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BFRP AS AN EFFECTIVE REPLACEMENT OF STEEL IN PRE-STRESSED BOX GIRDERS

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Abstract—Basalt fiber composites (BFRP) have been receiving increasing attention in civil infrastructures, due to their excellent mechanical and chemical properties and high performance. This paper studies the effect of "Basalt fiber reinforced polymer cables" in 3-span post-tensioned concrete bridge girder of grade M50. MIDAS CIVIL 2017 software is used for this analytical study. In this paper comparison of ultimate moment carrying capacity, Shear Capacity of the section, Deflection, and Loss of Pre-stress in tendons are done for the section with BFRP cables and High tensile steel tendons. Tendon profiles are same for both type of cables and tendon properties are mentioned below. At last several conclusions are made based on results available.

Keywords— Pre-stressed bridges, Fiber reinforced polymer (FRP), Basalt fiber reinforced polymer (BFRP), Post-tensioning, Ultimate Tensile Strength, High tensile steel cables, Shear capacity

I. INTRODUCTION

Pre-stressed concrete is a concrete which is stressed prior to the application of external loading. Stressing before the load application is done by tendons. There are various types of tendons available in market such as high tensile steel tendons, Carbon fibers reinforced polymer cables, Glass fiber reinforced polymer cables, Aramid fiber reinforced polymer cables and Basalt fiber reinforced polymer cables. With increase in demand use of long span pre-stressed bridges has increased. Due to increasing demand of high performance bridges steel cables are having many limitations. Basalt fibers are environmentally friendly and nonhazardous materials as they are produced from volcanic rocks by using single component raw material and drawing fibers from the molten rock In recent years BFRP tendons are found to be more useful in pre-stressing works because of their high tensile strength. Here are several advantages of basalt fiber cables such as Higher ultimate tensile strength than steel cables, Higher thermal protection, offers higher resistance to corrosion, chemically inert material, Cost is nearly same to the cost of high tensile steel tendons, Better seismic performance and Good bonding with concrete, durable than the high tensile steel.

II. MODEL DESCRIPTION

1. Bridge type: 3-span continuous Post-tensioned PSC Box Bridge
2. Bridge length: L = 40.0+ 45.0 + 40.0 = 125.0 m
3. Bridge width: B = 8.5 m (2 lanes)
4. Skew: 0˚ (No skew)
5. Grade of Concrete: M50

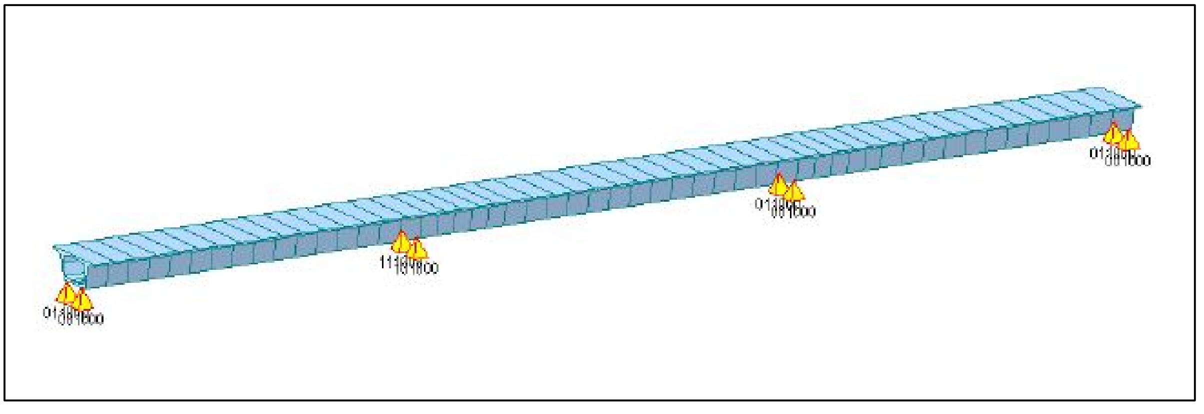

Figure 1. 3-Span continuous PSC box-girder

6. HT steel Tendon properties
   - Strand: Φ15.2 mm (0.6″strand)
   - Yield Strength: f_{py} = 1600 N/mm^2
   - Ult. Strength: f_{pu} = 1850 N/mm^2
   - Cross Sectional area: A_p = 2635.3 mm^2
   - Modulus of Elasticity: E_{ps} = 2.0 X 105 N/mm^2
   - Jacking Stress: f_{pj} = 1330 N/mm^2
   - Curvature friction factor: μ = 0.3 /rad
   - Wobble friction factor: k = 0.0066 /m
   - Anchorage Slip: Δ_s =6 mm (At the Beginning and at the End)

7. BFRP tendon properties
   - Strand: Φ15.2 mm (0.6″strand)
   - Yield Strength: f_{py} = 1950 N/mm2
   - Ult. Strength: f_{pu} = 2100 N/mm2
   - Cross Sectional area: A_p = 2635.3 mm2
   - Modulus of Elasticity: E_{ps} = 0.91 X 105 N/mm2
   - Jacking Stress: f_{pj} = 1330 N/mm2
   - Curvature friction factor:μ = 0.3 /rad
   - Wobble friction factor k = 0.0066 /m
   - Anchorage Slip: Δ_s = 6 mm (At the Beginning and at the End)

III. LOADING CONDITIONS

- Self-weight
- Superimposed dead load
  w = 35.796 kN/m
- Pre-stress
  Strand (φ15.2 mm19 (φ0.6″- 19))
  Area A_p = 2635.3 mm2
  Duct Size: 103 mm
  Prestressing force f_{pj}= 1330 N/mm^2
  Prestressing losses after the initial loss (automatically calculated by program)
  Final Loss (automatically calculated by program)
- Creep and Shrinkage
  Code: IRC 112.
  Characteristic compressive strength of concrete at the age of 28 days: 50 N/mm^2.
  Relative Humidity of ambient environment: 70%
  Creep Coefficient: Automatically calculated within the program
  Shrinkage Coefficient: Automatically calculated within the program
- Live loads
  Vehicle Load: IRC class-A, IRC class-AA
- Temperature Loads
  Temperature Range for Procedure A (assuming Moderate climate)
  10 degree to 80-degree F
  Temperature Gradient (assuming Zone 2)
  Positive temperature value
  T1 = 46˚F
  T2 = 12˚F
  Negative temperature value
  T1 = -0.3 X 46˚F= -13.8˚F
  T2 = -0.3 X 12˚F = -3.6˚F
- Wind Loads
  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
  Horizontal Load = 6.5 X 3 kN/m2 = 19.5 kN/m
  Moment = 19.5 kN/m X -1.46m = -28.47 kN-m/m

IV. SUPPORT CONDITIONS

Nodes 61 to 59 are the supports. For the load transfer RIGID link is provided between nodes these nodes and nodes above them. By providing rigid link they will displace as a whole rigid body. Rigid link is provided between the nodes at the support section as shown in table 1. Nodes 54, 52, 53 and 55 are allowed to move in X-dir., while nodes 56, 57, 58 and 59 are allowed to move in X-dir. and Y-dir.

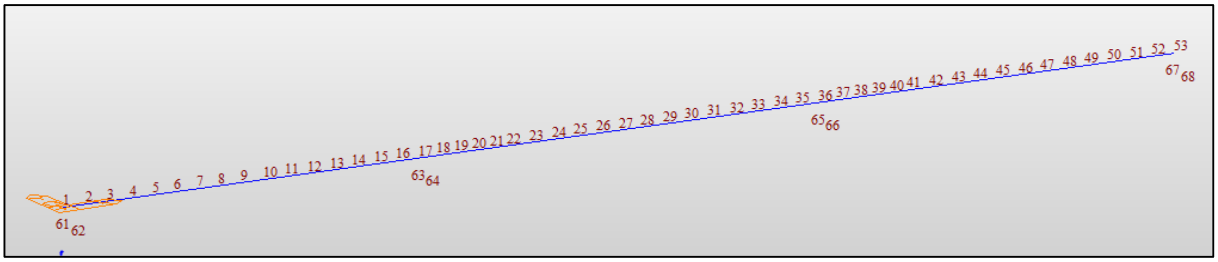

Figure 2. Layout of nodes

1 & 61	1 & 62
51 & 67	51 & 68
17 & 63	17 & 64
36 & 65	36 & 66

Table 1. Rigid links between nodes

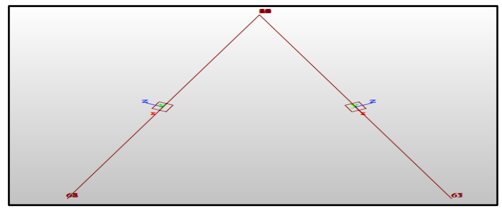

Figure 3. Modelling of Rigid link

V. STAGED CONSTRUCTION

Here, are 3 PSC girders to be analyzed by construction stage analysis. Staged construction of this problem is described below.

Stage 1 – Erect the first set of segments and apply self-weight (duration = 0 days)
Stage 2 – Apply post-tensioning (duration = 0 days)
Stage 3 – Erect the second set of segments and apply self-weight (duration = 0 days)
Stage 4 – Apply post-tensioning (duration = 0 days)
Stage 5– Erect the second set of segments and apply self-weight (duration = 0 days)
Stage 6 – Apply post-tensioning (duration = 0 days)
Stage 7 – Create an empty stage in which creep and shrinkage take effect (duration = 7 days)
Stage 8 – Apply super imposed dead loads (duration=10000 days)

VI. RESULTS OF ANALYSIS

After staged construction analysis is done and various quantities like ultimate moment carrying capacity, Shear capacity, Max. stresses, maximum deflection, Loss of stress in tendons are compared. Results are as below.

6.1 Ultimate moment carrying capacity

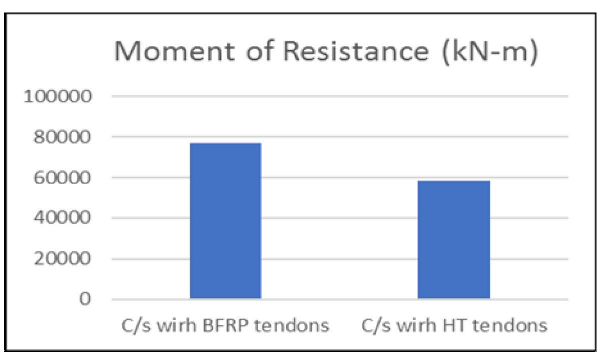

Figure 4. Comparison of Moment of resistance

6.2 Shear capacity

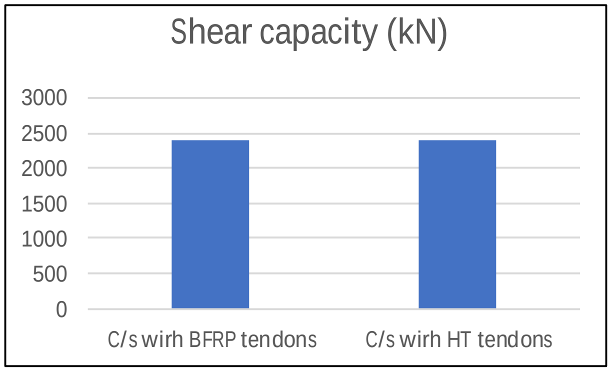

Figure 5. Comparison of Shear capacity.

pacity.

6.3 Deflection

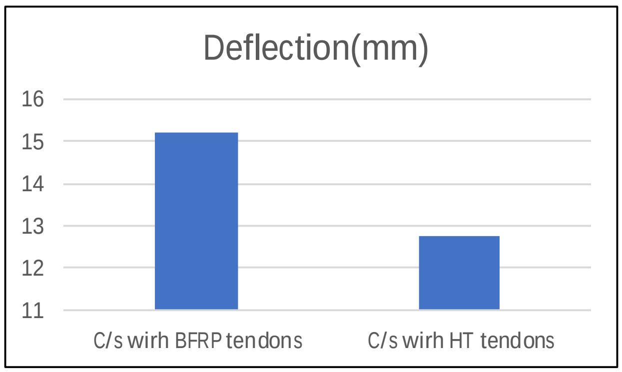

Figure 6. Comparison of deflections.

6.4 Loss of stress in tendons

	Initial stress in tendons (Mpa)	Stress in tendons after losses (Mpa)	% loss
H.T. tendons	1198.62	926.52	22.70
BFRP tendons	1242.41	1111.61	11.70

Table 2. Comparison of Losses of stress in tendons.

6.5 Comparison of stresses

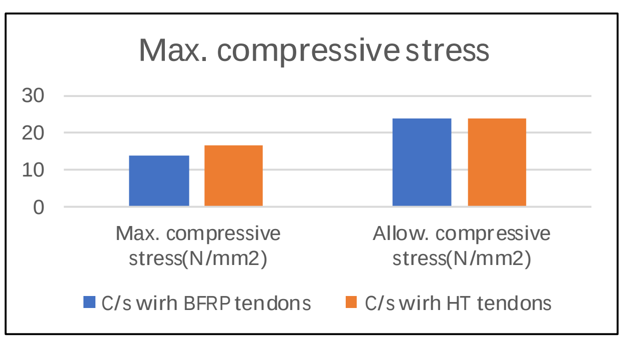

Figure 7. Comparison of compressive stress.

VII. RESULT DISCUSSION

From the analysis of post tensioned box girder bridge the following observations are made.

1. Cross-section with BFRP tendons has 25% more moment carrying capacity than one with HT tendons.
2. Shear capacity largely depends upon Grade of concrete and grade of shear reinforcement so, Shear capacity of the sections with BFRP tendons & HT tendons are more or less same.
3. Upward Deflection due to Pre-stressing tendons is more in case of BFRP tendons so overall downward deflection is 13-14% less in the section with BFRP tendons.
4. Loss of pre-stress in tendons is half in the girder with BFRP tendons compared to girder with HT Tendons.
5. Compression in whole c/s area is approx. 1.5 Mpa more than c/s with HT tendons.
6. Shear stresses are less in the cross-section with BFRP tendons as compared to cross-section with HT tendons.
7. Cross-section are can be reduced in the section with BFRP tendons.

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