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PERFORMANCE OF CFRP AND BFRP AS PRE-STRESSING TENDONS IN A PRESTRESSED CONCRETE BRIDGE

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Abstract - ***In this paper the effect of Carbon fibre reinforced polymer and basalt fibre reinforced polymer as a pre-stressing tendons in a pre-stressed bridge have been studied. CFRP and BFRP as a pre-stressing material provides advantages in the ductility of strengthened concrete and also avoid the low creep rupture limitations. Pre-stressing is generally having more application in long span bridge. The parametric study is done by creating different models of pre-stressed bridge with BFRP and CFRP tendons and then compared with high tensile steel tendons. The software used for analysis and design of bridge is Midas civil-2018. Construction stage analysis is done considering the effect of time dependent material properties such as creep, age and shrinkage. Result is then given by comparing the moment capacity, shear capacity, loss of stresses in tendons and deflections in the structure by changing the thickness and depth of the girder. An optimization is also done for the girders pre-stressed with BFRP and CFRP tendons to get an idea how much we can minimize a section by using these tendons. At last cost comparison is carried out for the same girder pre-stressed with BFRP, CFRP and HT tendons to know cost effectiveness.***

Keywords— **Pre-stressed Bridge, Carbon fibre reinforced polymer, basalt fibre reinforced polymer, high tensile steel.**

I. INTRODUCTION

Bridges are structures which provide passage over a gap without closing way ahead. Bridges are needed for a passage of railway, roadway, foot path etc. Bridge construction is required for better communication and easy transportation of vehicles and goods. It is an important factor for the development of civilization.

Pre-stressing is the introduction of a compressive force to the concrete to counteract the stresses arising from all the loads during its service period. There are two methods of introducing pre-stressing to a concrete i.e. pre-tensioning and post tensioning. Pre-stressed concrete is a concrete which is stressed by tendons by applying compression before the applied loading in the structure. These tendons are located within the concrete volume. Tendons are having single wires, multi-wire strands or threaded bars. These tendons are tensioned so that compression is produced in the concrete section. Tendons get bonded with the concrete when anchoring of the tendons is released at the end. The tension force from the tendon is transferred to the concrete as compression by static friction. In Post-tensioned concrete, the stressing of tendons is carried out after the casting of the concrete. The tendons are covered within a protective sleeve or duct. Tendons are not placed in direct contact with the concrete. Anchoring technique is fixed at the ends tendons which pull the tendon ends to generate compression in the concrete.

II. LITERATURE REVIEW

Xin Wang et.al (2015) studies the behaviour of high-strength basalt fibre-reinforced polymer (BFRP) tendons for fatigue strength in pre-stressed structures. Fatigue test for BFRP tendon is carried out by winding fibre sheets with suitable anchoring technique. This is done to prevent the premature failure at the anchorage. The analysis is done using fatigue failure mechanism at macroscopic and microscopic levels. From experimental data and reliability analysis effective stress range and failure stress were anticipated Result shows that the BFRP tendon fails in fatigue mainly due to the loss of bonding at the outer layer of the cables. The fatigue life of BFRP tendons are greatly affected by fatigue stress. The BFRP tendons can sustain 2 million cycles of loadings under a stress range of 0.05fu (85 MPa) and maximum stress of 0.6 fu (1,018 MPa). The elastic modulus of BFRP tendons does not depends on number of cycles, it remains constant.

Xin Wanga, Gang Wu, Zhishen Wu, Zhiqiang Dong and Qiong Xie (2015) studied the degradation of tensile properties of BFRP tendons, CFRP tendons and hybrid cables of Basalt and steel under marine or salty environment. Parameters are to be studied is tensile stress and aging in days. Relative modulus of elasticity was also studied. The observed that degradation of tensile strength of BFRP tendons is directly proportional to the increase of stress level and the Elastic modulus is relatively constant. Also the stress level of 60% of fu after 2 months of aging the BFRP tendons maintain the tensile strength of more than 90%, which shows a good resistance to salt corrosion. Hybrid basalt and CFRP tendons show even better resistance to salt corrosion in comparison to BFRP but the positive hybridization effect is only observed for the tendons of the other FRP tendons, due to the corrosion of steel wires inside.

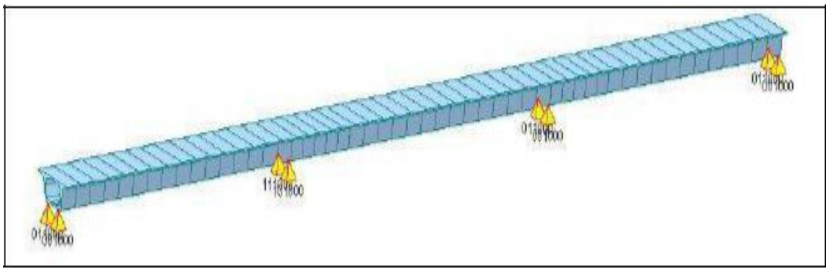
Mohamed Husain et.al (2015) studies the effects of some structural parameters on the behaviour of pre-stressed concrete beams with FRP pre-stressing tendons. A parametric study was conducted to examine the effects of reinforcement ratio, flexure strength, and level of initial pre-stressing on the beam. They concluded that Load & Moment carrying capacity of beam increases if reinforced with BFRP tendons than steel reinforcement. Deflection is less in case of reinforcement with BFRP than steel reinforcement. The crack widths are cpmparatively lesser under working loads in case of BFRP.

Xin Wang, Zhishen Wu, Gang Wu, Hong Zhu and Fanxing Zen (2012) studied the hybridization effect of basalt fibre cables with other fibre reinforced polymer materials for their application in long span bridge. BFRP tendons have low elastic modulus. Results shows that hybridization of BFRP cables increase its tensile strength as well as their fatigue strength. Elastic modulus of hybrid fibre is more than BFRP cables. By hybridization of basalt FRP or CFRP tendons with steel tendons performance of structures improves significantly because stiffness of hybridized tendons improves.

III. DESIGN METHODOLOGY

1. Model Specification

Bridge type: Sloping sided pre-stressed bridge of three span
Length: L = 40.0+ 45.0 + 40.0 = 125.0 m
Width: B = 8.5 m (2 lanes)
Skew: 0˚ (No skew)
Concrete Grade: M50
Steel Grade: Fe 415
Relative Humidity of ambient environment: 70%



2. Section Data

Clear span between webs (Top Flange)	4400 mm
Top flange thickness (Bottom Flange)	240 mm
Clear span between webs (Top Flange)	3864 mm
Bottom flange thickness (Bottom Flange)	250 mm
Web thickness	318 mm
c/c of the webs	4950 mm
Strand Diam. and No.	(φ15.2 mm)19
Duct Size	3

3. Loading Condition

3.1 Self weight
Input Self-Weight and Superimposed dead load
W= 35.80 kN/m (Calculated by program)

3.2 Live Load
IRC class AA Loading

3.3 Creep and Shrinkage

The creep and shrinkage coefficient is calculated automatically by the program. The creep and shrinkage factor is considered for concrete of grade M50. The nominal size of member is calculated as 364 mm. Load ending is taken as 10000 days.

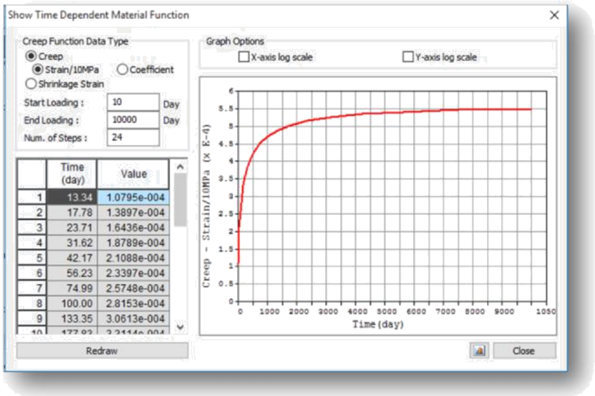


Fig 1. Creep Coefficient

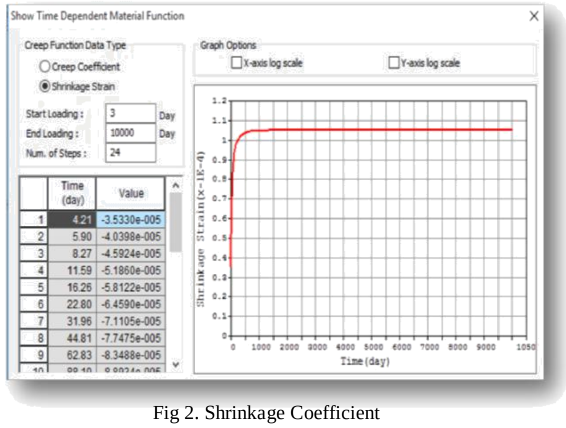


Fig 2. Shrinkage Coefficient

3.4 Seismic Loads

Response spectrum analysis for the time period of 4 seconds is used to consider the effect of seismic loads on the structure. Seismic zone is II, Damping Ratio - 5%, Importance Factor (I) - 1.0 & Response Reduction Factor (R) - 3.0

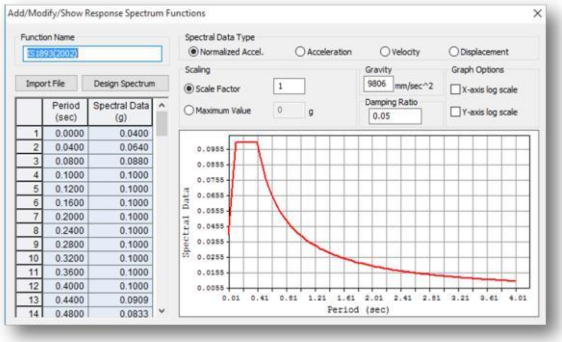


Fig 3. Response spectrum curve

3.5 Wind Load

Wind Load: 3 kN/m^2

Total Height = Section Depth + Barrier + Noise barriers = 3+1+2.5 = 6.5 m

Wind Pressure = 3 kN/m^2

Wind Load = 6.5 X 3 kN/m^2 = 19.5 kN/m (Horizontal Load)

= 19.5 kN/m * -1.46 m = -28.47 kN.m/m (Moment)

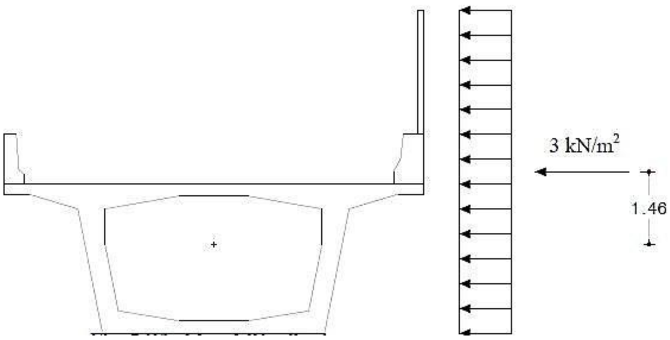


Fig 4. Wind load distribution

3.6 Pre-stressing force and eccentricity

Strand (φ15.2 mm 19 (φ 0.6″- 19))
Area: Ap = 2635.3 mm^2
Duct Size: 103 mm
Pre-stressing stress fpj = 1330 N/mm^2
Pre-stressing Force= 3500 kN
Load balancing concept is used to determine the eccentricity for Parabolic cable profile.
Pre-stress is taken as the 70% of ultimate tensile capacity of wire.
0.7(1900) = 1330 N/mm^2
Pre-stressing force = 1330 * 2635.3 = 3500 kN
Moment = Pre-stressing force * Eccentricity
Pre-stressing force and eccentricity is calculated at the points of maximum Moments in each girder.
Max. moment = 25725.00 kN.m

4. Tendon Properties and Allowable Stress

PROPERTY/TENDON	HT	CFRP	BFRP
PC Strand	Φ15.2 mm	Φ15.2 mm	Φ15.2 mm
Yield Strength (N/mm^2)	1600	2100	1950
Ultimate Strength (N/mm^2)	1900	2500	2100
Cross sectional Area (mm^2)	2635.32	2635.32	2635.32
Modulus of Elasticity (N/mm^2)	2×10^5	1.56×10^5	0.91×10^5
Jacking Stress (N/mm^2)	1330	1750	1330
Curvature Friction Factor (/rad)	0.3	0.3	0.3
Wobble Friction Factor (/m)	0.0066	0.0066	0.0066
Anchorage Slip (mm)	6	6	6

4.1 Tendon Profile

8 strands in each girder (4-Left and 4-Right)
Eccentricity = 2720 mm (for each strand)
Distance between two tendons = 300 mm

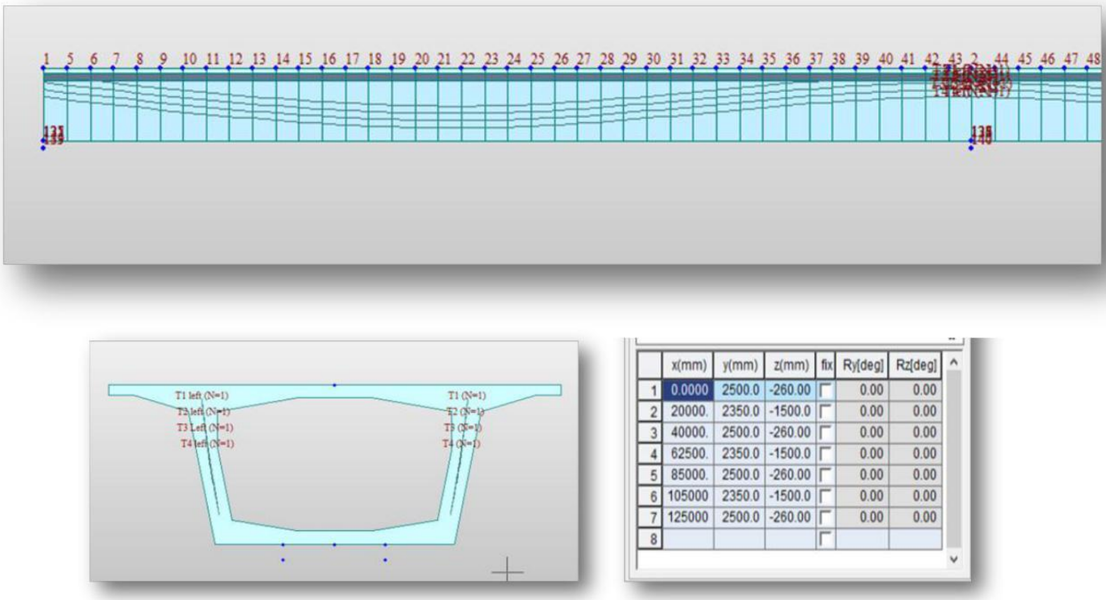


Fig 5. Tendon Profile

5. Construction Stage Analysis

Construction stage analysis is a static modelling, analysis, and design. In this method, the structural systems and load patterns are added and removed. The effect of time-dependent material properties such as creep, shrinkage, aging and relaxation of tendons is considered in analysis. Non-linearity in Material and geometry is applied in the construction stages.

Different stages for the analysis are:

Stage 1 – First girder is selected and self-weight is applied for 0 days
Stage 2 – Post tensioning is applied for 0 days
Stage 3 – Second girder is selected and self-weight is applied for 0 days
Stage 4 – Post tensioning is applied for 0 days
Stage 5 – Third girder is erected and self-weight is applied for 0 days
Stage 6 – Post tensioning is applied for 0 days
Stage 7 – creep and shrinkage is considered by taking an empty stage for 7 days
Stage 8 – Apply super imposed dead load for 10000 days

6. Parametric Study

Parameters to be changed in this study are Depth of girder and thickness of girder. Every combination having depth ranging from 2100 mm, 2400 mm, 2700 mm and 3000 mm. Cross-section of thickness 160 mm, 240 mm, 300mm and 360 mm for each depth. The same loading is applied in each cross-section.

IV. RESULT

1. Moment Capacity

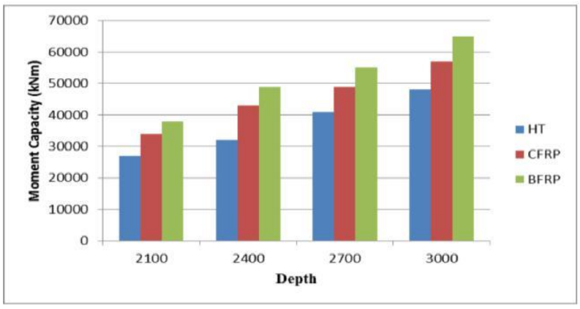


Fig. 7 Section with thickness 160 mm

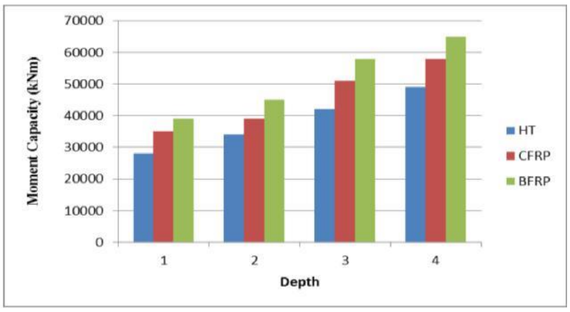


Fig. 8 Section with thickness 240 mm

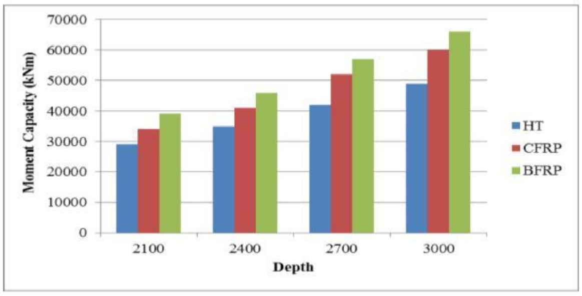


Fig. 9 Section with thickness 300 mm

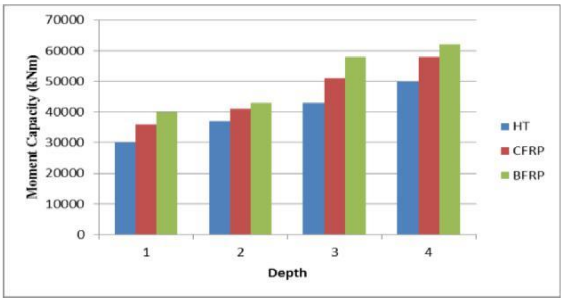


Fig. 10 Section with thickness 360 mm

2. Shear Capacity

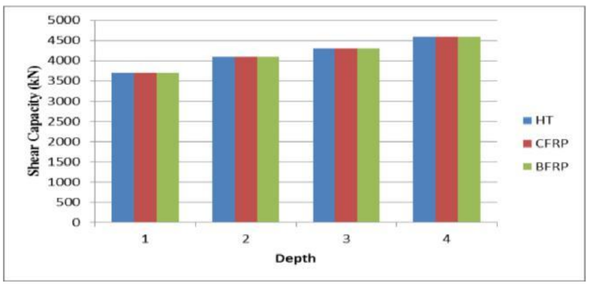


Fig. 11 Section with thickness 160 mm

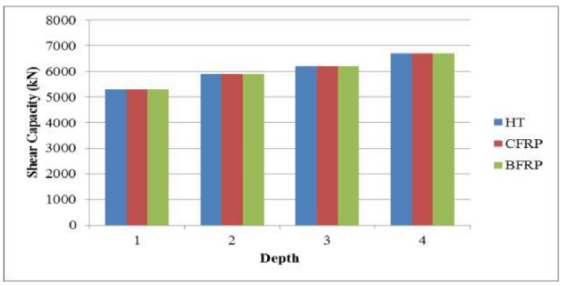


Fig. 12 Section with thickness 240 mm

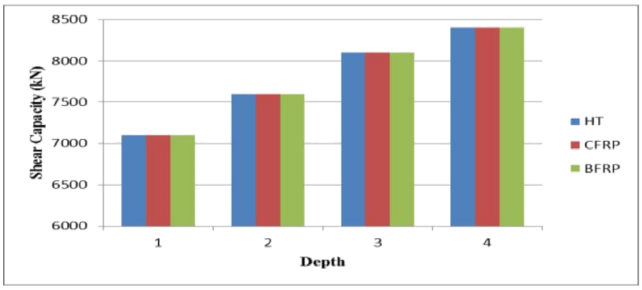


Fig. 13 Section with thickness 300 mm

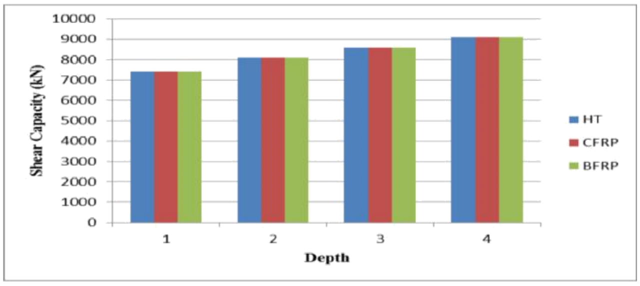
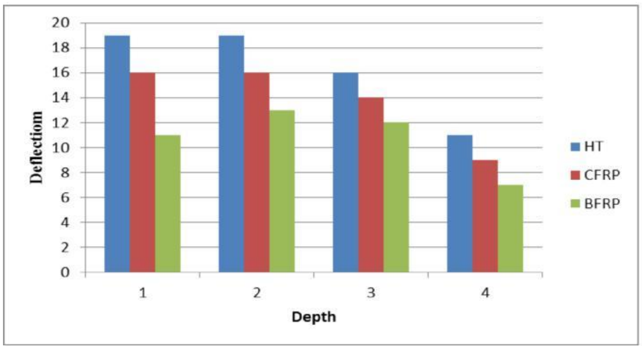


Fig. 14 Section with thickness 360 mm

3. Deflection



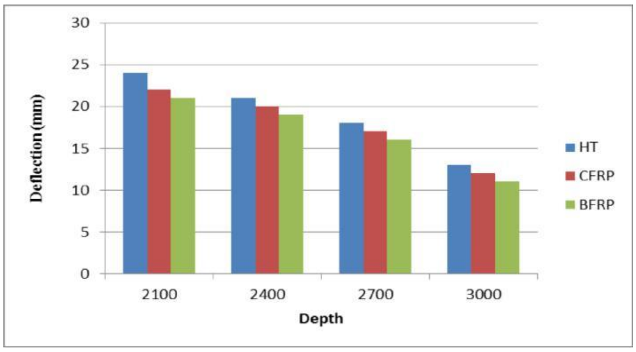


Fig. 15 Section with thickness 160 mm Fig. 16 Section with thickness 240 mm

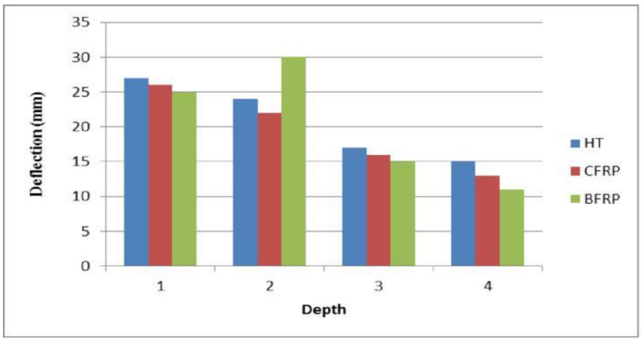


Fig. 17 Section with thickness 300 mm

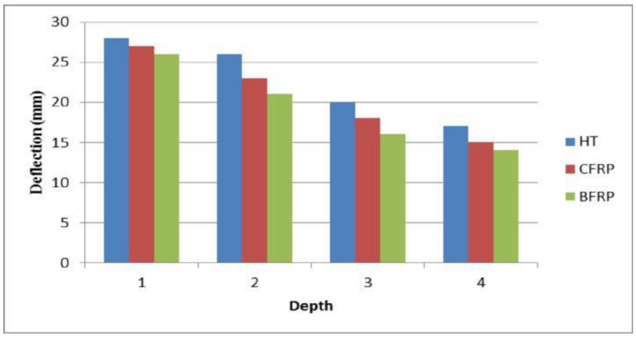


Fig. 18 Section with thickness 360 mm

4. Loss of stress in Tendons

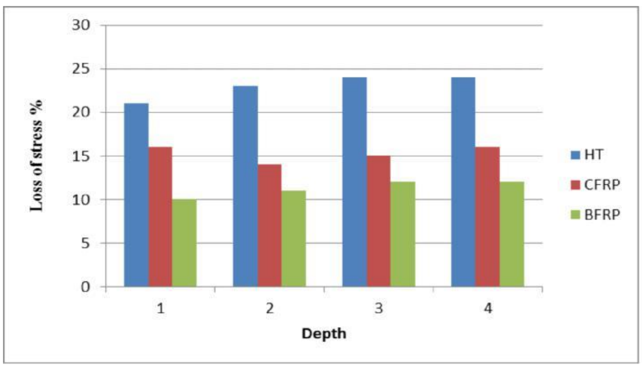


Fig. 19 Section with thickness 160 mm

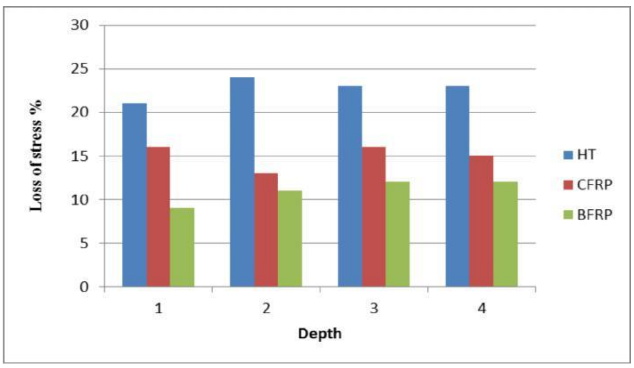


Fig. 20 Section with thickness 240 mm

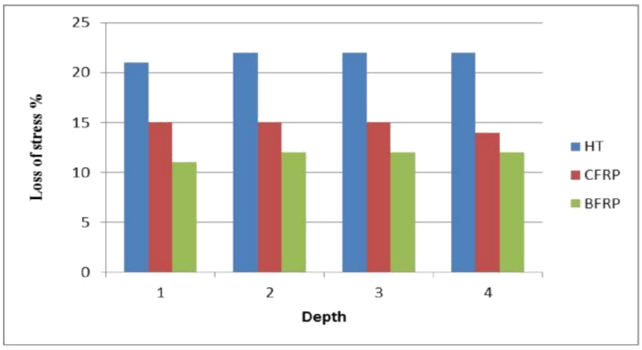


Fig. 21 Section with thickness 300 mm

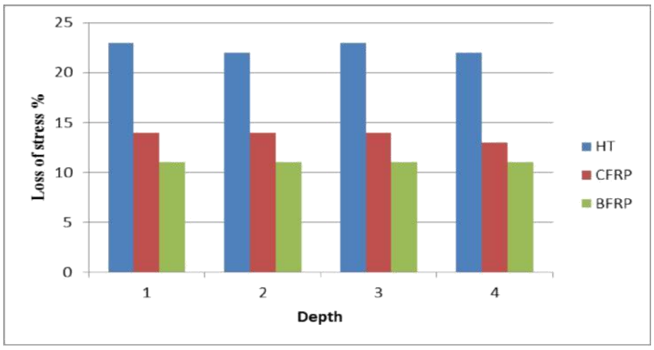


Fig. 22 Section with thickness 360 mm

5. Optimization of Section

Box-girders pre-stressed with BFRP tendons are having much larger ultimate moment carrying capacity than box-girders prestressed with HT and CFRP tendons. For the same loading box-girders prestressed with BFRP tendons require lesser area than box girders prestressed with regular HT tendons. To minimize the area the optimization process is carried out. Box girder simply behaves as a flexure member, so based on applied moment we can find out optimum dimensions to counteract the moment.

Dimensions				Inputs			
Top flange width	8500.00	mm		allowable stress	24.00	N/mm²	
Top flange thickness	220.00	mm		moment	58000000000.00	N-mm	
Bottom flange width	5500.00	mm		Loss ratio	0.8		
Bottom flange thickness	220.00	mm					
Web thickness	220.00	mm					
total depth	2800.00	mm					
Extensions	500.00	mm					
theta	21.19						
slant length	2530.89	mm					
Parts							
A1 (mm²)	1870000.00		A2	1210000		A3	968285.94
moment of inertia (mm⁴)	7542333333.33		iyy	4880333333		iyy	517440793436.45
Y bottom (mm)	2690.00		Y bottom (mm)	110		Y bottom (mm)	1439.73
			Checks				
Ybottom (mm)	1658.20						
Ytop (mm)	1141.80		ftop	12.11	N/mm²	okay	
total A (mm²)	427094 1.66		fbottom	17.59	N/mm²		
total iyy (mm⁴)	5467176865723.57		min section mod	2472792271.22	mm³	okay	
Ztop (mm³)	4788206315.61		Web thickness	180.78	mm	okay	
Zbottom (mm³)	3297056361.63		Flange thickness	200	mm	okay	

Fig. 23 Optimum dimensions for girder

	Optimized BFRP Section	Regular HT Section
Area (mm²)	3.9 x 10⁶	4.35 x 10⁶
Moment Capacity (kN.m)	59019	59787
Shear Capacity (kN)	5820	6890
Deflection (mm)	13.14	10.25
% loss of stress	11.58	23

Fig. 24 Result Comparison of optimized section

	Optimized BFRP Section	Regular HT Section
Length (m)	125	125
C/s area (mm²)	3.9 x 10⁶	4.35 x 10⁶
Total volume (m³)	487.5	543.75
Volume of tendon (m³)	5.75	7.5
Volume of concrete (m³)	481.75	536.25
Cost of concrete (INR)	31,14,926	36,09,605
Cost of tendon (INR)	9,76,540	19,16,200
Total cost (INR)	40,91,466	55,25,805

Fig. 25 Cost Comparison of optimized section

V CONCLUSIONS

From the study it is concluded that, the Ultimate moment carrying capacity of c/s with BFRP tendons is 25% higher than the c/s with HT tendons and 10% higher than the c/s with CFRP Tendons. It is observed that as the Depth increases, Ultimate moment carrying capacity increases. It is observed that the Shear capacity of cross section with BFRP tendons, CFRP tendon and HT tendons are nearly same because it only depends on type of concrete and cross-sectional area.

Deflections for the C/S with BFRP tendons are lesser in the range of 10 to 12% than C/S with HT tendons. Reduction in loss of pre-stress is nearly 50% in C/S with BFRP tendons compared to C/S with HT tendons. There is significant 7 to 8% reduction of c/s area of girders with BFRP tendons compared to HT tendons. By prestressing girders with BFRP tendons, reduction in cost is in range of 24% to 25% tendons than HT tendons. Most economical section out of all the combinations is the section pre-stressed with BFRP tendon.

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