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Comparative Study on Post Tensioned PSC T-Beam Strengthened By BFRP and GFRP under Flexure

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Abstract:
Pre-stressing technique has gaining an enormous application in the field of infrastructure. These structures are always susceptible to loss of pre-stress due to increase in moving load, constructional error or ageing strength deterioration. Therefore strengthening is necessary to accommodate higher load carrying capacity and better stiffness configuration. In this paper the experimental study has been made on the PSC T-beams strengthened with BFRP and GFRP fabrics. The experimental program comprises of testing eight T-beams. Of eight, six were post-tensioned by applying pre-determined pre-stressing force. One set of PSC beams were left unstrengthen and labelled as 'control PSC beams'. One set of strengthened beams, grouped as 'Group A' were strengthened with BFRP fabrics with single and double layer. Another set of strengthened beam, grouped as 'Group B' were strengthened with single and double layer of GFRP fabrics. Two RC beams were kept as 'control beam' and results have been compared with the strengthened specimen. These specimens were tested under two point loading. With different layer of BFRP and GFRP wrapping, parameters like deflection, ultimate load carrying capacity and crack pattern were studied. From the results of the experimental work, it was observed that by strengthening the beam with BFRP and GFRP fabric has marked an increase in load carrying capacity of the beam and reduced deflection.

Keywords: Post-Tensioned, BFRP fabric, GFRP fabric, flexure, ultimate load, strengthening beam,

I. INTRODUCTION

Pre-stressed concrete technique is acquiring more importance in civil engineering area due to its abundant constructional advantages over conventional construction technique. These PSC members should be properly designed as per codal provision, without which it may cause adverse structural behaviour like losses in pre-stress, strength deterioration and relaxation of strands. Some of the other causative demeanours witnessed in PSC members are degradation of concrete and steel and diminishing in stiffness mainly caused by aggressive environmental aspect, ageing, poor initial design or change in usage. Since the complete replacement of such deficient structural is not possible as it entails huge amount of money and time. Hence strengthening is more suitable to enhance the load carrying capacity and extending service life of such deteriorated structures.

The Fibre Reinforced Polymer (FRP) technique is the most common used strengthening technique and provide alternative to the various traditional techniques like externally bonded steel plates, steel jackets, concrete jackets and external post tensioning. FRP materials have high tensile strength, high strength to weight ratio, high specific stiffness, high specific weight, durable, resistance to corrosion and ease in installation. Basalt Fibre Reinforced Polymer (BFRP) and Glass Fibre Reinforced Polymer (GFRP) in the form of fabric sheets are the most common and well-known strengthening technique. Since BFRP and GFRP are having high elastic modulus and strength, it is used as externally bonded reinforcement in this experimental project. In this present work, experimental investigation of post-tensioned PSC T-beams strengthened with various layer of BFRP and GFRP fabric are presented. Brief study has been made on the behaviour of BFRP and GFRP strengthened beams for flexure, deflection, cracking pattern and ultimate load by adopting different layers of BFRP and GFRP fabrics.

II. R LATED WORKS

Tamer El-Maaddawy et.al [1] narrated in his experiment work that the severe corroded T-beam can be strengthened with Carbon or Basalt FRCM system. Test results concluded that Carbon FRCM strengthened specimen shows 90% regain in its initial strength while Basalt FRCM strengthened failed to show regaining its original flexural strength.

Magdy et.al [2] has made a comparative study on different configuration of wrapping CFRP fabric to strengthen a T-beam. From the experimental result it was noticed that fully soffit strengthened T-beam shows better performance compared to U-strip wrapping.

Vatsala et.al [3] has conducted an investigation on the behaviour of PSC beam strengthened with fully soffit wrapped GFRP fabric and concluded that there is an increase in load carrying capacity of beam due to GFRP strengthening.

Revathy et.al [4] performed an investigation of deflection and load carrying behaviour GFRP strengthened beam. From the result it was reported that externally bonded GFRP fabric wrapped at soffit specimen has better loading carrying capacity, deflection and ductility behaviour.

Chandran et.al [5] examined flexural behaviour of BFRP strengthened beam wrapped in different layer. All fabrics were bonded at the soffit portion of beam. It was concluded from the experimental work that every consecutive increase in layer of

BFRP fabric there is an increase in ultimate load by 5% and considerable reduction in crack width.

Bairavi et.al [6] has given comparative results of GFRP retrofitted beams wrapped in single and double layer and concluded that double layer wrapped GFRP strengthening has better flexural performance than single layer wrapped GFRP strengthening.

III. EXPERIMENTAL PROGRAM

The experimental study comprises of casting Post-Tensioned T-beams of dimension 300 mm x 75 mm at flange and 180 mm x 125mm at web. The specimens were tested under two-point loading. All the beams were designed to fail in flexure and hence study restricted to only flexural failure. The grade of concrete used was of M40 having 28 day compressive strength of 48.51MPa, with water cement ratio of 0.4. Steel having yield strength of 500MPa was used for longitudinal reinforcement and for stirrups. The structural reinforcement of specimen consist of 2 number of 12mm dia as tension reinforcement and 2 No. of 10mm dia and 2 No. of 8mm dia as hanger or compression reinforcement. 8mm dia two legged stirrups were provided at 125mm c/c as shear reinforcement. Post tensioned were pre-stressed with two numbers of tendons of 7mm dia, placed at an eccentricity of 40mm from the neutral axis. Each tendon is pre-stressed by applying a pre-stressing force of 38KN. The clear cover of 40mm was provided from the bottom. The beam reinforcement details and cross section dimension were shown in fig 1.

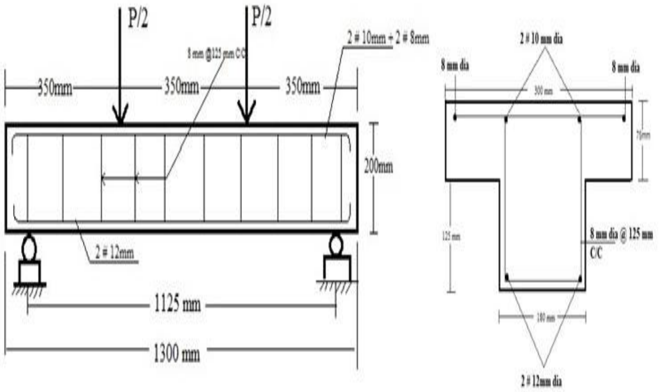

Figure.1. Beam reinforcement details

Post-tensioned beams were cast with a provision of flexible rubber tube of diameter 10mm, which eventually act as a'duct' running throughout the length of the beam. Duct houses high tensile steel tendons of 7mm dia of two numbers. These tendons were then stressed to induce post-tension in concrete portion. The concrete was compacted uniformly with the help of Vibrator. The beams are then de-moulded and placed in curing tank for 28days. After 28 days, tests were carried out on beams under two point loading. Mild steel plates of size 150mmX100mmX10mm were used as end bearing plates. Bearing plates plays an important role in inducing the stresses in the un-bonded PSC structures. Two holes were drilled in each end bearing plate for housing the tendons. High tensile tendons were placed through the holes in mild steel plates in particular ducts provided. Wedges and barrels were fixed to avoid relaxation of tendons. The tendons were sealed at one end and at other end tendon were stressed by hand operated hydraulic jack up to designed pre-stressing force. Fig 2 shows the post-tensioning of beams.

Figure.2. Post-tensioning of beams

In this experimental study the specimens were strengthened with externally bonded BFRP fabric in single layer (BSSL) and double layer (BSDL) and externally bonded GFRP fabric in single layer (GSSL) and double layer (GSDL). Fabrics were attached to the soffit portion of the beam for full length. The designation of beams were shown in table I

Table.1. Beam specimen details

Sl. No	Group	Particular	Designation	Wrapped Pattern	Number of layers
1	-	Control Beam	CB	Bottom fully wrapped	-
2	Un-Strengthened	Controlled PSC beam	PT-CB	Bottom fully wrapped	-
3	Strengthened Group A	GFRP strengthened Single layer	GSSL	Bottom fully wrapped	One
4		GFRP strengthened Double layer	GSDL	Bottom fully wrapped	Two
5	Group B	BFRP strengthened Single layer	BSSL	Bottom fully wrapped	One
6		GFRP strengthened Double layer	BSDL	Bottom fully wrapped	Two

IV. TEST SETUP

The beams were tested under loading frame of 50 tonnes capacity and all beams was tested under static loading as shown in figure – 3. The loading were applied at an interval of 10KN in the incremental order till the failure occurs. The load maximum load at which beam breaks is taken as ultimate load. For every incremental 10KN respective deflection were measured with aid of LVDT apparatus placed at right loading point, left loading point and at centre section of beam.

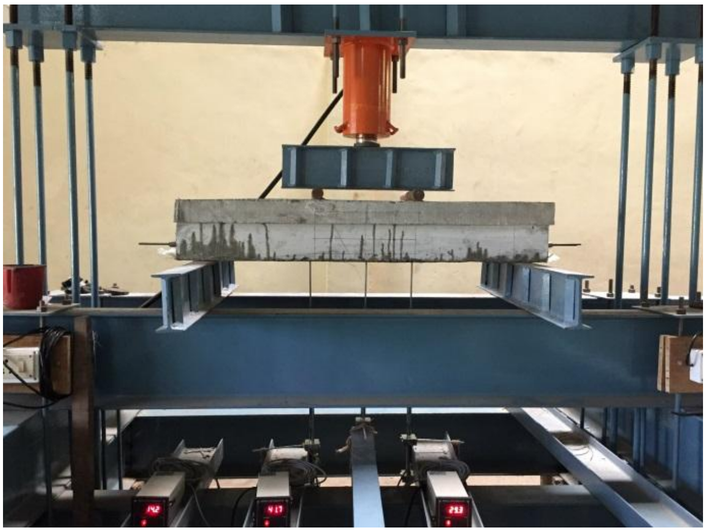

Figure.3. Test setup

V. RESULTS AND DISCUSSION

Parameters such as Ultimate load, deflection, stiffness, mode of failure, crack pattern of beam specimens is observed from experimental test. Table II gives deflection and maximum bending stresses of various beams.

Table.2. Deflection and Bending stresses of beams

Beams	Deflection in mm	Max. bending stress (σ_{bend},max) in Mpa
CB	18.2	19.58
PT-CB	16.9	25.82
BSSL	13.5	26.9
BDSL	12.1	29.05
GSSL	11.3	27.55
GSDL	10.9	30.13

A. LOAD-DEFLECTION BEHAVIOUR OF CONTROL BEAM (CB)

The maximum deflection occurred at the centre of beam. The centre deflection was found out to be 18.2mm.The maximum bending stress was found to be 19.58 Mpa. Fig 4a shows load v/s deflection curve for control beam.

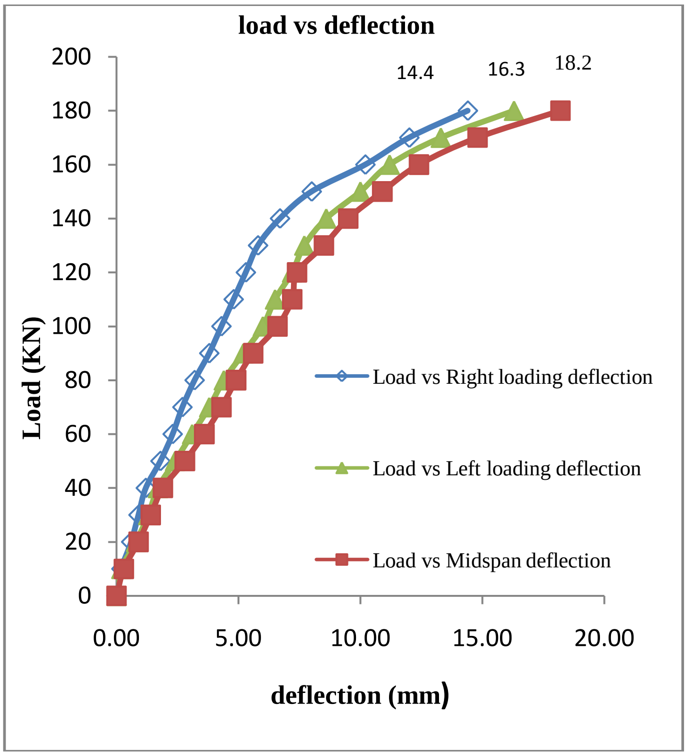

Figure.4a. Load v/s deflection curve for control beam

B. LOAD-DEFLECTION BEHAVIOUR OF POST TENSIONED CONTROL BEAM (PT-CB)

The centre deflection was found out to be 16.9 mm. It was noticed that Post-tensioned control beam (PTCB) has 37% less deflection when compared with control beam (CB). The stiffness of Post-tensioned control beam (PTCB) was found out to be 17% more when compared with control beam (CB). The maximum bending stress was found to be 25.82 Mpa. Fig 4b shows load v/s deflection curve for post-tensioned control beam.

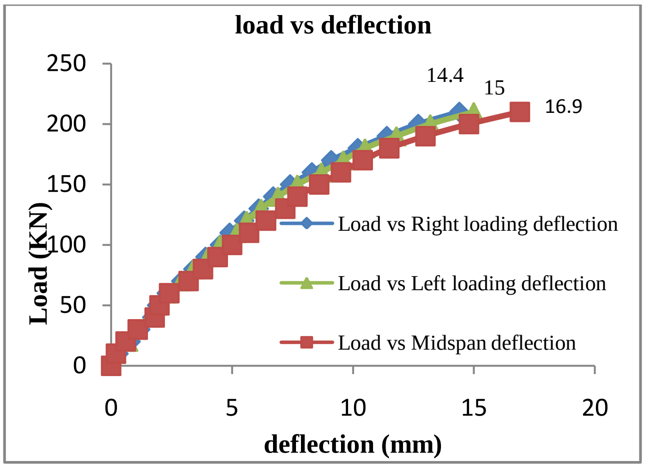

Figure.4b. load v/s deflection curve for PT-CB specimen

C. LOAD-DEFLECTION OF POST-TENSIONED BEAM STRENGTHENED WITH SINGLE LAYER OF BFRP (BSSL)

The ultimate deflection at the centre was found out to be 17.5mm at ultimate load. It was noticed that Post-tensioned beam wrapped with single layer of BFRP fabric (BSSL) has 37% less deflected when compared with control beam (CB) and 15% less than post-tensioned control beam (PT-CB). BSSL specimen has 28% more stiffness when compared to CB and 14% more stiffness compared to PT-CB. The maximum bending stress was found to be 26.9 Mpa. Fig 4c shows load v/s deflection curve for post-tensioned beam strengthened with single layer of BFRP fabric

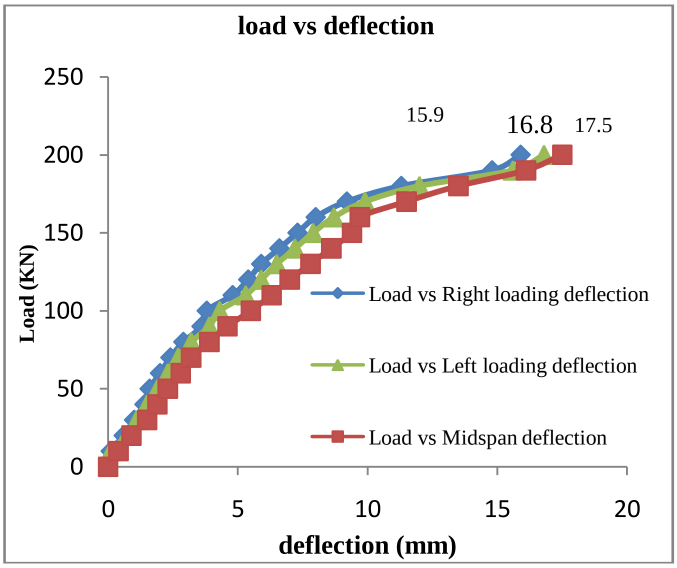

Figure.4c. Load v/s deflection curve for BSSL specimen

D. LOAD-DEFLECTION OF POST-TENSIONED BEAM STRENGTHENED WITH DOUBLE LAYER OF BFRP (BSDL)

The ultimate deflection was found to be 15.55 mm at the centre. Strengthening the Post-tensioned beam with double layer of BFRP fabric (BSDL) has resulted in 44% less deflection when compared with control beam (CB), 24.4% less than post-tensioned control beam (PT-CB) and 11.3% decrease when compared to BSSL specimen. BSDL specimen has 56.3 higher stiffness values when compared to CB and 48% more stiffness compared to PT-CB. The maximum bending stress was found to be 29.05 Mpa. Fig 4d shows load v/s deflection curve for post-tensioned beam strengthened with double layer of BFRP fabric

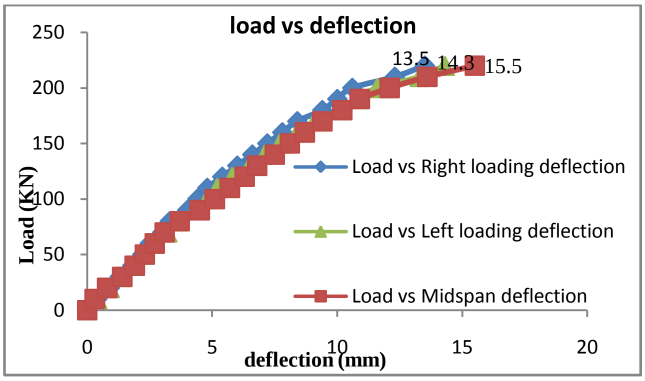

Figure.4d. Load v/s deflection curve for BSDL specimen

E. LOAD-DEFLECTION OF POST-TENSIONED BEAM STRENGTHENED WITH SINGLE LAYER OF GFRP (GSSL)

The ultimate deflection at the centre was found out to be17.1mm. Strengthened Post-tensioned beam with single layer of GFRP fabric (GSSL) has 49% less deflection when compared with control beam (CB) and 12% less than post-tensioned control beam (PT-CB). The increase in stiffness can be achieved by strengthening the post-tensioned beam with single layer. GSSL specimen has 49% more stiffness when compared to control beam (CB) and 31% increase when equalled with PT-CB. The maximum bending stress was found to be 27.55 Mpa Fig 4e shows load v/s deflection curve for post-tensioned beam strengthened with single layer of GFRP fabric

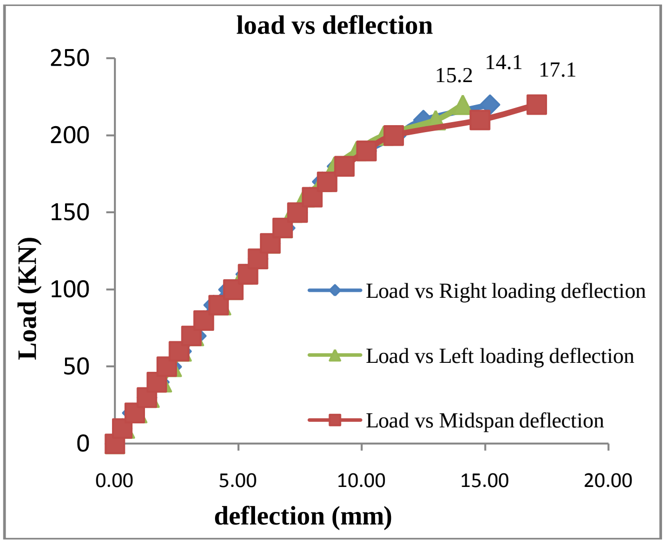

Figure.4e. Load v/s deflection curve for GSSL specimen

F. LOAD-DEFLECTION OF POST-TENSIONED BEAM STRENGTHENED WITH DOUBLE LAYER OF GFRP (GSDL)]

From the experimental test result it was remarked that maximum deflection occurs at the mid-span section of the beam. The maximum deflection at the mid-span of beam was 13.7mm. The deflection of double layer wrapped GFRP strengthened beam was found out to be 50% reduced when linked with control-beam (CB) and 20% reduction compared with PT-CB. GSDL specimen has 57% higher stiffness configuration compared to controlled beam (CB) and 49% more stiffness than PT-CB. The maximum bending stress was found to be 30.13 Mpa. Fig 4f shows load v/s deflection curve for post-tensioned beam strengthened with double layer of GFRP fabric.

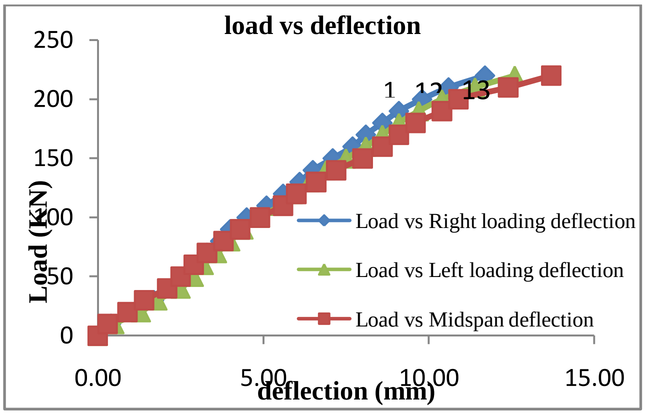

Figure.4f. Load v/s deflection curve for GSDL specimen

G. ULTIMATE LOAD

The load at which beam undergo irreversible damage is taken as ultimate load. It is that load where beam breaks or fails. In this experimental study all the beams were loaded to failure. Fig 5 gives comparison of ultimate load of various tested beams. Table III gives ultimate load, increase in ultimate load of various beam specimens.

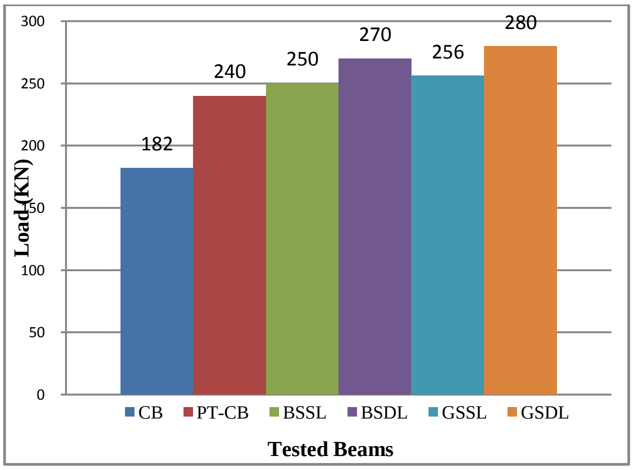

Figure.5. ultimate load of various beams

Table.3. Ultimate load comparison table

Beams	ultimate load	% increase in ultimate load when compared to beam CB	% increase in strength due to wrapping
CB	182		
PT-CB	240	24.2%	
BSSL	250	27.2%	4.0%
BSDL	270	32.6%	11.1%
GSSL	256	29.0%	6.3%
GSDL	280	35.0%	14.3%

From the above table we can see that the post-tensioned specimen has more load carrying capacity than nominal RC specimen. Post-tensioned controlled beam (PT-CB) has 24.2% more load carrying capacity than normal RC control beam (CB). By strengthening the post-tensioned beam with single layer wrapped BFRP fabric (BSSL), an increase in ultimate load about 4% can be achieved. Post-tensioned specimen strengthened with double layer of BFRP fabric (BSDL) has

11.1% higher ultimate than post-tensioned controlled beam (PT-CB). BSDL specimen has 32.6% more load carrying capacity than normal control beam (CB). GFRP strengthening shows significant increase in ultimate load compared to control and PSC control beam. An increase in ultimate load of about 6.3% can be achieved by strengthening the post-tensioned beam with GFRP fabric wrapped in single layer (GSSL). GSSL has 29% more load carrying capacity than conventional RC control beam (CB). Post-tensioned beam strengthened with GFRP fabric wrapped in double layer (GSDL) has 14.3% high ultimate load carrying capacity than post-tensioned control beam (PT-CB) and 35% more than normal RC control beam (CB).

VI. CONCLUSION

From the experimental results, the following conclusions were drawn,

- Under same structural configuration, post-tensioned PSC beam has more load taking capacity unlike conventional RC T-beam
- All post-tensioned beam strengthened with FRP in different configuration were capable of taking more load than without strengthened beams (control beams).
- Post-tensioned beam strengthened with double layer GFRP fabric (GSDL) were found out to be more effective in increasing the ultimate load of about 35% compared to control beam. An increase of about 14.3% in ultimate load is noticed when compared to unstrengthen post-tensioned beam (PT-CB).
- Post-tensioned beam experience much lesser deflection when compared with control specimen.
- Strengthening with BFRP and GFRP proved to be remedy in order to control the overall deflection of the specimen.
- The number of crack and its width was considerable less in post-tensioned PSC T-beams compared to normal RC T-beam.
- There was an increase in stiffness and moment carrying capacity of BFRP and GFRP strengthened beams.
- GRFP double wrapped strengthening was found to be effective in increasing stiffness by 49% and deduction in deflection by 20%.
- BFRP strengthened in double layer has lesser deflection compared to other strengthened specimen.
- In terms of stiffness and ultimate load, GFRP strengthened beam in double layer has found out to be more suitable compared to other strengthened beams.

VII. REFERENCES

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