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STRENGTHENING OF COUPLED SHEAR WALLS IN HIGH- RISE BUILDINGS

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ABSTRACT: The present work is concerned with the analytical and theoretical study of the behavior of braced reinforced concrete coupled shear walls in high-rise buildings. The braced reinforced concrete coupled shear walls (B.R.C.C.S.W) are used to resist loading in high- rise buildings and lateral forces from wind and earthquakes. A non-linear analytical model was developed using the Finite Element Program (ETABS v 9.2).

Using ETABS in the analysis and design of structural three dimensional high- rise buildings: the procedure consists of choosing the units, drawing three dimensional structural model, choosing material properties, classification of all elements of frame sections such as (beams or bracing or beams and bracing and columns), wall piers and slabs sections, choosing reinforcing bars for all concrete sections, choosing supports, defining loads (dead, live, wind, earthquake and combination), run the analysis and design for all cases and parametric studies. In the case studies, buildings are consisting of columns and walls as well as slabs. Walls are connected together by means of beams or bracing or both of beams and bracing, in all floors.

Analytical results show that using of bracing instead of beams in coupled shear walls, decreases the displacement in high- rise buildings by about 40 % approximately, and increases the normal force for walls by about 7 - 10 % approximately while decreases the moment by about 40 – 45 %. Analytical results show also the possibility of increasing durability of high- rise buildings against lateral loads, as well as the possibility of duplication of building height in zone 2, and one time and half in zone 3.

Key words: Reinforced Concrete, Coupled Shear Walls, High- Rise Buildings, Lateral Loads, Bracing, Beams, Non-linear Analysis, Finite Element Method.

1 INTRODUCTION

The analysis of coupled shear walls in high-rise buildings becomes an interested subject for many civil engineers in recent years. From the standpoint of structural analysis, the problem is highly redundant, and a mathematical analysis for stresses and deformations of the coupled shear walls with connecting beams or bracing or both of them is extremely complex. For this reason, a simplified and more accurate method for analysis of coupled shear walls would contribute in perfect engineering design. The intention herein is to illustrate the use of the finite-element method in determining the stress distributions in (B.R.C.C.S.W) as well as the prediction of more accurate values for the bending moments, axial and shear forces which act upon the connecting beams or bracing when the coupled shear walls are subjected to lateral loads. In high- rise buildings, lateral loads such as winds and earthquakes are generally resisted by the (B.R.C.C.S.W). Since the reinforced concrete building could be as low as one storey and as high as 120 stories or more, then some special design considerations should be taken. The definition of the high rise buildings is a subjective matter for all engineers. Simply, the structural engineer defines the high rise buildings as the one whose structural system should to be modified in order to make it sufficiently economic to resist lateral loads within the prescribed design criteria for displacement and comfort of occupants. Shear walls, coupled shear walls and wall frame were studied by many researches [4, 6, 7, 8 and 9] and they did not compare the use of beam and bracing in different floors.

2 NUMERICAL PROGRAM

In this paper, a numerical program model, using a finite-element program, is developed to study the behavior of (B.R.C.C.S.W). The program is applied to twelve reinforced concrete buildings, each of 60 floors, these buildings are divided into two groups: group (1): buildings without connecting beams for columns defined as buildings without frame as shown in Fig. (1); and group (2): buildings with connecting beams for columns defined as buildings with frame as shown in Fig. (2). Using The Egyptian Code for Calculation of Loads and Forces in Structural and Building Works, each group has six buildings covering the studied parameters such as the type of connections between shear walls (beam, bracing and beam and bracing together) and the seismic zone (2 & 3). Table (1) illustrates the description of the models in numerical program. The present study has been performed to ascertain from using bracing instead of beams in analysis of the (B.R.C.C.S.W) by the finite element method (ETABS v 9.2).should be Times New Roman font, 11 points and single line spacing. Only the following text should be italicized: headings, mathematical parameters (not for log, sin, cos, ln, max., d (in d*x*), etc), and the titles of journals and books.

Table 1 : The description of the models in numerical program.

Group	Connecting elements	Concrete dimensions	Zone 2	Zone 3
		(cm x cm)	Building No.	Building No.
Group (1) Building without Frame	Beam only	30 x 60	1	7
	Bracing only	30 x 60	2	8
	Beam and Bracing	30 x 60	3	9
Group (2) Building with Frame	Beam only	30 x 60	4	10
	Bracing only	30 x 60	5	11
	Beam and Bracing	30 x 60	6	12

Each of the twelve buildings has dimensions of 42 m length and 42 m width in plan, and 60 floors with a storey height of 3 ms. And total height (H) of 180 ms. Six building (no. 1 to no. 6) are located in zone 2 while the other six buildings (no. 7 to no. 12) are located in zone 3. The thickness of slab in all floors is 22 cm with floor cover of 0.15 ton/m2 and live load of 0.30 ton/m2. Concrete dimensions of cross sections for columns and walls are shown in table (2) and the steel reinforcement was neglected in analysis. Fig. (3,4&5) show elevations of coupled shear walls connecting by means of beam, bracing and beam and bracing respectively.

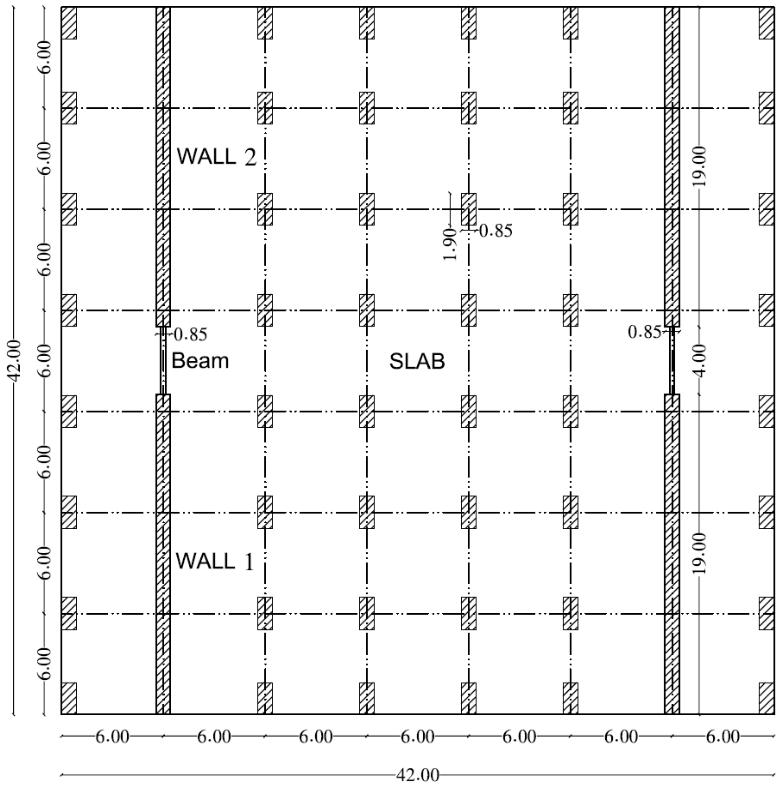

Fig. 1: Typical structural plan of buildings in group (1) without frame.

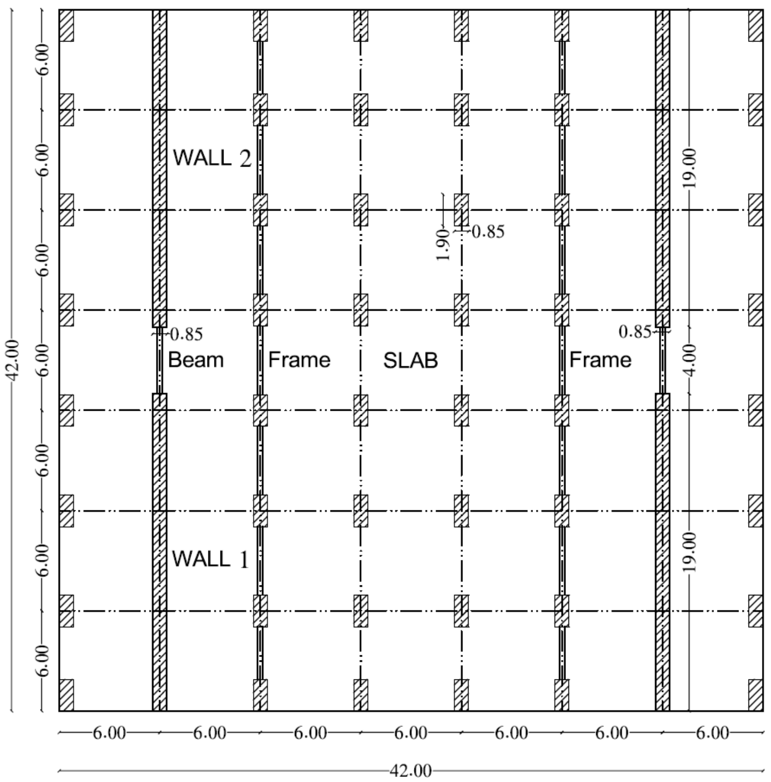

Fig. 2: Typical structural plan of buildings in group (2) with Frame.

Table 2 : Sections columns and walls in buildings.

Floor	Columns Sections (m x m)	Walls Sections (m x m)	Floor	Columns Sections (m x m)	Walls Sections (m x m)	Floor	Columns Sections (m x m)	Walls Sections (m x m)
60	0.30 X 0.60	0.30 X 19	40	0.50 X 1.20	0.50 X 19	20	0.70 X 1.60	0.70 X 19
59	0.30 X 0.60	0.30 X 19	39	0.50 X 1.20	0.50 X 19	19	0.70 X 1.60	0.70 X 19
58	0.30 X 0.60	0.30 X 19	38	0.50 X 1.20	0.50 X 19	18	0.70 X 1.60	0.70 X 19
57	0.30 X 0.60	0.30 X 19	37	0.50 X 1.20	0.50 X 19	17	0.70 X 1.60	0.70 X 19
56	0.30 X 0.60	0.30 X 19	36	0.50 X 1.20	0.50 X 19	16	0.70 X 1.60	0.70 X 19
55	0.35 X 0.75	0.35 X 19	35	0.55 X 1.30	0.55 X 19	15	0.75 X 1.70	0.75 X 19
54	0.35 X 0.75	0.35 X 19	34	0.55 X 1.30	0.55 X 19	14	0.75 X 1.70	0.75 X 19
53	0.35 X 0.75	0.35 X 19	33	0.55 X 1.30	0.55 X 19	13	0.75 X 1.70	0.75 X 19
52	0.35 X 0.75	0.35 X 19	32	0.55 X 1.30	0.55 X 19	12	0.75 X 1.70	0.75 X 19
51	0.35 X 0.75	0.35 X 19	31	0.55 X 1.30	0.55 X 19	11	0.75 X 1.70	0.75 X 19
50	0.40 X 0.90	0.40 X 19	30	0.60 X 1.40	0.60 X 19	10	0.80 X 1.80	0.80 X 19
49	0.40 X 0.90	0.40 X 19	29	0.60 X 1.40	0.60 X 19	9	0.80 X 1.80	0.80 X 19
48	0.40 X 0.90	0.40 X 19	28	0.60 X 1.40	0.60 X 19	8	0.80 X 1.80	0.80 X 19
47	0.40 X 0.90	0.40 X 19	27	0.60 X 1.40	0.60 X 19	7	0.80 X 1.80	0.80 X 19
46	0.40 X 0.90	0.40 X 19	26	0.60 X 1.40	0.60 X 19	6	0.80 X 1.80	0.80 X 19
45	0.45 X 1.05	0.45 X 19	25	0.65 X 1.50	0.65 X 19	5	0.85 X 1.90	0.85 X 19
44	0.45 X 1.05	0.45 X 19	24	0.65 X 1.50	0.65 X 19	4	0.85 X 1.90	0.85 X 19
43	0.45 X 1.05	0.45 X 19	23	0.65 X 1.50	0.65 X 19	3	0.85 X 1.90	0.85 X 19
42	0.45 X 1.05	0.45 X 19	22	0.65 X 1.50	0.65 X 19	2	0.85 X 1.90	0.85 X 19
41	0.45 X 1.05	0.45 X 19	21	0.65 X 1.50	0.65 X 19	1	0.85 X 1.90	0.85 X 19

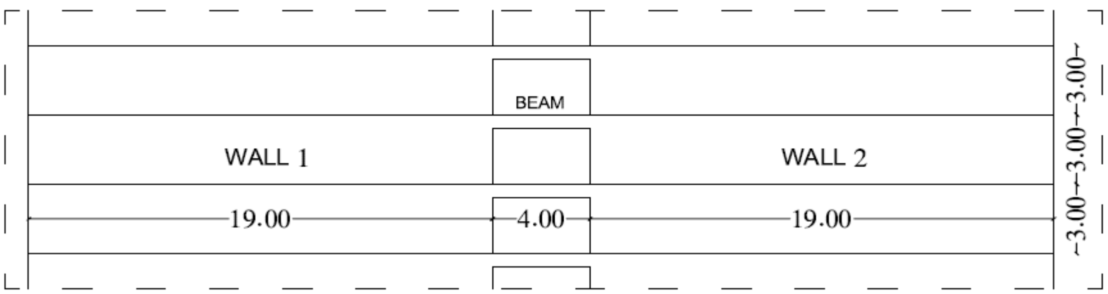

Fig. 3: Elevation of coupled shear walls connecting by beams.

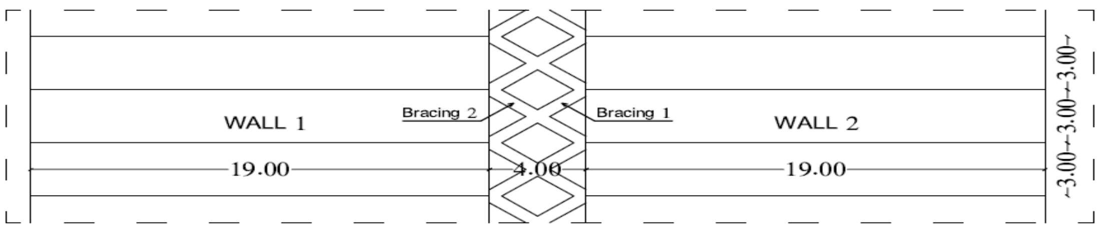

Fig. 4: Elevation of coupled shear walls connecting by bracing.

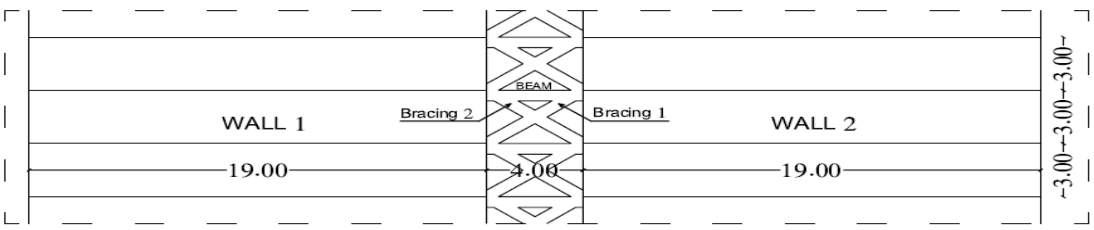

Fig. 5: Elevation of coupled shear walls connecting by beams and bracings.

Table 3 : Values of displacement, normal force and moment for the walls in buildings.

Floors	Zone 2						Zone 3					
	without Frame			with Frame			without Frame			with Frame		
	Building 1	Building 2	Building 3	Building 4	Building 5	Building 6	Building 7	Building 8	Building 9	Building 10	Building 11	Building 12
	Displacement			Displacement			Displacement			Displacement		
	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
60	15.53	9.31	9.32	11.67	7.03	7.04	23.29	13.97	13.98	17.50	10.55	10.56
55	13.98	8.21	8.21	10.51	6.20	6.20	20.97	12.31	12.32	15.76	9.29	9.30
50	12.47	7.18	7.18	9.37	5.42	5.42	18.71	10.77	10.78	14.05	8.13	8.14
45	10.91	6.16	6.16	8.20	4.65	4.65	16.36	9.24	9.24	12.29	6.97	6.98
40	9.31	5.16	5.16	7.00	3.89	3.89	13.97	7.73	7.74	10.49	5.84	5.84
35	7.70	4.19	4.19	5.79	3.16	3.17	11.55	6.28	6.29	8.68	4.75	4.75
30	6.12	3.28	3.28	4.60	2.48	2.48	9.18	4.92	4.92	6.90	3.71	3.71
25	4.60	2.44	2.44	3.46	1.84	1.84	6.90	3.65	3.66	5.19	2.76	2.76
20	3.20	1.68	1.69	2.41	1.27	1.27	4.80	2.53	2.53	3.61	1.91	1.91
15	1.97	1.04	1.04	1.48	0.79	0.79	2.95	1.56	1.56	2.22	1.18	1.18
10	0.97	0.53	0.53	0.73	0.40	0.40	1.46	0.79	0.79	1.10	0.60	0.60
5	0.29	0.17	0.17	0.22	0.13	0.13	0.43	0.25	0.25	0.32	0.19	0.19
0	0	0	0	0	0	0	0	0	0	0	0	0
Floors	Wall 2 Zone 2			Wall 2 Zone 2			Wall 2 Zone 3			Wall 2 Zone 3		
	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton
60	-275.77	-250.23	-250.70	-271.52	-252.30	-252.77	-289.30	-251.00	-251.48	-281.74	-252.91	-253.38
55	-1737.85	-1653.13	-1655.96	-1712.17	-1648.24	-1651.07	-1820.74	-1694.08	-1696.91	-1774.74	-1679.31	-1682.14
50	-3252.77	-3142.34	-3147.55	-3202.26	-3119.59	-3124.75	-3411.05	-3244.76	-3250.02	-3321.72	-3197.14	-3202.35
45	-4800.08	-4695.69	-4703.30	-4719.65	-4642.41	-4649.92	-5042.46	-4883.73	-4891.50	-4902.54	-4784.60	-4792.24
40	-6368.17	-6301.32	-6311.41	-6252.34	-6204.52	-6214.43	-6703.90	-6599.54	-6609.94	-6505.57	-6429.86	-6440.01
35	-7952.02	-7955.87	-7968.54	-7795.70	-7802.58	-7814.96	-8389.36	-8388.84	-8402.00	-8125.47	-8129.58	-8142.34
30	-9545.84	-9657.28	-9672.66	-9345.03	-9434.65	-9449.62	-10090.79	-10249.17	-10265.26	-9755.81	-9881.57	-9897.09
25	-11142.65	-11403.79	-11422.02	-10895.06	-11099.37	-11117.06	-11797.68	-12177.87	-12197.08	-11388.68	-11683.80	-11702.24
20	-12734.75	-13194.00	-13215.30	-12440.36	-12796.09	-12816.67	-13497.56	-14172.00	-14194.57	-13015.08	-13534.46	-13556.03
15	-14312.60	-15023.58	-15048.21	-13974.33	-14522.13	-14545.83	-15174.79	-16223.68	-16249.98	-14623.86	-15428.25	-15453.24
10	-15863.91	-16876.32	-16904.69	-15488.41	-16265.97	-16293.14	-16809.34	-18307.08	-18337.64	-16200.61	-17346.37	-17375.23
5	-17372.81	-18696.88	-18729.56	-16971.39	-17986.10	-18017.23	-18375.64	-20338.29	-20373.86	-17726.82	-19225.76	-19259.11
1	-18533.57	-20021.73	-20057.70	-18123.37	-19263.71	-19297.89	-19555.72	-21761.71	-21801.01	-18893.36	-20577.93	-20614.68
0	0	0	0	0	0	0	0	0	0	0	0	0
Floors	Wall 2 Zone 2			Wall 2 Zone 2			Wall 2 Zone 3			Wall 2 Zone 3		
	Moment	Moment	Moment	Moment	Moment	Moment	Moment	Moment	Moment	Moment	Moment	Moment
	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m	Ton.m
60	-704.94	-410.24	-420.40	-653.35	-431.41	-441.68	-812.63	-373.11	-383.14	-733.91	-403.44	-413.62
55	-892.85	128.72	130.60	-686.03	77.33	78.73	-1295.84	235.21	237.96	-985.35	158.23	160.31
50	-841.69	602.56	606.94	-613.95	465.07	468.68	-1282.87	885.14	890.93	-940.88	678.96	683.67
45	-457.82	1115.90	1121.66	-322.99	855.99	860.75	-715.04	1647.84	1655.53	-512.18	1258.00	1264.22
40	340.47	1750.86	1757.92	272.73	1334.75	1340.50	482.76	2600.76	2610.31	382.14	1976.49	1984.14
35	1591.13	2520.03	2528.44	1206.00	1914.13	1920.91	2360.40	3756.13	3767.61	1784.33	2847.10	2856.23
30	3349.40	3424.92	3434.71	2519.99	2595.94	2603.75	4999.58	5115.14	5128.60	3757.98	3871.48	3882.09
25	5689.13	4466.38	4477.38	4272.83	3380.87	3389.60	8510.97	6678.97	6694.23	6387.67	5050.54	5062.51
20	8711.54	5654.56	5666.39	6540.22	4275.93	4285.27	13048.03	8464.57	8481.01	9790.36	6396.46	6409.34
15	12522.14	7008.76	7021.00	9395.64	5287.23	5297.00	18785.16	10519.06	10535.67	14092.79	7936.49	7949.66
10	17137.18	8540.19	8551.04	12815.07	6379.23	6388.21	25827.08	12950.54	12964.28	19339.14	9708.59	9719.88
5	22834.12	10946.72	10935.98	17025.93	8096.76	8085.61	34557.81	16768.26	16757.29	25839.31	12493.64	12482.46
1	32727.97	19441.37	19466.68	25390.58	15511.34	15537.00	47610.87	27503.78	27527.60	36592.68	21604.92	21629.62
0	0	0	0	0	0	0	0	0	0	0	0	0

3 ANALYSIS AND DISCUSSION

Analytical results should be considered for displacement, normal force and bending moment for the coupled shear walls in all floor levels.

Table (3) shows the values of displacement for the twelve buildings in the program at each five floors level. As an example, Figure. 6(a) illustrates displacement comparison between three buildings in zone2 without frame. Building (1) connecting beams between reinforced concrete coupled shear walls was displacement 15.53 cm, building (2) connecting bracing was displacement 9.31 cm and building (3) connecting beams and bracing was displacement 9.32 cm. So the connecting bracing is a better solution than connecting with beams only or beams and bracing in (H.R.B). Show in figure. 6(b) illustrates displacement comparison between three buildings in zone2 with frame. Building (4) connecting beams between reinforced concrete coupled shear walls was displacement 11.67 cm, building (5) connecting bracing was displacement 7.03 cm and building (6) connecting beams and bracing was displacement 7.04 cm. And show in figure. 7(a) illustrates displacement comparison between three buildings in zone3 without frame. Building (7) connecting beams between reinforced concrete coupled shear walls was displacement 23.29 cm, building (8) connecting bracing was displacement 13.97 cm and building (9) connecting beams and bracing was displacement 13.98 cm. And it show in figure. 7(b) illustrates displacement comparison between three buildings in zone3 with frame. Building (10) connecting beams between reinforced concrete coupled shear walls was displacement 17.50 cm, building (11) connecting bracing was displacement 10.55 cm and building (12) connecting beams and bracing was displacement 10.56 cm. So the connecting bracing is a better solution than connecting with beams only or beams and bracing in (H.R.B). And maximum displacement (H/1000) were studied by many researches [1, 2 and 3] whereas total height (H) of 180 meter. So maximum limit displacement (0.18) meter. So all buildings safe displacement without building 7 in zone 3 unsafe displacement. Therefore using of bracing instead of beams in reinforced concrete coupled shear walls, decreases the displacement in high rise buildings by about 40 % approximately.

Show in figure. 10(a) illustrates normal force for walls2 comparison between three buildings in zone2 without frame. Building (1) connecting beams between reinforced concrete coupled shear walls was normal force 18533.57 ton, building (2) connecting bracing was normal force 20021.73 ton and building (3) connecting beams and bracing was normal force 20057.70 ton. These increases in the normal force for walls by about 7 - 10 % approximately. Show in figure. 10(b) illustrates normal force for walls2 comparison between three buildings in zone2 with frame. Building (4) connecting beams between reinforced concrete coupled shear walls was normal force 18123.37 ton, building (5) connecting bracing was normal force 19263.71 ton and building (6) connecting beams and bracing was normal force 19297.89 ton. And show in figure. 11(a) illustrates normal force for walls2 comparison between three buildings in zone3 without frame. Building (7) connecting beams between reinforced concrete coupled shear walls was normal force 19555.72 ton, building (8) connecting bracing was normal force 21761.71 ton and building (9) connecting beams and bracing was normal force 21801.01 ton. And it show in figure. 11(b) illustrates normal force for walls2 comparison between three buildings in zone3 with frame. Building (10) connecting beams between reinforced concrete coupled shear walls was normal force 18893.36 ton, building (11) connecting bracing was normal force 20577.93 ton and building (12) connecting beams and bracing was normal force 20614.68 ton. These increases in the normal force for walls by about 7 - 10 % approximately. These increases from the bracing to convert lateral loads due to winds or earthquakes to vertical force by most percentage from horizontal force to another walls in (H.R.B).

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3.1 Columns

The same result approximately at using beam or bracing or beam and bracing between coupled shear walls for columns in normal force, shear force and moment without frame or with frame in zone 2 or zone 3.

3.2 Bracing

Design bracing however column tension or compression on status.

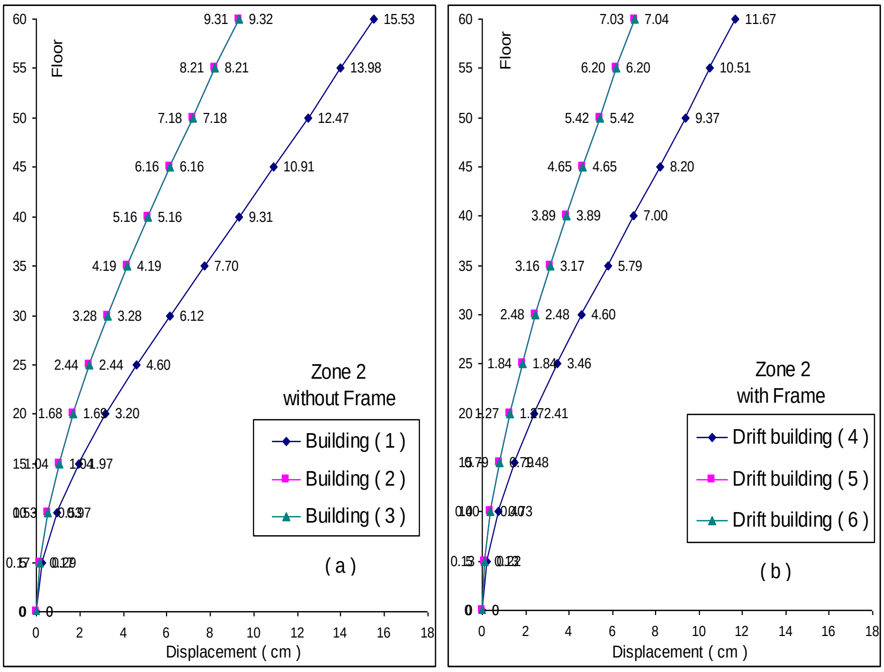

Fig. 6: Displacement comparison between buildings in zone 2.

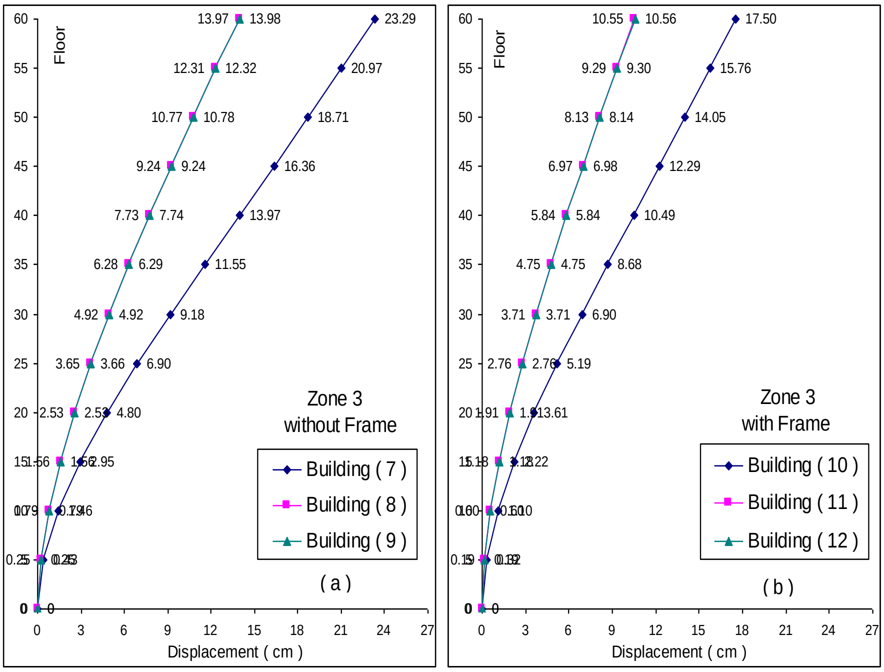

Fig. 7: Displacement comparison between buildings in zone 3.

4 SUMMARY AND CONCLUSIONS

The connecting bracing between reinforced concrete coupled shear walls is a better solution than connecting with beams only or beams and bracing in (H.R.B). The bracings in building with frame is a better than connecting with beams only or beams and bracing between coupled shear walls in (H.R.B). The braces convert lateral loads due to wind and earthquakes to vertical forces by most percentage from horizontal forces so it increases the normal force for walls by 7 % in (H.R.B). When displacement decreases the shear force and moment for columns and shear walls decreases. It decreases also possibility of failure to buildings and also risk of feeling fear to people.

We can summarize the important conclusions in this research as follows:

1. The (B.R.C.C.S.W) increase the safety and the stability of in high- rise buildings, specially against lateral loads. It also decreases the displacement by about 40 % approximately.

2. The (B.R.C.C.S.W) could increase durability of high- rise buildings against lateral loads, and

increases its height with the same displacement conditions.

3. The connection between walls in order to have (B.R.C.C.S.W) result in increasing the normal forces in walls by about 7 % approximately and decreasing the moment in walls by about 40 % approximately along the building height, there force this solution is considered as an economical solution.

4. Decrease cracks in first floors for columns and coupled shear walls in high rise buildings to against wind and earthquake loads.

5. All structural engineers are encouraged to used bracing between coupled shear walls in high rise buildings.

REFERENCES

1.ACI Code-318 " Building Code Requirements for Structure concrete (ACI 318-08) and Commentary (ACI 318R-08) " American Concrete Institute, 2008.

2.Fintel, M. " Handbook of Concrete Engineering " chapter 10, Multistory structures, second edition, 1985.

3. Coull, A., and Smith, B.S, " Tall Building structures: Analysis and Design ", 1991.

4. ECL (1993), The Egyptian Code for Calculation of Loads and Forces in Structural and Building Works, Cairo, Egypt.

5. Ahmed kamel, “Behavior of Braced Reinforced Concrete Coupled Shear Walls”, MSc. Thesis, Ain Shams University Faculty of Engineering, Cairo, Egypt.

6.Khan, Fazlur. " Computer Design of 100-Story Jone Hancock Center " Journal of the Structure Division, ASCE, Vol.92- Dec 1966, Page 55:75.

7.Heidehrecht A.C, " Analysis of Symmetric Coupled Shear Walls " Journal of the Structure Division, ASCE, No. STS. May 1971, pp. 1407-1422.

8.Girijavallabhan, C.V. " Analyzing of Shear Wall with Openings " Journal of the Structure Division, ASCE, October 1969, pp, 2093-2103.

9.Coull, Alexander. and Puri, Ravi D. " Analysis of pierced Shear Walls " Journal of the Structure Division, ASCE, Vol. 94, No. ST1, Jan 1968, pp. 71-82.