are generated by using ABAQUS using a three- dimensional framework. The concrete is modeled as a solid element and the steel is modeled as a wire. The reinforcement is meshed by using truss elements as the bending stiffness is neglectable. To make interaction between the steel and concrete, the reinforcement is embedded into the concrete and was assumed to be perfectly bonded. Cyclic loading was conducted in ABAQUS to study the effect of each parameter on the strength and behavior of the coupling beam. The model assemblage is as shown in Fig. 4.2.



(a)CRCB (b) DRCB (c) DBCB

Fig. 4.2. ABAQUS Model Assemblage
(a)CRCB, (b) DRCB and (c) DBCB

The boundary conditions that were applied in the models are shown in Fig.4.3. The end conditions applied in the models were hinged supports at the bottom pin assemblies and at the top surface of the shear walls, cyclic loading was applied at the top of the shear walls to transfer the lateral load to the coupling beams. The lateral load was applied on the shear walls as a displacement.

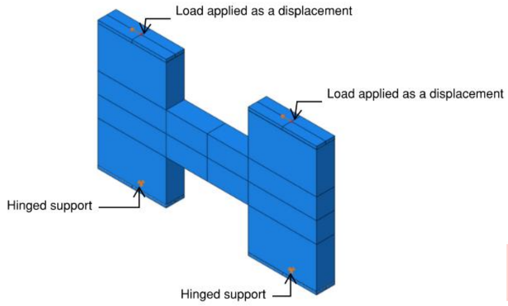


Fig. 4.3 Loading and Boundary Conditions

4.2 RESULTS

The elasto-plastic model is implemented for the reinforcement and the damage plasticity model is implemented for the concrete. The lateral load obtained is now plotted against displacement for group 1 as shown in Fig. 4.7, Fig. 4.8, and Fig. 4.9 for CRCB, DRCB and DBCB respectively. For the CRCB with specimens SP-01, SP-02 and SP-03, the peak lateral load reached by the SP-01 with 50 MPa concrete compressive strength for the shear walls and the coupling beam was 420 KN while specimen SP-02 with different concrete compressive strength between walls and beam had reached to 361 KN and specimen SP-03 with different concrete compressive strength between walls and beam had reached to 338 KN. For the DRCB with specimens SP-04, SP-05 and SP-06, the peak lateral load reached by the SP-04 with 50 MPa concrete compressive strength for the shear walls and the coupling beam was 540 KN while specimen SP-05 with different concrete compressive strength between walls and beam had reached to 465 KN and specimen SP-06 with different concrete compressive strength between walls and beam had reached 435 KN. For the DBCB with specimens SP-07, SP-08 and SP-09, the peak lateral load reached by the SP-07 with 50 MPa concrete compressive strength for the shear walls and the coupling beam was 449 KN while specimen SP-08 with different concrete compressive strength between walls and beam had reached to 388 KN and specimen SP-09 with different concrete compressive strength between walls and beam had reached to 360 KN. The lateral load obtained is now plotted against displacement for group 2 as shown in Fig. 4.10, Fig. 4.11, and Fig. 4.12 for CRCB, DRCB and DBCB respectively. For the CRCB with specimens SP-10, SP-11, SP-12 and SP-13, the peak lateral load reached by the SP-10 with aspect ratio 2.5 was 310 KN while specimen SP-11 with aspect ratio 3.0 had reached to 266 KN and specimen SP-12 with aspect ratio 4.0 had reached to 223 KN and specimen SP-13 with aspect ratio 4.5 had reached to 111 KN. For the DRCB with specimens SP-14, SP-15, SP-16 and SP-17, the peak lateral load reached by the SP-14 with aspect ratio 2.5 was 409 KN while specimen SP-15 with aspect ratio 3.0 had reached to 397 KN while the peak lateral load reached by the SP-16 with aspect ratio 4.0 was 337 KN while specimen SP-17 with aspect ratio 4.5 had reached to 198 KN.

For the DBCB with specimens SP-18, SP-19, SP-20 and SP-21, the peak lateral load reached by the SP-18 with aspect ratio 2.5 was 347 KN while specimen SP-19 with aspect ratio 3.0 had reached to 291 KN while the peak lateral load reached by the SP-20 with aspect ratio 4.0 was 273 KN while specimen SP-21 with aspect ratio 4.5 had reached to 138 KN.

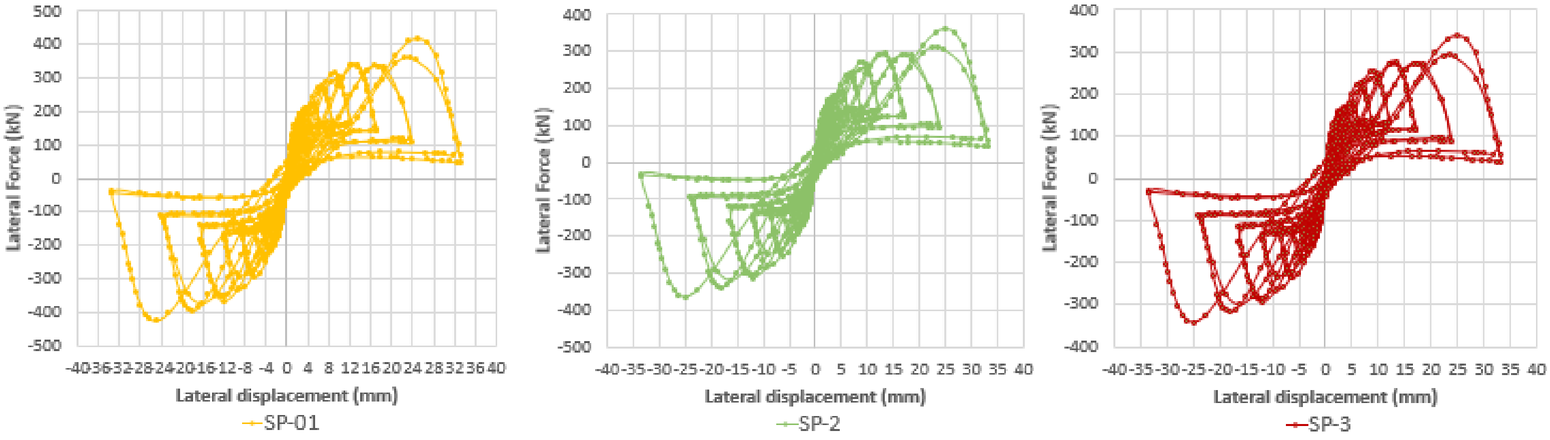


Fig. 4.7. Lateral Load-displacement relationship for CRCB's specimens at group 1.

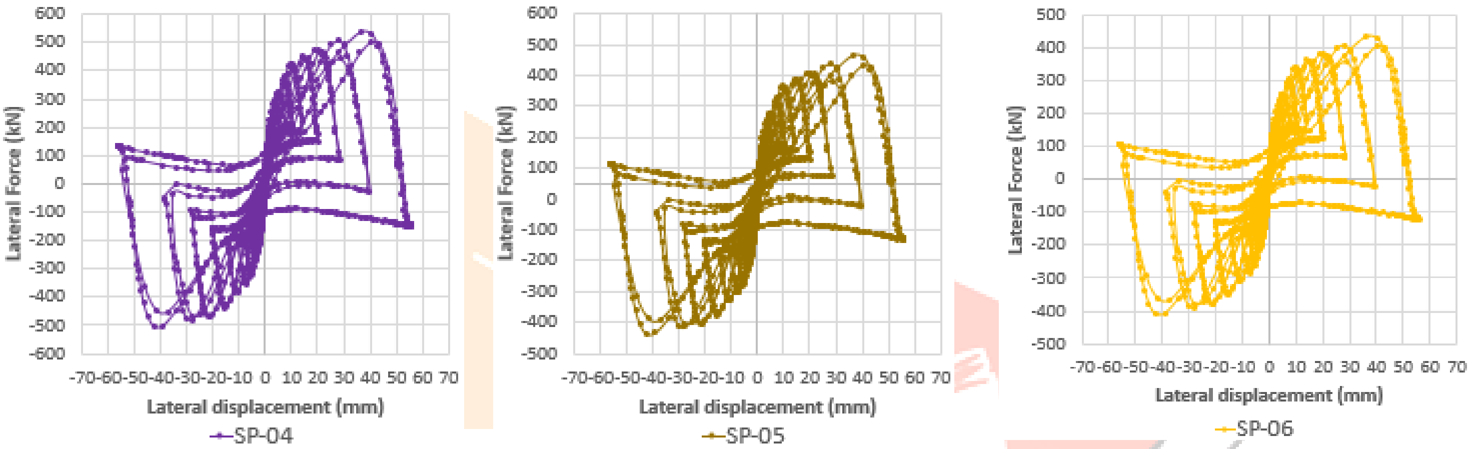


Fig. 4.8. Lateral Load-displacement relationship for DRCB's specimens at group 1.

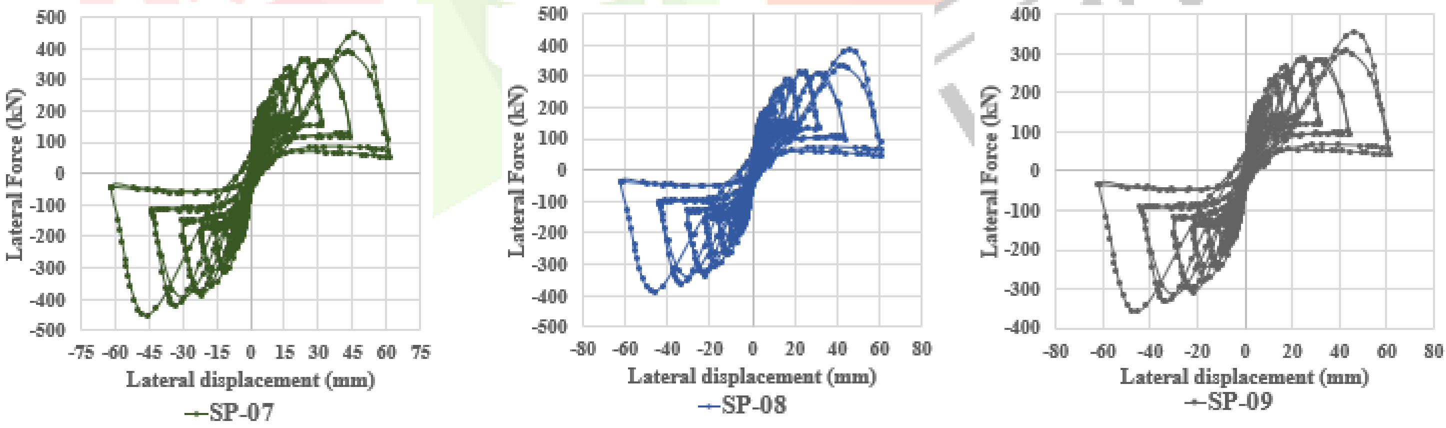


Fig. 4.9. Lateral Load-displacement relationship for DBCB's specimens at group 1.

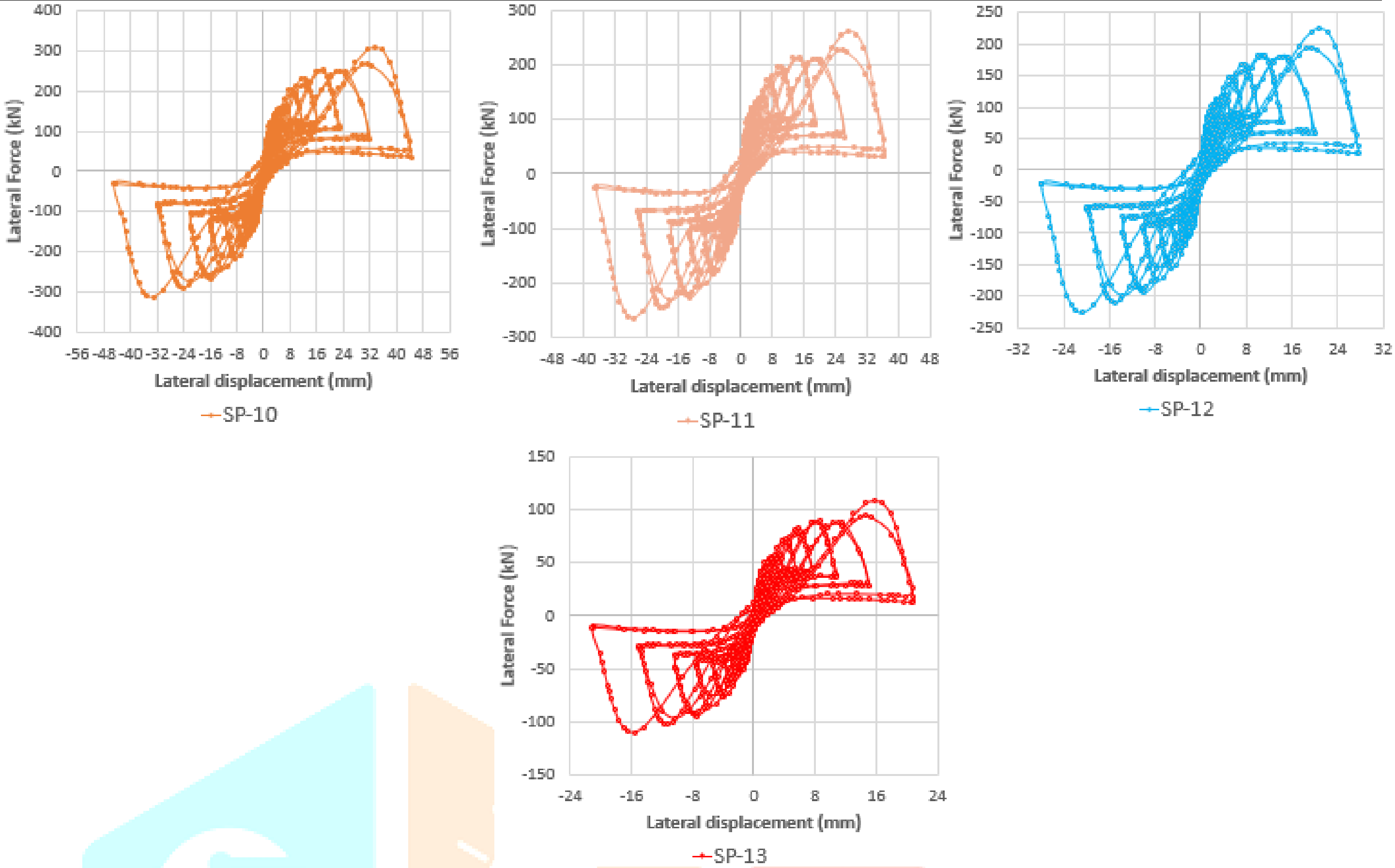


Fig. 4.10. Lateral Load-displacement relationship for CRCB's specimens at group 2.

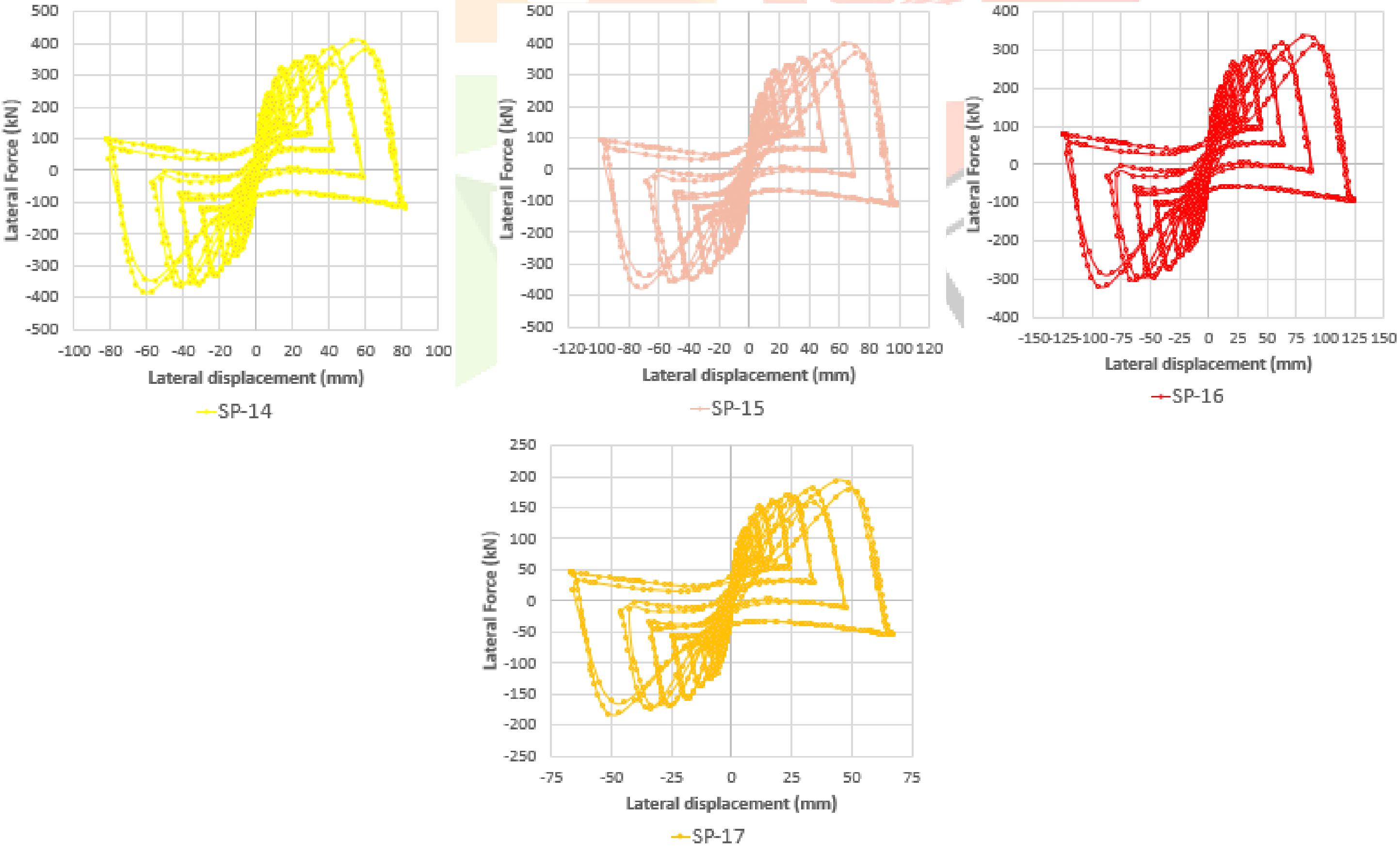


Fig. 4.11. Lateral Load-displacement relationship for DRCB's specimens at group 2.

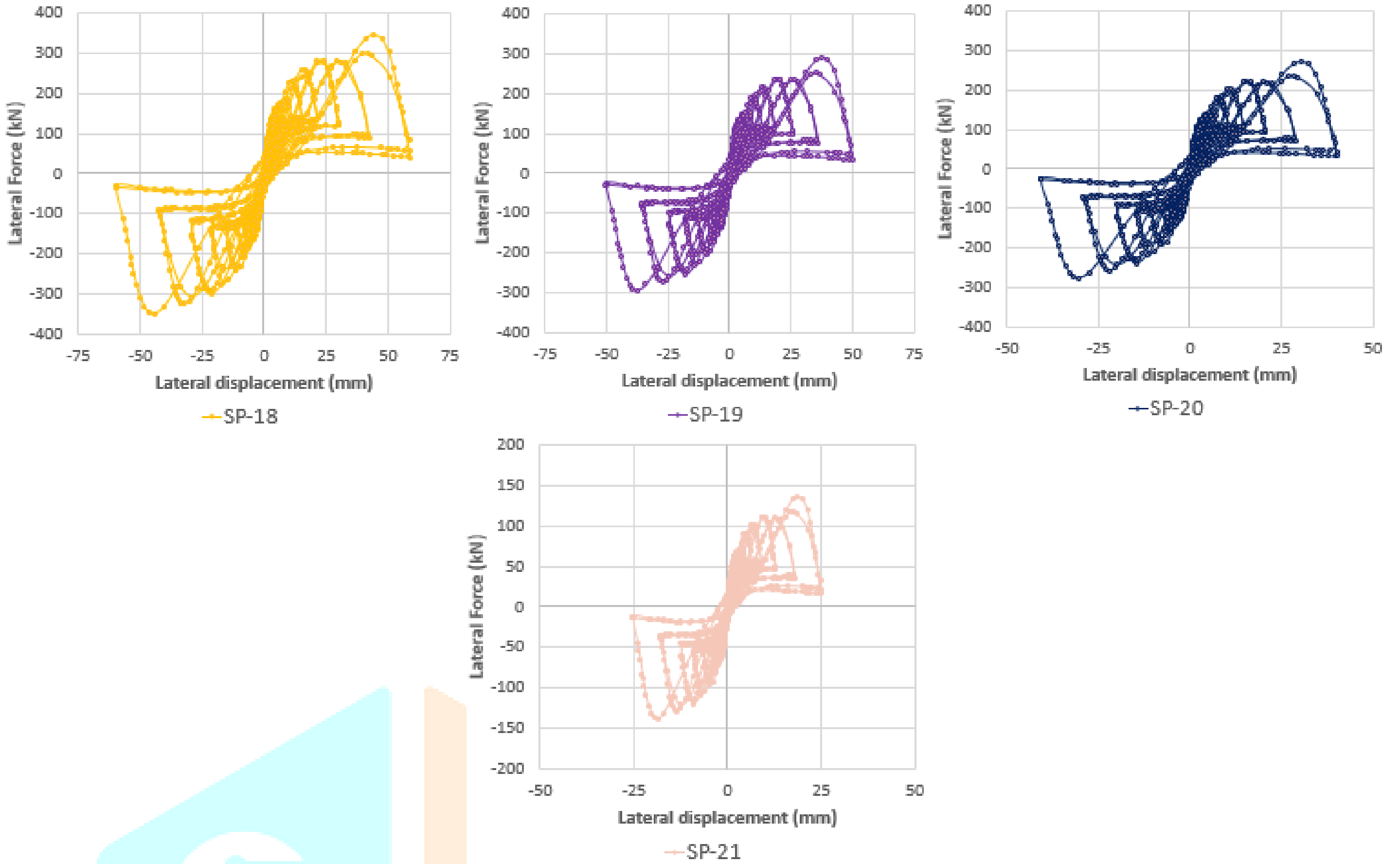


Fig. 4.12. Lateral Load-displacement relationship for DBCB's specimens at group 2.

5 Summary and Conclusion

The aim of this study is to investigate the behavior of coupling beams with different reinforcement details. Three different reinforcement details were used for this study, conventionally reinforcement, diagonally reinforcement and double reinforcement. Parametric studies were conducted to investigate the effect of increasing the concrete compressive strength on the strength of the coupling beams with three different details. Non-linear finite element analysis ABAQUS was used for the studies of the verification and the parametric studies.

Analyzing the results has given the following conclusions:

- Double beam coupling beams get higher lateral strength than conventionally reinforcement coupling beams by almost 11% and higher ductility by almost 20%
- By using concrete compressive strength for the shear walls higher than that used for the coupling beams, the results obtained that there are decreasing in the lateral strength by 14-19%.
- It's recommended to use the concrete compressive strength for the coupling beams same as that used for the shear walls to avoid the decreasing in the lateral strength.
- When the aspect ratio increase for the conventionally reinforced coupling beams and double beam coupling beams the strength and ductility will be decreased as it will be more brittle.
- For the diagonally reinforced coupling beams when used aspect ratios 2.5 and 3, it's obtained that there isn't a significant effect on strength and increasing in ductility for the specimens. On the other hand, when used aspect ratio 4, it's obtained that there is decreasing in strength by 15% and increasing in ductility by 20%.
- By exceeding the codes requirements related to the aspect ratio for the diagonally reinforcement coupling beams, it's obtained that there are high degradation in strength and ductility by 40% and 46% respectively so it isn't recommended to use the diagonally reinforcement if the aspect ratio will be higher than 4.

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