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Strengthening of Reinforced Concrete Building by Externally Bonded Carbon Fiber System

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Abstract- This paper deals with the strengthening of deteriorated reinforced concrete building by externally bonded carbon fiber composites. Four storied reinforced concrete residential building is selected for case study. It was constructed in 1992 and various deterioration symptoms are found. Static and dynamic analyses are performed by E-Tabs software using the various strength of members obtained from rebound hammer technique. The overstressed members are strengthened by externally bonded carbon fiber sheet. Experimental work for compression test on concrete cylinders externally bonded by carbon fiber sheets is performed. Compressive strength increment depends on the number of composite layers and percentage of wrap on concrete specimens. The required areas and thickness of carbon fiber wrapped sheet for the members are calculated by using Sika Carbodur FRP analysis software. For flexural strengthening, the maximum area required is 92 mm^2, for shear strengthening and confinement the maximum thickness of FRP required are 0.35 mm and 0.18 mm respectively.

Index Terms- strengthening, carbon fiber wrapped sheet, E-Tabs software, experimental works, Sika Carbodur FRP analysis software.

I. INTRODUCTION

Reinforced concrete is one of the most common materials used by the construction industry all over the world. It is used for the construction of transportation infrastructure, offshore platforms, dams and a wide range of public and private buildings. Owing to the wide variety applications, reinforced concrete structures are subjected to a range of exposure conditions, including marine, industrial or other severe environments. Due to increasing the ingress of aggressive agents into the reinforced concrete structures the microstructure and consequently the properties change with time. Due to the increasing decay of infrastructure and buildings, upgrading and strengthening of those structures is important. Various methods and different materials are available for repair and upgrading of concrete structures. In recent years, the use of externally applied fiber-reinforced polymers (FRP) has gained significant popularity for strengthening and repair of concrete structures. The FRP composites have been used successfully for rehabilitation and upgrading of deficient reinforced-concrete (RC) structures such as buildings, bridges, parking garages, chimneys, etc.

II. STRUCTURAL CONFIGURATION

The case study building is four storied reinforced concrete residential building located in Chan Aye Tharzan Township, Mandalay It was constructed in 1992 and various deterioration symptoms are found. The total length is 36 m and the width is 10.36 m. The total height is 15.84 m. The bottom storey height is 2.74 m and typical storey height is 2.59 m. Typical floor plan for the building is shown in Fig.1.

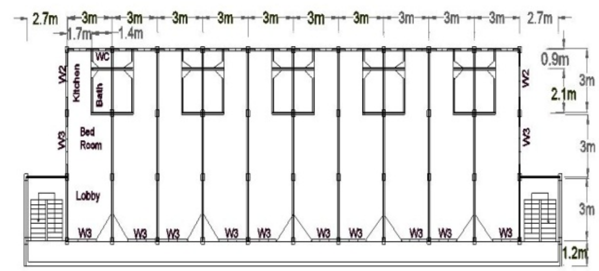

Figure 1.Typical floor plan for the case study building

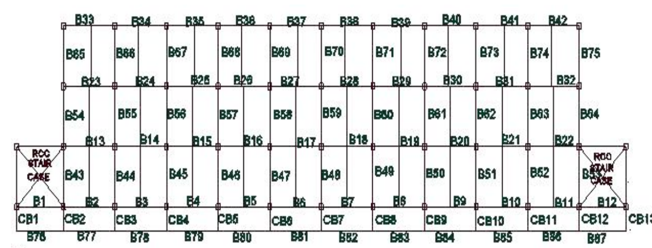

Figure 2. Beam layout plan for the case study building

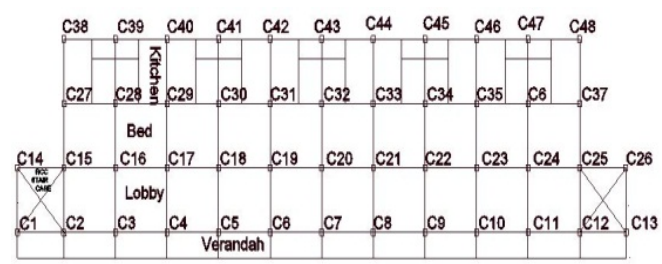

Figure 3. Column layout plan for the case study building

The beam sizes are 0.23 m x 0.3 m for main beams, 0.23 m x 0.23 m for secondary beams and 0.152 m x0.23 m for cantilever beams. The column sizes are 0.23 m x 0.3 m from first floor to roof level. Beam layout plan and column layout plan for the case study building are shown in Fig. 2 and Fig. 3.

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III. DATA PREPARATION FOR ANALYSIS

A. Material properties

Material properties for structural data are as follows:

Compressive strength of concrete f'c = 17MPa
Yield strength of reinforcing steel = 276 MPa
Modulus of elasticity of steel = 2 x10^6 MPa

B. Loading Consideration

The applied loads are gravity loads, including dead loads and,(17) live loads, and lateral loads that include earthquake load and wind load.

C. Dead Load

Data for dead load are as follows:

Unit weight of concrete = 23.55 kN/m^3 (150 pcf)
229mm (9 in) thick brick wall = 4.78 kN/m^2 (100 psf)
115mm (41/2 in)) thick brick wall = 2.39 kN/m^2 (50 psf)
Weight of finishing = 0.96 kN/m^2 (20 psf)

D. Live Load

Data for live load are :

Live load on residential area = 1.92 kN/m^2 (40psf)
Live load on walkway = 1.92 kN/m^2 (40psf)
Live load on stair = 2.87 kN/m^2 (60psf)
Live load on roof = 0.96 kN/m^2 (20psf)

E. Wind Load

Required data for wind load are:

Exposure Type = Type B
Basic wind speed = 128.7 km/h (80mph)
Important factor = 1
Windward coefficient = 0.85
Leeward coefficient = 0.5
Effective wind exposure height =12.8m

F. Earthquake Load

The required data for earthquake loading are as follows:

Seismic zone = 4
Seismic source type = A
Soil Type = SD
Seismic response coefficient (Ca) = 0.44Na
Seismic response coefficient (Cv) = 0.64Nv
Near Source factor Na = 1
Near Source factor Nv = 1
Response modification factor = 8.5

G. Load Combination

Design Load combination s are as follows :

(1) 1.4(DL+SD)
(2) 1.4(DL+SD)+1.7LL
(3) 1.05(DL+SD)+1.27LL+1.275WXP
(4) 1.05(DL+SD)+1.27LL+1.275WXP
(5) 1.05(DL+SD)+1.275LL+1.275WYP
(6) 1.05(DL+SD)+1.27LL+1.275WYP
(7) 0.9 (DL+SD)+1.3WXP
(8) 0.9 (DL+SD)+1.3WXN
(9) 0.9 (DL+SD)+1.3WYP
(10) 0.9 (DL+SD)+1.3WYN
(11) 1.05(DL+SD)+1.28LL+EX
(12) 1.05(DL+SD)+1.28LL-EX
(13) 1.05(DL+SD)+1.28LL+EY
(14) 1.05(DL+SD)+1.28LL-EY
(15) 0.9 (DL+SD)+1.02EX
(16) 0.9 (DL+SD)-1.02EX
(17) 0.9 (DL+SD)+1.02EY
(18) 0.9 (DL+SD)-1.02EY
(19) (19) 16 DL+1.28LL + EX
(20) 1.16 DL+1.28LL - EX
(21) 1.16 DL+1.28LL + EY
(22) 1.16 DL+1.28LL - EY
(23) 0.9 DL+ 1.02EX
(24) 0.9 DL- 1.02EX
(25) 0.9 DL+ 1.02EX
(26) 0.9 DL- 1.02EX

H. Modelling of the Case Study Building

Three dimensional view (3D) of the proposed building is shown in Fig .4.

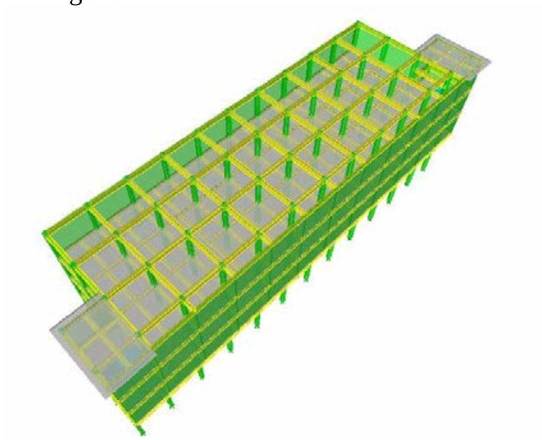

Figure 4. 3D View of the proposed building

IV. STATIC AND DYNAMIC ANALYSIS FOR CASE STUDY BUILDING

For the case study building, since deterioration symptoms such as cracking and spalling are observed, it is required to know the condition of concrete. So rebound hammer technique has been used to know the in-situ compressive strength of concrete. The in-situ compressive strengths of floor beams and first floor columns obtained from rebound hammer technique are shown in Fig.5 to Fig.9.

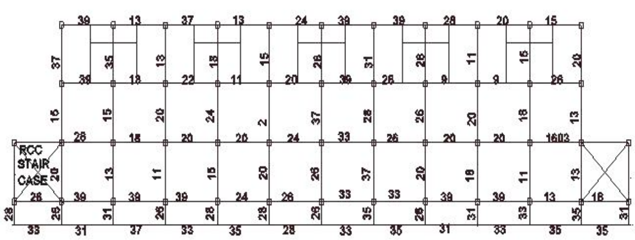

Figure 5. Compressive strength (MPa) of first floor beams

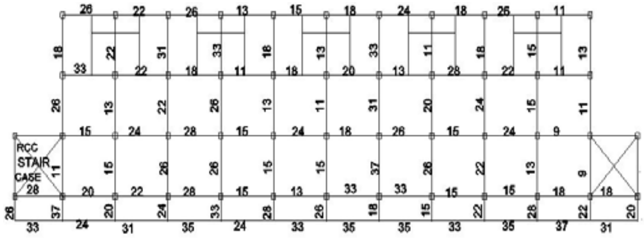

Figure 6. Compressive strength (MPa) of second floor beams

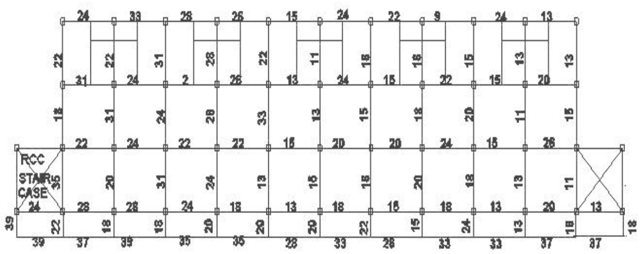

Figure 7. Compressive strength (MPa) of third floor beams

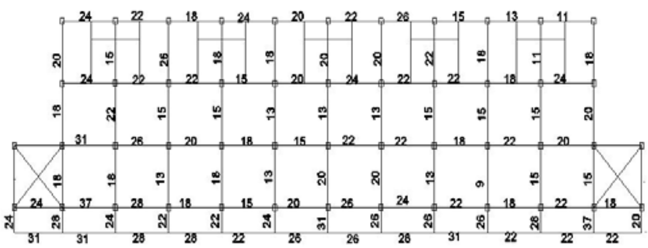

Figure 8. Compressive strength (MPa) of roof beams

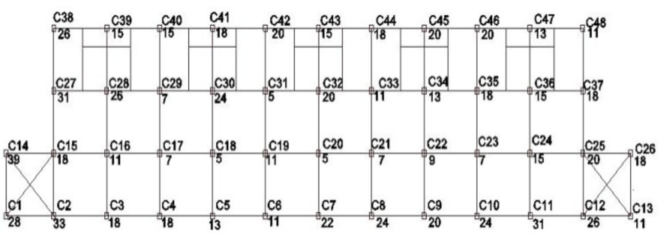

Figure 9. Compressive strength (MPa) of first floor columns

Static and dynamic analyses are performed using these various compressive strengths of the building to check the member sizes and structural capacity. The design strength of the case study building is 17 Mpa. The minimum and the maximum steel ratios are 0.005 and 0.0232. For all cantilever beams (0.152 m x 0.23 m), the minimum and maximum steel areas are 145 mm^2 and 674 mm^2. For main beams (0.23 m x 0.3 m) the minimum and maximum steel areas are 276 mm^2 and 1280 mm^2.The provided steel area is 258 mm^2at top and bottom for cantilever beams and 604 mm^2 for main beams. According to static and dynamic analysis results, all the cantilever beams CB1 to CB13 and the main beams B23 to B32 in all storey levels require to be strengthened. The compressive strength of columns less than 20MPa in the first floor are also necessary to be increased to satisfy the dynamic analysis. Table.1 shows the members require to be strengthened from first floor to roof levels from static and dynamic analysis results.

Table 1. Floor Beams and Columns Required to be Strengthened

Floor	Beam	Strength Obtained (MPa)	Size (m x m)
1^{st} F	CB1,CB5,CB6 CB2,CB4,CB7, CB9	< 30	0.152x0.23 0.152x0.23
	CB3,CB10, CB13,CB11, CB18	< 35	0.152x0.23
	CB8,CB12	< 40	0.152x0.23
	B23,B28	< 40	0.152x0.23
	B24,B26,B30, B31	< 17	0.23x0.3
	B25,B27	< 25	0.23x0.3
	B29,B32	< 30	0.23 x 0.3
	C5,C6,C13,C16, C19,C33,C34	12 < 17	0.23 x 0.3
	C17,C18,C20, C21,C22,C23 C29,C31	9 < 17	0.23 x 0.3
	C25,C32	20	0.23 x 0.3
	C36	16 < 17	0.23 x 0.3
	C15,C26	18	0.23 x 0.3
2^{nd} F	CB1,CB7, CB6,CB11	< 30	0.152x0.23
	CB2	< 40	0.152x0.23
	CB3,CB13, CB4, CB10,CB12	< 25	0.152x0.23
	CB5	< 35	0.152x0.23
	CB8,CB9	< 20	0.152x0.23
	B23	< 35	0.23x0.3
	B24,B31	< 25	0.23x0.3
	B25,B27,B28	< 20	0.23x0.3
	B26,B29,B32	< 17	0.23x0.3
3^{rd} F	CB1	< 40	0.152x0.23
	CB2,CB10	< 25	0.152x0.23
	CB3,CB4,CB5, CB6,CB7,CB9, CB12,CB13	< 20	0.152x0.23
	CB10	< 25	0.152x0.23
	CB11	< 17	0.152x0.23
	B23	< 35	0.23x0.3
	B24,B28,B30	< 25	0.23x0.3
	B25,B26	< 30	0.23x0.3
	B27,B29,B31	< 17	0.23x0.3
	B32	< 20	0.23x0.3
Roof	CB2,	< 30	0.152x0.23
	CB12	< 40	0.152x0.23

V. EXPERIMENTAL WORK FOR FRP CONFINED CONCRETE CYLINDERS

Axial compression test for concrete cylinders bonded by carbon fiber composite is performed to investigate the strength results. Concrete specimens for selected three concrete mixtures 6 MPa, 10 MPa and 15 MPa are prepared using 150 mm x 300 mm cylindrical molds. The design slump of the concrete is between 75 to 100 mm. The carbon fiber sheets used in this study are the UT 70-30 G product, a unidirectional wrap made in Japan. The manufacturer's guaranteed tensile strength for this carbon fiber is 3.4 kN/mm^2, with a tensile modulus of 245 kN/mm^2, and a sheet thickness of 0.167 mm. The resin system used to bond the carbon fabrics over the cylinders in this work is Sikadur-330, the epoxy resin made of two-parts, resin and hardener. The mixing ratio of the two components was 4:1. The properties of the resin are given in Table 2.

Table 2. Properties of the Resin Sikadur-330

Properties	Values
Density about	1.3 at 20℃
Ultimate elongation	0.9% after 7 days at 23℃
Tensile strength	30MPa after 7 days at 23℃
Tensile modulus	4500MPa after 7 days at 23℃
Flexural modulus	3800MPa after 7 days at 23℃
Temperature resistance	Exposure condition until 50℃

After 28 days of curing concrete cylinders, FRP jackets are applied to the specimens by hand lay-up of CFRP wraps with an epoxy resin. The components are thoroughly mixed with a mixing spindle for at least 3min. The concrete cylinders are cleaned and completely dried before the resin is applied. The mixed Sikadur-330 epoxy resin is directly applied to the substrate. The fabric is carefully placed into the resin with gloved hands and any irregularities or air pockets are smoothed out using a plastic laminate roller. The roller is continuously used until the resin is reflected on the surface of the fabric, an indication of full wetting. After the application of the first wrap of the CFRP, a second layer of resin is applied to the surface of the first layer to allow the impregnation of the second layer of the CFRP. Before testing the wrapped cylinder specimens are stored at room temperature for one day. Specimens are loaded under a monotonic uniaxial compression load upto failure. The applied compressive load is 0.3 MPa/s and is recorded automatically. The compressive strength results of 6 MPa and 10 MPa, fully jacketed with carbon fiber sheet throughout the height of the specimens are listed in Table 3.

For concrete cylinders 6 MPa, confined with CFRP composite, the one-layer specimen exhibits an increase in 289% and the two-layer specimen exhibits an increase in 478% of strength.

Table 3. Compressive Strength Results for 6MPa and 10MPa

Mix (MPa)	No of Specimens	Unconfined Strength	Strength (1Layer) (Full)	Strength (2Layer) (Full)
6	9	9MPa	35MPa	52MPa
10	9	11.3MPa	37MPa	74MPa

For concrete mixture 10 MPa, the one- layer specimen exhibits an increase in 236%. The two-layer specimen exhibits an increase in 555% in strength greater than the one-layer specimen. For concrete mixture15 MPa, only 75% (100 mm at the middle) and 33% (50 mm at the middle) of the height of the specimens are jacketed by carbon fiber sheet. The failure patterns of confined concrete cylinders are shown in Fig.10. Fully confined concrete cylinders fail by rupturing of only the center part of the carbon fiber sheet by giving a snapping song in an explosive manner. For 75% and 33%, the cylinder fails starting from the cracking of unconfined concrete at the top or bottom part of the cylinders.

Figure 10. Failure patterns of FRP confined concrete

Table 4. Compressive Strength Results for 15MPa

Mix (MPa)	No of Specimens	Unconfined Strength	Strength (1Layer)	Strength (2Layer)
15 (75%)	9	13MPa	40MPa	45MPa
15 (33%)	9	13MPa	19MPa	25MPa

The compressive strengths for 15MPa obtained from compression test are shown in Table 4. For 75% wrapping, the one layer specimen shows an increase in 208% of compressive strength while for the two- layer specimens, the increment of strength is 246%. For 33% wrapping, strength increments are much lower than that of 75% wrapping. The one-layer specimen exhibits an increase in 46% while for the two-layer specimen, there is an increment of 92% in compressive strength. Overall, it can be seen that carbon fiber composite can be used to enhance the ultimate strength.

VI. FRP REQUIREMENT FOR THE CASE STUDY BUILDING

In this case, the members require to be strengthened are externally bonded with fiber reinforced polymer (FRP) composites because this method is suitable for the existing building. Flexure strengthening of concrete beams is accomplished by epoxy bonding the FRP sheet to the tension face; for shear strengthening, the FRP wrapped sheets are bonded to the beam web. The required FRP dimensions (area/thickness) for the members of case study building are calculated by using Sika Carbodur FRP analysis software. For flexural strengthening FRP dimensions are given as area (mm^2) and for shear strengthening and confinement, thickness (mm) of FRP are given by software as in Table 5. For flexural strengthening, 100 mm wide FRP strips are applied to the bottom of the beams and for shear strengthening, U-shape wrapping of 300 mm wide strips are used. For confinement of columns, 300 mm wide strips are applied around the columns.

Table 5. Required FRP for Strengthened Beams and Columns

Floor	Beam	Static		Dynamic	
		Flexure (mm2)	Shear (mm)	Flexure (mm2)	Shear (mm)
1^{st}F	CB2, CB12 CB9, CB4,CB7,	66.8	0.26	66.8	0.32
	CB3,CB5,CB6, CB8,CB10,CB11	83.5	0.26	83.5	0.26
	CB1 ,CB13	-	0.09	-	0.09
	B23,B28 B29,B32	-	0.32	-	0.32
	B24,B25,B26, B27,B30,B31	-	0.42	-	0.42
	C5,C6,C13,C16, C19,C33,C34				0.12
	C17,C18,C20, C21,C22,C23 C29,C31				0.18
	C15,C26,C36				0.07
	C25,C32				0.04
2^{nd}F	CB2,CB6, CB12 CB9	66.8	0.33 0.35	66.8	0.33 0.35
	CB3,CB4,CB5, CB7, CB10 , CB8	83.5	0.33 0.35	83.5	0.33 0.35
	CB11	85	0.33	66.8	0.33
	CB1,CB13	-	0.1	-	0.1
	B25,B26,B27, B29,B32		0.39		0.39
	B23,B24,B28, B30,B31		0.33		0.33
3^{rd}F	CB1,CB13		0.03		0.03
	CB2,CB11, CB9, CB12	66.8	0.13	66.8	0.13
	CB3,CB4,CB5, CB6,CB7,CB8	83.5	0.13	83.5	0.13
	CB10	92	0.11	92	0.13
	B23-B26 B28-B32		0.33		0.33
	B27		0.38		0.38
Roof	CB2,CB12	7.56	0.24	7.56	0.24

VII. CONCLUSIONS

This paper deals with strengthening of deteriorated reinforced concrete building by externally bonded carbon fiber composites. Static and dynamic analyses are performed using E-Tabs software to check the adequacy of member sections. The overstressed members are strengthened by externally bonded FRP wrapped sheet. According to experimental work for concrete cylinders bonded by carbon fiber sheet UT 70-30 G product, the use of carbon fiber sheet can enhance the strength of the concrete. The required FRP for flexural, shear strengthening and confinement are calculated by using Sika Carbodur FRP analysis software. For flexural strengthening, the maximum area required is 92 mm^2 and for shear strengthening, the maximum thickness of FRP required is 0.38 mm and for confinement of columns, the maximum thickness required is 0.18 mm respectively.

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