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Performance Evaluation of a Beam-Column Joint Strengthened Using Various Materials

Kharva Hardik. J.[1] Dhayani Dhruti. J.[2]

[1]*Civil-Structure, Sardar Vallabhbhai Patel Institute of Technology, Vasad.*

[2]*Civil-Structure, Sardar Vallabhbhai Patel Institute of Technology, Vasad.*

Abstract* — Recently, the utilization of FRP composites is one of the advanced procedures for repairing, strengthening or retrofitting the existing structures in order to resist the higher loads and to rectify the issues of the damage. This paper displays the results of experimental investigation of use of Uni- directional Carbon Fiber Reinforced Polymer (CFRP) and Chopped Strand Mat (CSM) to strengthen the beam-column joints, which are the critical regions of the structures. Twelve interior beam-column joints were casted for this study and were named as virgin specimen. These specimens were tested up to failure point. Three specimens were externally wrapped with CFRP and three were wrapped with CSM. Hybrid wrapping was adopted for the remaining six joints. Two types of hybrid wrapping configuration is used i.e. CFRP on CSM and CSM on CFRP. These rehabilitated specimens were again tested up to failure. This study is just limited to static loading. Effect of the different wrapping techniques has been concentrated on. The performance of the rehabilitated specimens is compared with that of virgin specimens. Results demonstrate that both the material used in the investigation study increases the load carrying capacity of the joints and decreases the deflection.

***Keywords* – Fiber Reinforced Polymers, Beam-Column Joint, Rehabilitation, Flexural Strength, Deflection, Concrete.**

I. INTRODUCTION

Sometimes structures require to be strengthened or retrofitted to resist higher design loads. Strengthening may also be required due to a change of use or when the structures are damaged due to an aggressive environment. In these cases, the most widely recognized retrofitting procedure has been refined by the utilization of ordinary materials, for example, steel plates externally bonded or steel and concrete jackets. However, recently the use of innovative materials like fiber reinforced polymer (FRP) has risen as another option to the utilization of the customary procedures and it is by all accounts the most encouraging technique to be utilized in structural engineering. The FRP is portrayed by high quality strands installed in polymer resin; they demonstrate a straight stress–strain relationship until breakdown. The most well-known sort of FRP in industry is made with carbon, aramid or glass filaments. Since FRP represent the main load carrying element and have an extensive variety of firmness and qualities they are generally utilized reinforcement of the structures even under various forms as: strips, rods, and sheets. One of the strategies of reinforcing the RC structural members is through external confinement by high strength fiber composites which can essentially upgrade the quality, strength, ductility and will result in large energy absorption capacity of structural members. Fiber materials are used to strengthen a variety of reinforced concrete elements to improve the flexural, shear and axial load carrying capacity of elements. Beam-column joints, being the lateral and vertical load resisting members in reinforced concrete structures are particularly vulnerable to failures during earthquakes and subsequently their strengthening is often the key to successful seismic strengthening technique. Survey of existing constructions uncovers that strengthening of structures is vital in some conditions. The structure is inadequately designed for the present load conditions. The inadequately detailed for the present loading. This additionally incorporates those structures that are discovered insufficient under seismic conditions. The structure is damaged and requires strengthening. The motivation behind this program is to examine the performance of fiber reinforced polymer composites (FRPC) in strengthening of damaged joints. In this study an experimental investigation was conducted to study the effectiveness of wrapping with CFRP, CSM, and Hybrid FRP for both materials. Ramakrishna et. al (2012) proposes a strengthening scheme for damaged reinforced concrete interior beam - column joints under the static loading. The rehabilitated specimens are improved its load carrying capacity, stiffer than the virgin specimen and the crack widths in the rehabilitated specimens are relatively less. Attari et. al (2010) examines the effects of an external strengthening of reinforced concrete beam–column joints against cyclic loading using CFRP laminates and GFRP sheet. It was observed that the combination of CFRP laminates and GFRP sheet improves the shear resistance and the ductility of the RC joints to a great extent.

The objectives of the present study is to examine the effectiveness of wrapping of FRP material on internal beam column joints. Flexural strength of the internal joints enforced by FRP is also studied. Ultimate load carrying capacity of internal joint enforced by FRP was also found and concentrated on.

II. MATERIAL PROPERTIES

Table 1. Material properties GFRP/CSM

Properties	GFRP	Chopped Strand Mat
Thickness (mm)	2.8	0.5
Weight (gm/sq.m)	410	300
Tensile Strength (MPa)	3555	108
Flexural Strength (MPa)	423	204

III. EXPERIMENTAL WORK

3.1. Specimen Details

The experimental program consists of the testing reinforced concrete interior beam-column joint specimens. The columns had a cross section of 150 mm x 150 mm with an overall length of 750 mm and the beams had a cross section of 150 mm x 150 mm with an overall length of 750 mm. There is a cantilever length of 300 mm on either side of the column. The beam and column are reinforced with 4 numbers of 8mm diameter tor steel bars. The lateral ties in the columns of the specimens are 6 mm diameter bars with the spacing of 150 mm c/c. Beams had double legged stirrups of 6 mm diameter mild steel bar at 150 mm c/c. They were designed such that failure would be due to flexural in the joint during the test, so as to evaluate the contribution of CSM and CFRP to the flexural capacity of joint.

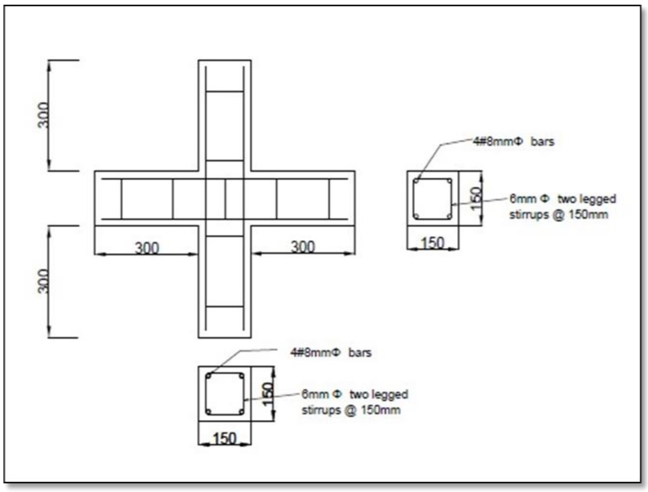

Figure 1. Reinforcement detail for the test specimen

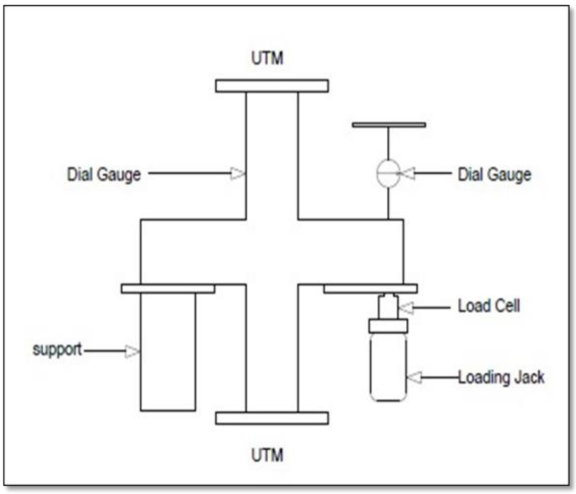

Figure 2. Schematic Diagram

All the twelve reinforced concrete beam-column joint (virgin) specimens casted and cured for one month. The experimental programme consist of rehabilitation using Chopped Strand Mat (CSM), carbon fibre reinforced polymer (CFRP) and hybrid wrapping using both the fibres. Out of these twelve virgin specimens, three Chopped Strand Mat specimens were named as CSM1, CSM2 & CSM3 and other three Carbon Fibre Specimen were named as CFRP1, CFRP2 & CFRP3 before conducting test. Hybrid wrapping specimen were named as CSM on CFRP (1), (2) and (3) and CFRP on CSM (1), (2) and (3).

3.2. Procedure of Wrapping

- Crushing the surface from joint to 150 mm and to get an even surface. All projections are grounded off.
- Apply GP resin & cobalt (hardener) to be readied solid surface area using brush. Work site must be completely ventilated amid the utilization of chemicals.
- The fiber sheet must be cut before use of GP resin & hardener into recommended sizes utilizing scissors or cutters.
- On the epoxy fix the measured CSM/CFRP sheets and roll in the beam longitudinal course.

Two wrapping configurations are used in the study. First being the single fibre material wrapping on the specimen and second being the hybrid wrapping of the two fibre material on the beam-column joint specimen. For single fibre wrapping configuration, the fibre was wrapped in 'L' shape as shown in the Figure 3. The dimension of one lef of 'L' shape was 150mm x 150mm. For hybrid wrapping configuration, one fibre was used in 'L' shape as used in the single wrapping configuration and the other fibre was wrapped as a single strip in the centre as shown in Figure 4 of dimension 75mm x 300 mm.

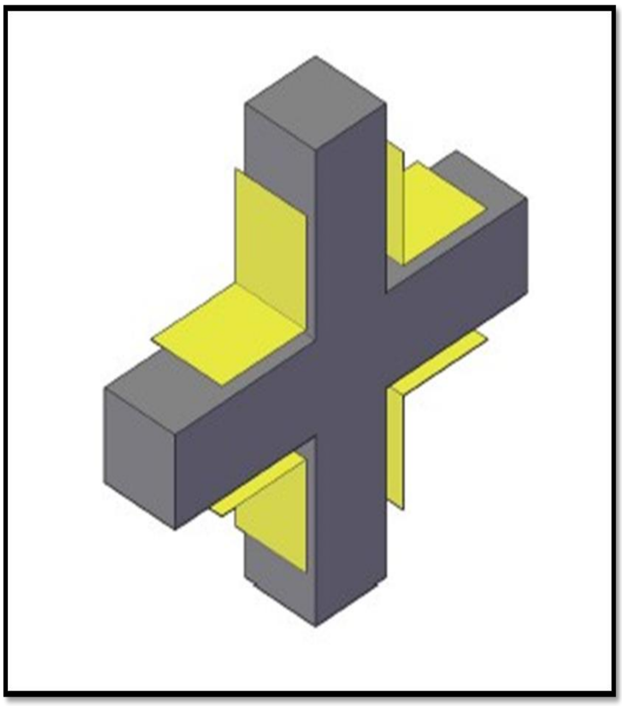

Figure 3. Wrapping of Single Strengthening material

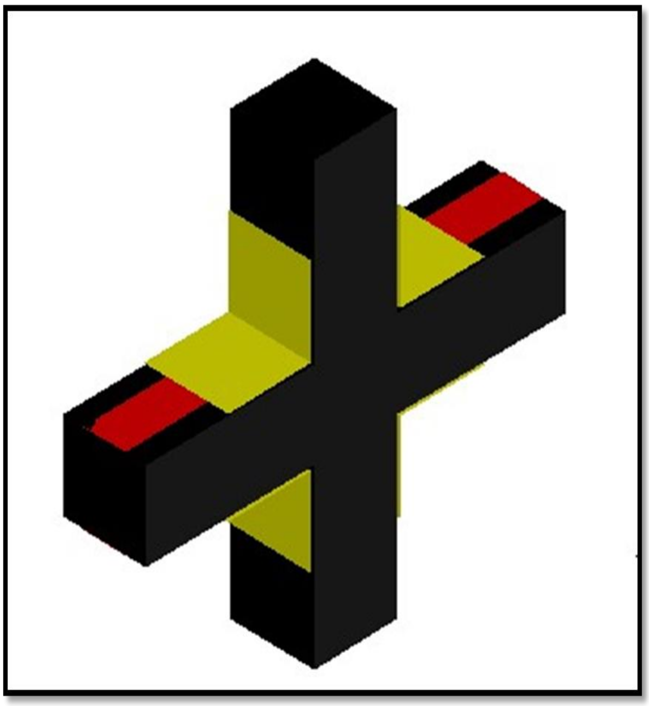

Figure 4. Hybrid Wrapping of Strengthening material

Figure 5. Wrapping of CFRP

Figure 6. Hybrid Wrapping of CSM on CFRP

3.3. Test Setup

The specimens is fixed on universal testing machine such that the both ends of column are fixed by UTM. Loading is applied with the help of loading jack to damage the specimen and detailed assessment of the damaged specimen is done and the damaged zones are identified. Each damaged specimen is wrapped with different strengthening materials and allowed to set. Further the damaged specimen is wrapped in hybrid pattern i.e. two strengthening materials are used simultaneously as shown in figure. Finally again the loading will be applied with the help of loading jack and Universal Testing Machine (UTM) as shown in figure to the Strengthened specimen and the results are evaluated.

Figure 7. Test arrangement for Virgin Specimen

Figure 8. Test arrangement for Rehabilitated Specimen

IV. TEST RESULTS AND GRAPHS

The loads and the corresponding deflections on virgin and rehabilitated specimens were plotted on graphs. These results were obtained by conducting load test on virgin specimens and rehabilitated specimens. The graphs are plotted based on loads and deflections of both the specimens.

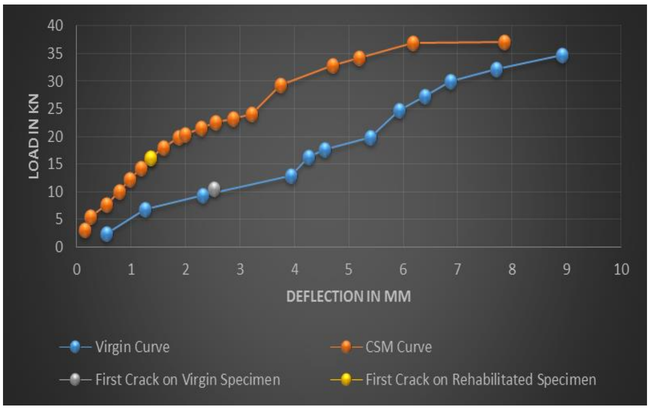

Figure 9. Load vs Deflection Curve for CSM1

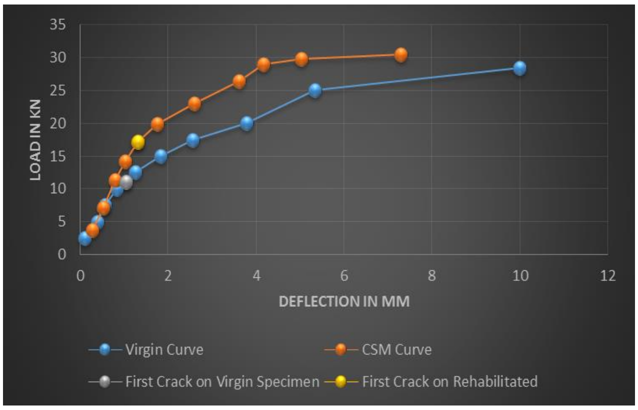

Figure 10. Load vs Deflection Curve for CSM2

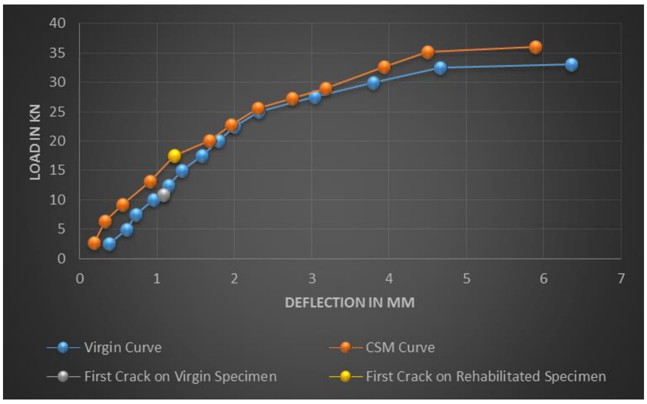

Figure 11. Load vs Deflection Curve for CSM3

Table 2. Results of Strength for wrapping configuration of CSM

SAMPLE NO	LOAD AT FIRST CRACK (KN)		% OF INCREASE IN STRENGTH	AVERAGE INCREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CSM		
CSM1	10.55	16.06	52.23	56.22
CSM2	11.06	17.22	55.7	
CSM3	10.88	17.49	60.75	

Table 3. Results of Deflection for wrapping configuration of CSM

SAMPLE NO	ULTIMATE DEFLECTION (mm)		% DECREASE IN DEFLECTION	AVERAGE DECREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CSM		
CSM1	8.92	7.85	11.99	15.42
CSM2	9.99	7.3	26.9	
CSM3	6.36	5.89	7.39	

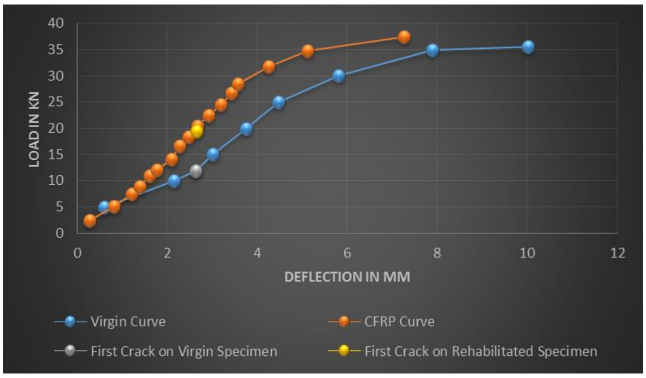

Figure 12. Load vs Deflection Curve for CFRP1

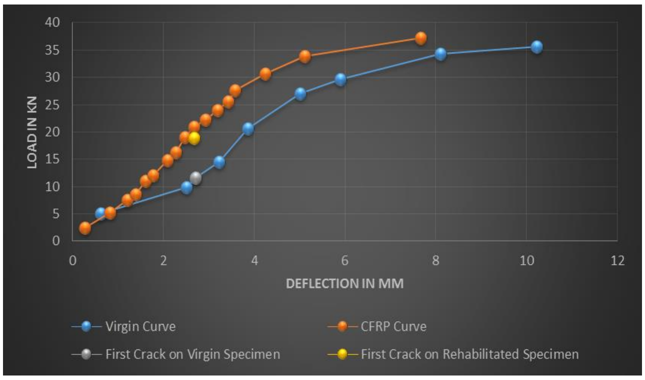

Figure 13. Load vs Deflection Curve for CFRP2

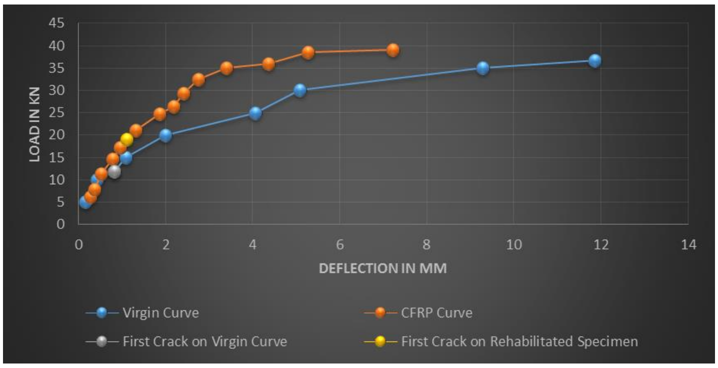

Figure 14. Load vs Deflection Curve for CFRP3

Table 4. Results of Strength for wrapping configuration of CFRP

SAMPLE NO	LOAD AT FIRST CRACK (KN)		% OF INCREASE IN STRENGTH	AVERAGE INCREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CFRP		
CFRP1	11.82	19.5	64.97	63.02
CFRP2	11.58	18.92	63.39	
CFRP3	11.91	19.14	60.71	

Table 5. Results of Deflection for wrapping configuration of CFRP

SAMPLE NO	ULTIMATE DEFLECTION (mm)		% DECREASE IN DEFLECTION	AVERAGE DECREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CFRP		
CFRP1	10.02	7.26	27.54	30.53
CFRP2	10.22	7.66	25.04	
CFRP3	11.86	7.23	39.03	

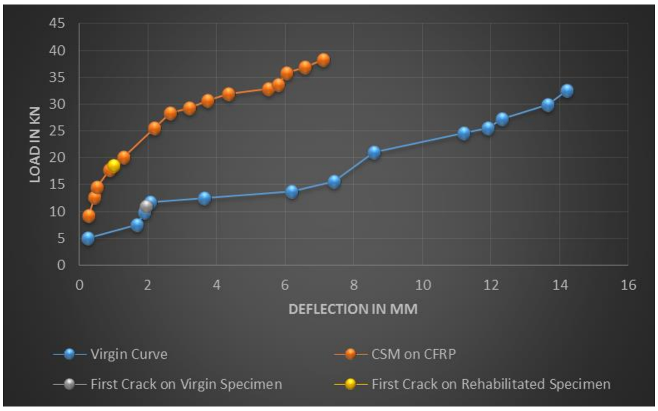

Figure 15. Load-Deflection Curve for CSM on CFRP(1)

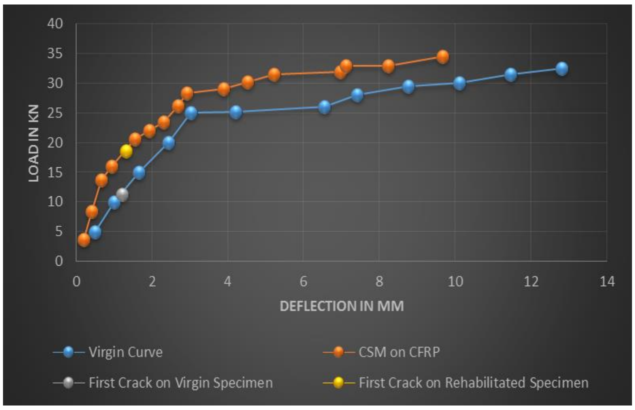

Figure 16. Load- Deflection Curve for CSM on CFRP(2)

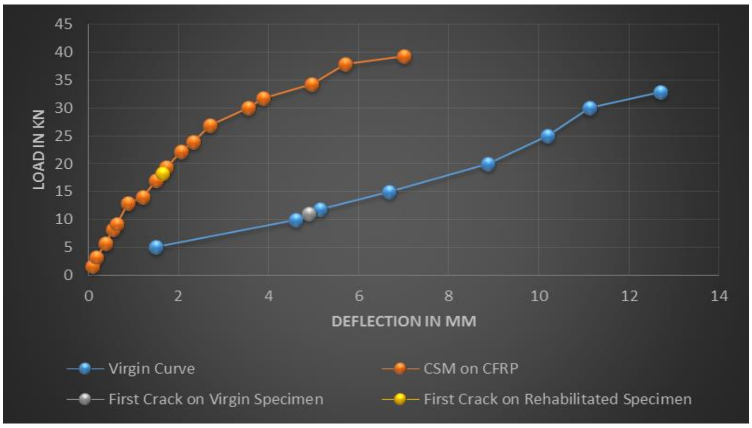

Figure 17. Load- Deflection Curve for CSM on CFRP(3)

Table 6. Results of Strength for wrapping configuration of CSM on CFRP

SAMPLE NO	LOAD AT FIRST CRACK (kN)		% OF INCREASE IN STRENGTH	AVERAGE INCREASE(%)
	VIRGIN SPECIMEN	SPECIMEN WITH CSM ON CFRP		
CSM ON CFRP(1)	10.91	18.54	69.94	67.15
CSM ON CFRP(2)	11.21	18.65	66.37	
CSM ON CFRP(3)	11.02	18.32	66.24	

Table 7. Results of Deflection for wrapping configuration of CSM on CFRP

SAMPLE NO	ULTIMATE DEFLECTION (mm)		% OF INCREASE IN STRENGTH	AVERAGE DECREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CSM ON CFRP		
CSM ON CFRP(1)	14.22	7.11	50	39.76
CSM ON CFRP(2)	12.82	9.68	24.49	
CSM ON CFRP(3)	12.70	7.01	44.80	

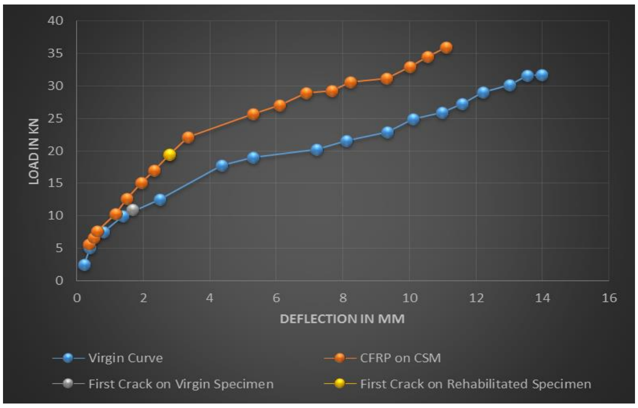

Figure 18. Load-Deflection Curve for CFRP on CSM(1)

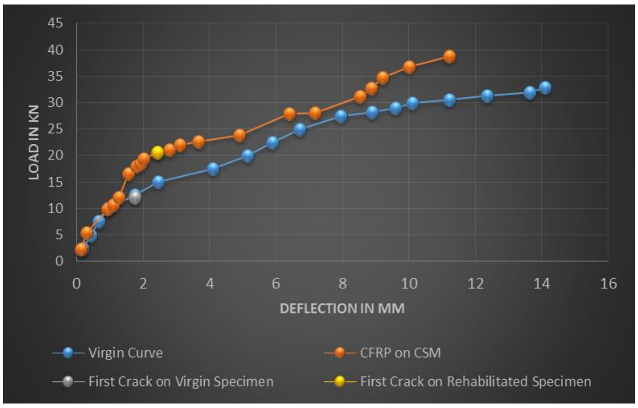

Figure 19. Load- Deflection Curve for CFRP on CSM(2)

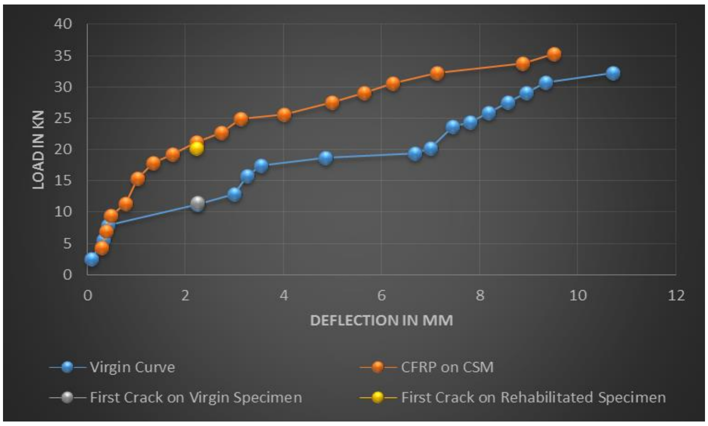

Figure 20. Load- Deflection Curve for CFRP on CSM(3)

Table 8. Results of Strength for wrapping configuration of CFRP on CSM

SAMPLE NO	LOAD AT FIRST CRACK (kN)		% OF INCREASE IN STRENGTH	AVERAGE INCREASE(%)
	VIRGIN SPECIMEN	SPECIMEN WITH CFRP ON CSM		
CFRP ON CSM(1)	11`	19.49	77.18	74.12
CFRP ON CSM(2)	12.12	20.61	70.05	
CFRP ON CSM(3)	11.55	20.23	75.15	

Table 9. Results of Deflection for wrapping configuration of CFRP on CSM

SAMPLE NO	ULTIMATE DEFLECTION (mm)		% OF INCREASE IN STRENGTH	AVERAGE DECREASE (%)
	VIRGIN SPECIMEN	SPECIMEN WITH CFRP ON CSM		
CFRP ON CSM(1)	13.98	11.11	20.53	17.38
CFRP ON CSM(2)	14.1	11.22	20.42	
CFRP ON CSM(3)	10.72	9.52	11.19	

V. CONCLUSIONS

Based on the experimental investigations carried out on the virgin and rehabilitated beam-column joint specimens using CFRP and CSM wrapping, the following conclusions were drawn.

1. The rehabilitation technique using wrapping system for the damaged R.C.C interior beam – column joints have proved to be effective. The ultimate load carrying capacity of the restored joint was improved with decrease in deflections.
2. Both CFRP and CSM can be efficiently used for rehabilitation of reinforced concrete joints. Tests on rehabilitated specimens suggest that both the FRP materials restores its original strength.
3. Comparing the results of the above study it is seen that CFRP proves to be effective in strengthening the specimen when used individually by increasing the strength up-to 63.02 % as compared to that of CSM which is 56.22 %
4. Further it is also seen that the combined use of both the materials (i.e. hybrid wrapping) in a proper configuration proves to be much more effective in strengthening the specimen as compared to the strength obtained by using each material individually.
5. The study shows that if in hybrid wrapping CFRP is applied over CSM then the results are far more effective than the wrapping of CSM applied over CFRP. Applying CFRP over CSM increases the strength by about 74.12 % while in vice-versa the average increase in strength is about 67.15%
6. Also CSM being much cheaper than CFRP the hybrid wrapping of CFRP above CSM can be considered as a most viable solution in terms of increase in strength and economy.

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