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# Analysis and Design of Post Tensioned Box Girder Bridge Using SAP 2000

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## ABSTRACT

A box girder bridge is an apparent bridge sector in which main beams contain girders in the hollow box shape. The box girder usually includes either structural steel, pre-stressed concrete or in the form of reinforced concrete or composite section. It is typically trapezoidal, square or rectangular in cross section. In this paper a proposed two lane bridge of span 240m is analyzed and designed as two cell post tensioned box girder bridge (Trapezoidal cross section) for Dead loads, Super imposed dead load, Prestresssing force and moving loads as per IRC 6:2014 recommendations, IS 1343:2012 and also as per IRC 18:2000 and IRC 112:2011 specifications. The analysis of post tensioned box girder bridge is done using SAP 2000 v 19 software and prestressed with parabolic tendons. The Freyssinet system of post tensioning anchorages is selected for the present study.

**Keywords:** Two cell, Post tensioned, box girder, Trapezoidal cross section, SAP2000

## I. INTRODUCTION

As Span increases, dead load is an important increasing factor. To reduce the dead load, unnecessary material, which is not utilized to its full capacity, is removed out of section, this results in the shape of box girder or cellular structures. A box girder is formed when two web plates are joined by a common flange at both the top and the bottom. The closed cell which is formed has a much greater torsional stiffness and strength than an open section and it is this feature which is the usual reason for choosing a box girder configuration. The box is typically rectangular or trapezoidal in cross section. Box girder bridges are commonly used for highway flyovers and for modern elevated structures of light rail Transport.

In case of long span bridges, large width of deck is available to accommodate prestressing cables at bottom flange level. For large spans, bottom flange could be used as another deck accommodates traffic also. The maintenance of box girder is easier in interior space which is directly accessible without use of scaffolding. Alternatively space is hermetically sealed and enclosed air may be dried to provide a non-corrosive atmosphere.

In this paper a proposed flyover located in Calicut district in state of Kerala is selected. The method of post tensioning is used for prestressing the box girder bridge. The Freyssinet system of post tensioning anchorages is used. The anchorage selected consist of strands of 7 ply prestressed tendons having diameter of 12.7mm and strength of 183.47kN. The tendon profile is considered as parabolic in nature. The tendon is prestressed at the beginning and at the end span by using suitable jackying method.

Typical section of a two cell box girder consists of two exterior web, one interior web, one top slab and one bottom slab. In post tensioning the concrete units are first cast by in cooperating ducts or grooves to house the tendon. When concrete attains sufficient strength the high tensile wires are tensioned by means of jack bearing on the end faces of members and anchored by wedges or nuts. The force is transmitted to the concrete by means of the end anchorages, when the cable is curved through the radial pressure between the cable and duct. The space between the tendon and ducts are generally grouted after tensioning operation. The analysis of the box girder bridge is done using SAP 2000 v 19 by applying Dead load (DL), super imposed dead load (SIDL), live load(LL), and prestressing force according to the relevant Indian Standard (IS) codes and relevant Indian Road Congress (IRC) and are checked for allowable stress at transfer and service condition, Deflections and other failure conditions.

## II. METHODOLOGY AND MATERIAL PROPERTIES

A proposed bridge of 8 spans of 30m each giving a total span of 240m and having a total width of 8.5m including carriage way and crash barrier is selected for the present study. As the first step of modelling the bridge in SAP2000 v 19, the span to depth ratio is selected as 15.

L/d= 15, d= 2m

Depth and width of the box girder at the anchorage, at the mid section and at the column are fixed as 2m and 8.5m respectively and are shown in figure 1 to figure 3.

**Table 1**. Box Girder Geometry

| | Depth of top slab (m) | Depth of bottom slab (m) | Width of web(m) |
|---|---|---|---|
| Section at anchorage | 0.25 | 0.22 | 0.8 |
| Mid section | 0.25 | 0.22 | 0.45 |
| Section at column | 0.25 | 0.32 | 0.45 |

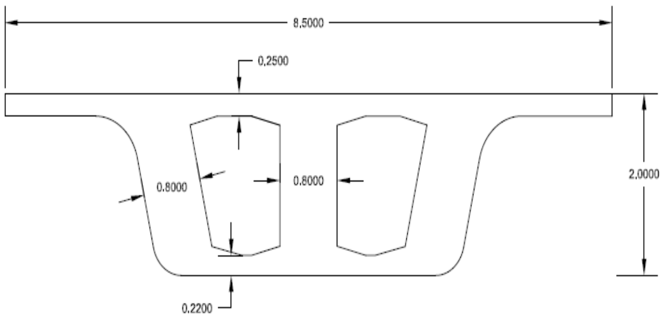


**Figure 1:** Section at Anchorage

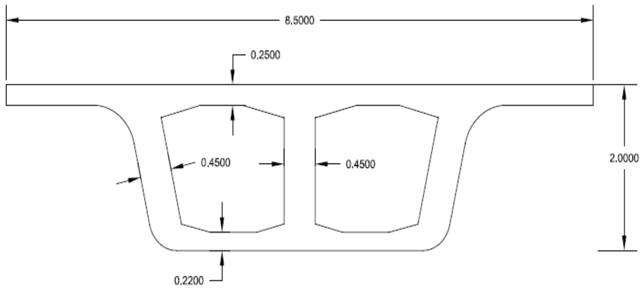


**Figure 2: M**id Section

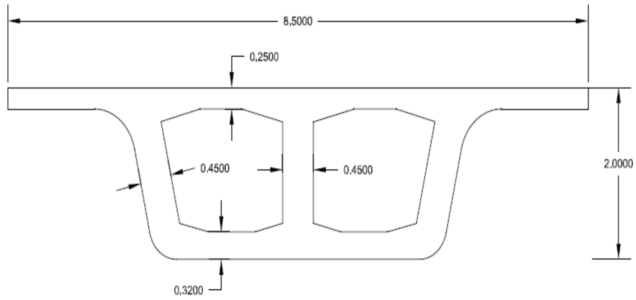


**Figure 3:** Section at column

The modelling of the bridge is done by considering the bridge as a continuous line beam. The material for the bridge is defined as concrete of grade M45. For defining the section properties each span is divided into ten equal portions of 3m each. Pin joints are assigned as joint restraints at each support. Loads are defined into the bridge which includes Dead load (DL), super imposed dead load (SIDL) and prestressing force (PSG). Live load (LL) considering impact factor according to IRC 6:2014 is defined for the bridge separately.
Prestressing force is determined according to IS 1343:2012 and the tendon profile is considered as parabolic in nature. Both immediate loss and time depended loss according to IS 1343:2012 is considered. The analysis of the bridge is done using SAP2000 v 19 and is checked for deflection, allowable stress and for ultimate strength.

## III. MODELLING AND ANALYSIS

### A. Loading

The loading for the bridge includes dead load, super imposed dead load, live load and prestressing force.

1) Dead load (DL): dead load consists of self weight of various structural components of the bridge super structure such as self weight of deck slab. The dead load can be estimated fairly during analysis and can be controlled during construction.

2) Super imposed dead load (SIDL): The super imposed loads considered are wearing coat of concrete having thickness 80mm and crash barrier along the full length of the bridge having a width of 400mm on both sides of the bridge.
Total Super Imposed Dead Load = 33.32 kN/m

3) Live load combination (LL): live load considered for the present study is taken from IRC 6:2014 (section II), the load combination for 7.5m is one lane of class 70R or two lane of class A vehicles, class 70R wheeled loading can be replaced by class 70R tracked, class AA tracked or class AA wheeled vehicle. For the present study 70R tacked vehicle, 70R wheeled vehicle and class A vehicle is selected. According to IRC 6:2014 the provision for impact shall be made by an increment of the live load by an impact allowance expressed as a fraction or percentage of the applied load

**Table 2.** Impact factor for live load

| Live load | Impact factor |
|---|---|
| Class A | 0.125 |
| 70R Tracked vehicle | 10% |
| 70R wheeled vehicle | 12% |

The live load is defined to the bridge in SAP 2000 v 19 by considering the wheel arrangement specified in IRC 6:2014, the wheel arrangement for 70R wheeled vehicle,70R tracked vehicle and for Class A Train of vehicle are shown in Figure 4 and Figure 5 respectively.

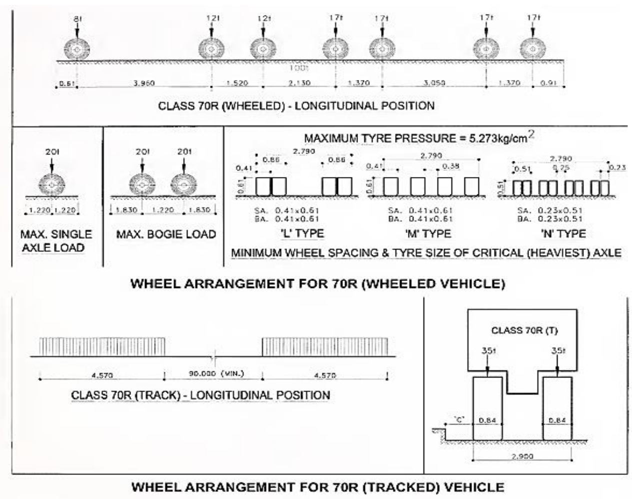


**Figure 4:** wheel arrangement for 70R wheeled and 70R tracked vehicle

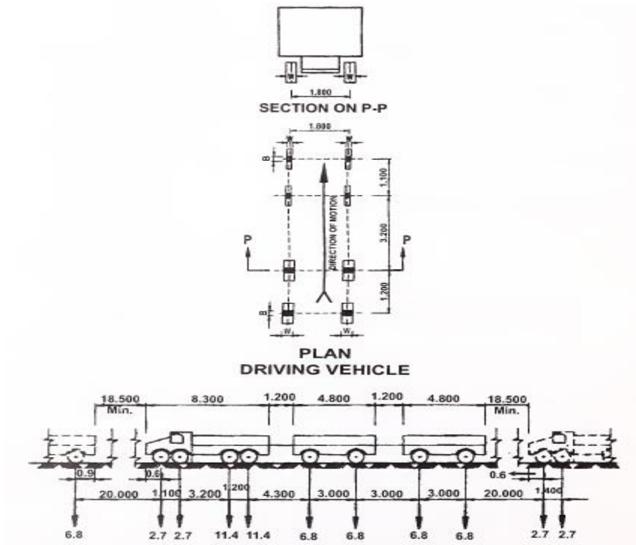


**Figure 5 :** Wheel arrangement for Class A train of vehicles

**B. Prestressing Force**

Prestressing force is calculated as per IS 1343:2012, the maximum initial prestress ($f_{pi}$) behind the anchorages shall not exceed 76% of ultimate tensile strength ($f_{pu}$) of the strand. As two cell box girder, there are three webs and six cables are provided in each web. Each cable consist of 16 strands (7 ply prestressed tendons having diameter of 12.7mm)

**Table 3.** Determination of prestressing force

| | |
|---|---|
| ultimate tensile strength ($f_{pu}$) of the strand | 183.7kN(Freyssinet manual) |
| Number of web | 3 |
| Number of cable in each web | 6 |
| Number of strands in each cable | 16 |
| Prestressing force | 40208kN |

The tendon profile of the bridge along the full span is shown in figure 6.

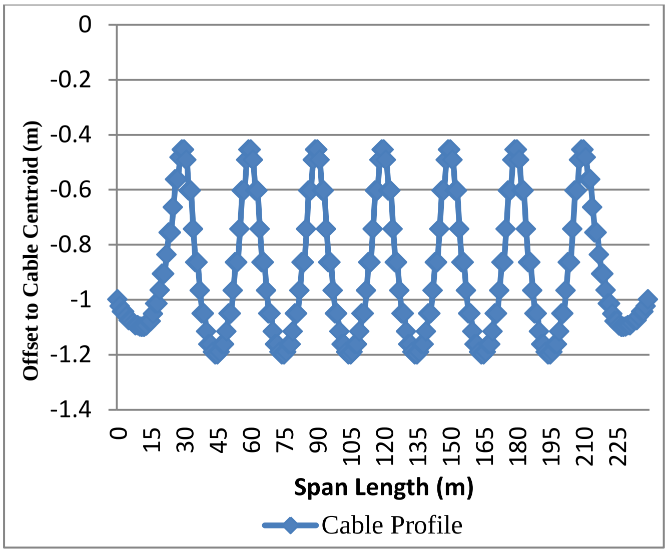


**Figure 6:** Tendon profile for the entire span of bridge

## IV. RESULTS AND DISCUSSION

### A. Bending Moment and Shear Force:

The bending moment, shear force and deflection of the bridge due to dead load, Super imposed dead load, and live load are obtained by analysing the bridge in SAP 2000 v 19. Live load includes class A vehicles, 70R wheeled and 70R tracked vehicles.

The bending moment for 8 spans at the mid span (0.5L) due to dead load, super imposed dead load, live load is shown in table 4.

**Table 4.** Bending moment for 8 spans at 0.5L

| Span No. | DL (KNm) | SIDL (kNm) | LL (kNm) | Total (kNm) |
|---|---|---|---|---|
| 1 | 8940 | 2157 | 5040 | 16137 |
| 2 | 4010 | 982 | 4173 | 9165 |
| 3 | 5291 | 1287 | 4114 | 10692 |
| 4 | 4976 | 1212 | 4109 | 10297 |
| 5 | 4976 | 1212 | 4109 | 10297 |
| 6 | 5291 | 1287 | 4114 | 10692 |
| 7 | 4010 | 982 | 4173 | 9165 |
| 8 | 8940 | 2157 | 5040 | 16137 |

The shear force for 8 spans at 0.9L of each span due to dead load, super imposed dead load and Live load is shown in table 5.

**Table 5.** Shear force for 8 spans at 0.9L

| Span No. | DL (kN) | SIDL (kN) | LL (kN) | Total (kN) |
|---|---|---|---|---|
| 1 | 2091 | 506 | 882 | 3479 |
| 2 | 1529 | 372 | 848 | 2749 |
| 3 | 1677 | 407 | 844 | 2928 |
| 4 | 1636 | 397 | 843 | 2876 |
| 5 | 2656 | 402 | 843 | 3901 |
| 6 | 1615 | 392 | 843 | 2850 |
| 7 | 1762 | 428 | 837 | 3027 |
| 8 | 1221 | 294 | 746 | 2261 |

### B. losses of Prestress:

For the present study the type of prestressing selected is post tensioning, both immediate loss and time depended losses are considered as specified in IS 1343:2012 and are shown in Table 6

Total loss of prestress = 23.7%

**Table 6.** Losses of prestress

| Immediate loss | Loss value (MPa) | Time depended loss | Loss value (MPa) |
|---|---|---|---|
| Loss due to elastic deformation of concrete | 26.05 | Loss due to relaxation of strees in steel | 52.30 |
| Loss due to friction | 6.69 | Loss due to shrinkage of concrete | 28.35 |
| Loss due to anchorage slip | 39 | Loss due to creep of concrete | 78.29 |
| Total | 71.74 | Total | 106.64 |
| Percentage | 23.7% | | |

### C. Allowable Stress

The allowable stress at top and bottom fiber at transfer and at service condition is checked as per IS 1343:2012 clause 24.3.2. The allowable stress at transfer and service condition depends on the cube strength of concrete at transfer and at service respectively. For the present study M45 grade of concrete is used. At support of each span top fiber is at tension and bottom fiber is at compression, at the centre of each span top fiber is at compression and bottom fiber is at tension. The maximum stresses at transfer and at service for each span and their corresponding length is shown in Table 7.

**Table 7.** Stress at top and bottom fiber

| Span No. | Span (m) | At transfer | | At service | |
|---|---|---|---|---|---|
| | | Top fiber (MPa) | Bottom fiber (MPa) | Top fiber (MPa) | Bottom fiber (MPa) |
| 1 | 0.9L | 8.26 | 4.08 | 8.24 | 3.63 |
| 2 | 1L | 8.9 | 2.95 | 6.25 | 3.52 |
| 3 | 0L | 8.9 | 2.95 | 7.26 | 3.35 |
| 4 | 1L | 8.67 | 3.27 | 6.9 | 3.88 |
| 5 | 0L | 8.67 | 3.27 | 7.01 | 3.72 |
| 6 | 1L | 8.9 | 2.95 | 6.93 | 3.84 |
| 7 | 0L | 8.9 | 2.95 | 7.14 | 3.52 |
| 8 | 0.1L | 8.26 | 4.08 | 8.24 | 3.63 |

Compressive stress

At transfer =4.08 MPa <0.455 $f_{ci}$ = 13.65 MPa

At service = 8.24 MPa < 0.38 $f_{ck}$ = 17.1 MPa

Hence safe

### D. Check for Flexural Strength

According to IRC 18:2000 ultimate strength for severe exposure condition is given by 1.5DL+2SIDL+2.5LL.

Ultimate moment for the first span

$M_u$ = 30324 kNm

under ultimate load condition the failure may either occur by

Failure by yield of steel

$M_{ult} = 0.9\ d_b\ A_s\ f_p$

$M_{ult}$ = 66801.033kNm > 30324 kNm

Hence safe

Failure by crushing of concrete

$M_{ult} = 0.176\ b\ d_b^2\ f_{ck} + (2/3)\ 0.8\ (B_f - b)\ (d_b\text{-}t/2)\ t\ f_{ck}$

$M_{ult}$ = 51057.004 kNm > 30324 kNm

Hence safe

### E. Check for Deflection

According to IS 1343:2012 total deflection due to prestressing force (PSG), Dead load (DL), super imposed dead load (SIDL) and Live load (LL) should not be greater of span/350 mm or 20mm (whichever is less) and the total deflection due to Dead load (DL) and prestressing force (PSG) should not be greater than span/250.

**Table 8.** Deflection

| Deflection (mm) | |
|---|---|
| DL+PSG | DL+PSG+SIDL+LL |
| 6.514 | 6.147 |
| Permissible = 12mm | Permissible = 20mm |
| 6.514mm < 12mm | 6.147 mm < 20mm |

The deflection due to DL and PSG along the entire span of bridge is shown in figure 7 and deflection due to DL , SIDL, LL and PSG along the entire span is shown in figure 8

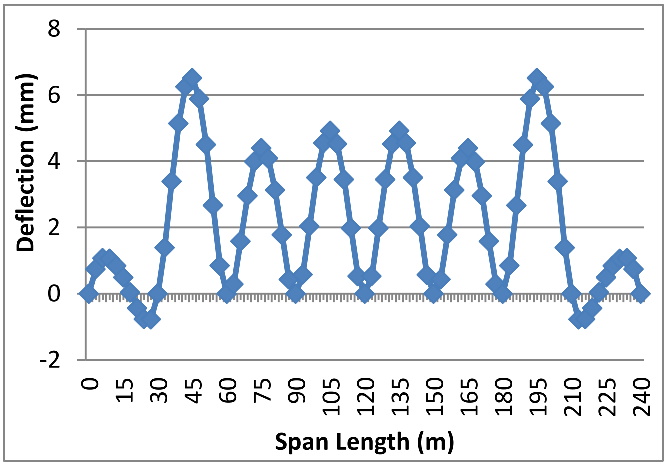


**Figure 7:** Deflection due to DL and PSG along the entire span of the bridge

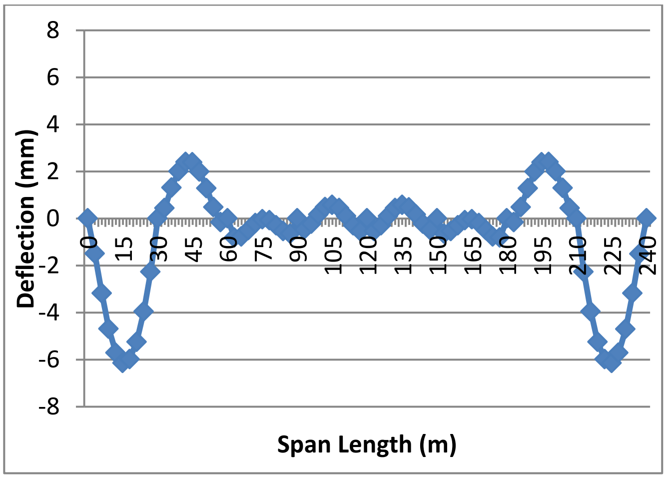


**Figure 8**: deflection due to DL, SIDL, LL and PSG along the entire span of the bridge

### F. Reinforcement Design in Box Girder Bridge

The section at anchorage of the box girder bridge is designed.The concrete chosen is of M45 grade and steel is of grade Fe 415 is used.

| | |
|---|---|
| Effective prestressing force | = P (1-loss) |
| Prestressing force P | = 40208 kN |
| Total percentage loss | =23.7% |
| Effective prestressing force | = 30678.7kN |
| d | = 1800m |
| $b_w$ | = 800mm |

Assume 200mm wide and 200mm deep distribution plate located concentrically at centre

According to IRC 18:2000 end blocks are selected

| | |
|---|---|
| $Y_{po}$ | = 30mm |
| $Y_o$ | = 100mm |
| $Y_{po}/Y_o$ | = 0.3 |

From table 8 of IRC 18:2000

| | |
|---|---|
| $F_{bst}/P_k$ | = 0.23 |
| $P_k$ | = 2939.2 kN |
| $F_{bst}$ | = 676.016 kN |

According to IRC 18:2000 clause 15

Area of steel in longitudinal and transverse direction = 0.18% area of web

| | |
|---|---|
| Area of web | = 1444200 $mm^2$ |
| $A_{st}$ | = 2599.56$mm^2$ |

Provide 16mm diameter bars at 125mm c/c in horizontal and vertical direction, same reinforcement is provided up to 750mm in longitudinal direction and same reinforcement in other web also.

1) Side face reinforcement:

According to IS 1343:2012 clause 19.6.3.3. When depth of the web exceeds 500mm

| | |
|---|---|
| Minimum area of steel | = 0.05% of web |
| Area of web | = 1444200$mm^2$ |
| $A_{st}$ | = 722.1 $mm^2$ |

Provide 8 – 12mm dia bars on each face of the web.

2) Main reinforcement:

| | |
|---|---|
| Minimum longitudinal (HYSD bars) reinforcement | = 0.15% of total concrete area |
| Total area | = 7002900$mm^2$ |
| $A_{st}$ | = 10504.35 $mm^2$ |

Provide 16 mm dia bars at 120 mm c/c

3) Top slab and soffit slab:

According to IRC 18:2000

0.18% of gross cross-sectional area for HYSD bars

| | |
|---|---|
| Area | = 2125000 $mm^2$ |
| $A_{st}$ | = 3825 $mm^2$ |

Provide 16 mm dia bars at 100 mm c/c

The reinforcement is equally distributed at the top and bottom slab.

For avoiding fissure cracks at chamfer location 16mm dia bars at 150 mm c/c and 12mm dia bars at 300mm c/c is provided. Reinforcement detailing for the cross-section of box girder for anchorage section is shown in Figure 9.

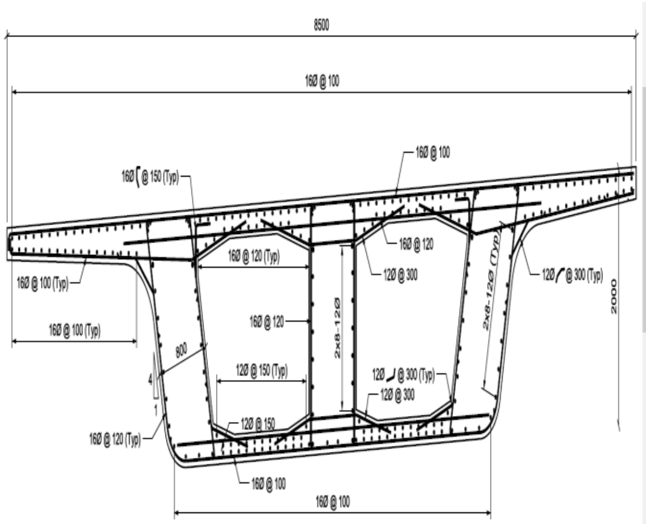


**Figure 9**: Reinforcement detailing of the section at anchorage

## V. CONCLUSION

After completing the analysis and design of post tensioned box Girder Bridge I have reached at the following conclusion.

- The un-tensioned steel required for the box girders are less because post tensioned tendons act as main reinforcement.
- In case of post tensioned box girder bridge, the deflection due to dead load and prestressing force are low and are within the permissible limits.
- The deflection due to Dead load, live load, super imposed dead load and prestressing force is also low and within the permissible limits.
- The max compressive stress at transfer and at service condition for top and bottom fiber is checked with allowable stresses and is within the permissible limits as specified by IS 1343:2012.
- The ultimate flexural strength for severe exposure condition centre of span are checked against failure by yield of steel and failure by crushing of concrete as specified by IRC 18:2000 and is safe.
- Immediate loss and time depended losses are calculated as per IS 1343:2012 for post tensioning systems and the total percentage loss are within the limits.
- In case of box girder bridges the slab thickness and self weight of the bridge is reduced.
- As post tensioning method of prestressing is used the more strength of the concrete is utilised
- For post tensioned box girder bridges precast sections are used so the time for construction is considerably reduced.

- The cable profile has been determined so as to suit the bending moment diagram and parabolic cable profile adopted in the box girder is found to be most suitable.

## VI. ACKNOWELDGEMENT

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