Analysis and Design of Prestressed Box Girder Bridge by IRC: 112-2011

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Abstract: *Bridge construction today has achieved a worldwide level of importance. Bridges are the key elements in any road network and use of prestress girder type bridges gaining popularity in bridge engineering fraternity because of its better stability, serviceability, economy, aesthetic appearance and structural efficiency. In this thesis analysis and design of prestressed concrete bridges (Deck Slab, T-Girder and Box Girder) are carried out using IRC:112-2011. The unified concrete code (IRC:112) published by the Indian Road Congress in November 2011 combining the code for reinforced concrete and prestressed concrete structures represents a new generation code, which is significantly different as compared to previous codes (i.e. IRC:21 for RCC structures and IRC:18 for PSC structures). IRC:21 and IRC:18 stands withdrawn, with the publication of IRC:112. The fundamental difference between IRC:112 and old codes is that IRC:112 based on limit state theory while the previous codes were based on working stress design philosophy.*

Keywords: *prestress, Deck slab, T-slab, Box Girder, IRC:112.*

1. INTRODUCTION

Bridges are defined as structures which are provided a passage over a gap without closing way beneath. They may be needed for a passage of railway, roadway, footpath and even for carriage of fluid, bridge site should be so chosen that it gives maximum commercial and social benefits, efficiency, effectiveness and equality. Bridges are nation's lifelines and backbones in the event of war. Bridges symbolize ideals and aspirations of humanity. They span barriers that divide, bring people, communities and nations into closer proximity. They shorten distances, speed transportation and facilitate commerce. Bridges are symbols of humanity's heroic struggle towards mastery of forces of nature and these are silent monuments of mankind's indomitable will to attain it. Bridge construction constitutes an importance element in communication and is an important factor in progress of civilization, bridges stand as tributes to the work of civil engineers.

Classification of Bridges:

Bridges are classified based on different criteria as follows

- According to function as aqueduct (canal over a river), viaduct (road or railways valley, pedestrian, highway, railway, road-cum-rail or pipe line bridge.

- According to material of construction of super structure as timber, masonry, iron, steel, reinforced concrete, prestress concrete, composite or aluminum bridge.

- According to form or type of super structure as slab, beam, truss, arch, suspension bridge.

- According to inter span relation as simple, continuous and cantilever bridge.

- According to position of bridge floor relative to superstructure as a deck, trough, half-trough or suspension bridge.

- According to span length as culvert (less than 8m), minor bridge (8m to 30m) or long span bridge.

2. BASIC CONCEPT OF PRESTRESSING

Prestressing is the application of an initial load on a structure, to enable it to counteract the stresses arising from subsequent loads during its service period. prestressing has been practiced from ancient times the behaviour of spokes of the bicycle when it is loaded, is also example of prestressing. Prestressed concrete is basically a concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from external loads are counteracted to desired degree. In reinforced concrete members, the prestress is commonly the steel reinforcement.

The minimum grade of concrete in prestressing technique is M40 for pre tensioning and M35 for post tensioning. The tensile strength of concrete is only 8-14% of its compressive strength of concrete.
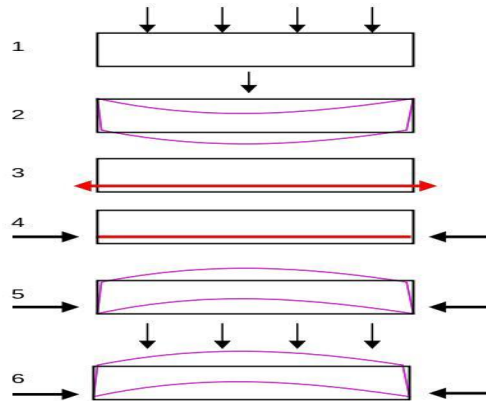

**Fig1.1.** *Behavior of RC member with and without prestressing*

Types of Prestress Girders and its Purposes:

One of the most commonly used forms of superstructure in concrete bridges is precast girders with cast-in-situ slab. This type of superstructure is generally used for spans between 20 to 40 m. Majority of prestress concrete bridges, constructed in India are post tension type. The span to depth ratio is usually kept as 20 for simply supported spans and 25 for continuous spans. The girder spacing of 2 to 3 m. The deck slab overhang should be provided as required to provide the desirable aesthetic effect and to reduce transfer moments. Different types of girder bridges as shown in Figure 2.1

a. Cross section of T-Girder with cast in situ deck
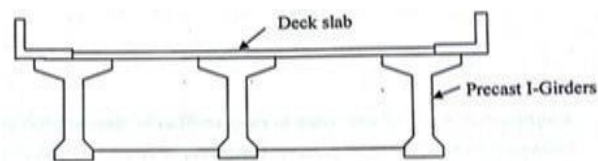
b. I-Girder with cast in situ deck
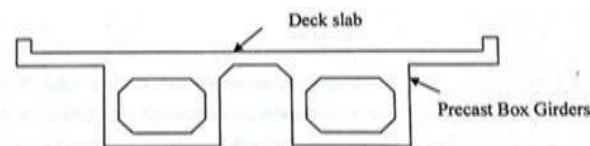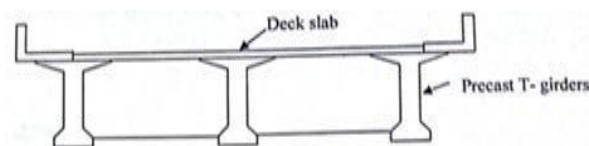

c. Box girder with cast in situ deck

**Fig2.1.** *Different types of girder sections*

3. FINITE ELEMENT METHOD

The finite element method is a technique for analyzing complicated structure by nationality cutting up the continuum of the prototype into a number of small elements which are connected at discrete joints called nodes. For each element, approximate stiffness equation are derived relating the displacements

of the nodes to the node forces between elements and, in the same way that slope defection equations can be solved for joints in a continuous beam, an electronic computer is used to solved the very large number of simultaneous equations that relate node forces and displacements.
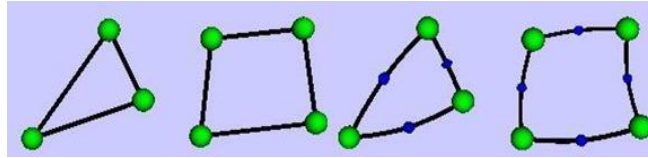
a) 3 Noded Triangle, 4 Noded Quadrilateral, 6 Noded Triangle, 8 Noded Quadrilateral
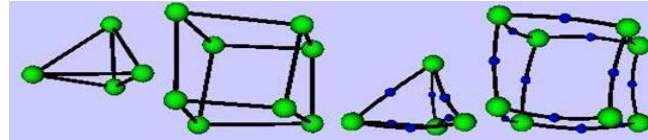
b) 9 Noded Hexahedron, 10 Noded tetrahedron, 20 Noded Curved solid

4. IRC RECOMMENDATIONS ON DESIGN OF BRIDGES

The first and major step in any bridge analysis is selection of type of loading, they are dead load, live load, impact effect, wind load, longitudinal force due to tractive effort of vehicles, longitudinal force due to braking of vehicle, seismic effects, earth pressure, vehicle collision forces etc. Out of these loads live load plays a major role.

Vehicle Live Loads:

Vehicle live loads are categorized based on their configuration and intensity as IRC Class 70R, IRC Class AA (tracked and wheeled type), IRC Class A and IRC Class B loading.

Load Combinations:

All critical loading stages shall be investigated. The stages stated below

- At the stage of prestressing

- construction stages including temporary loading, transport, handling and erection or any occasional loads that may occur during launching of girders

- design loads according to IRC:6 that includes service dead load, prestress with full losses and service dead load, live load and prestress with full losses

- For the combination of loads with differential temperature gradient effects, maximum 50 per cent live load shall be considered

- Ultimate strength: A prestressed concrete members checked for failure conditions at an ultimate load of

a.1.25 G + 2 SG + 2.5 Q---under moderate conditions

b.1.5 G + 2 SG + 2.5 Q--- under severe exposure conditions.

- For sections, where the dead load causes effects opposite to those of live loads shall be checked for G + SG + 2.5 Q.

Calculation of Ultimate Strength:

There are two conditions of failure at which strength should be calculated and minimum of these shall be considered for design. They are

a) Failure by yield of steel

$$M_{ult} = 0.9\ d_b\ A_s\ f_p \qquad\qquad (2.1)$$

b) Failure by crushing of concrete

$$M_{ult} = 0.176\ b\ d_b^2\ f_{ck} \qquad\qquad (2.2)$$

5. ANALYSIS OF BOX GIRDER BRIDGES

The methods for the analysis of box girder bridges are as follows

- Simple line analysis or beam analysis
- Grillage analysis
- BEF Analysis (Beams on elastic foundation)
- Space frame analysis
- Finite element method

For study of box girder bridges finite element method is more accurate method.

5.1. Description of Model

Loading on Box Girder Bridge:

The various type of loads, forces and stresses to be considered in the analysis and design of the various components of the bridges are given in IRC 6.

Thickness of Web:

The thickness of the web shall not be less than d/36 plus twice the clear cover to the reinforcement plus diameter of the duct hole where 'd' is the overall depth of the box girder measured from the top of the deck slab to the bottom of the soffit or 200 mm plus the diameter of duct holes, whichever is greater.

Thickness of Bottom Flange:

The thickness of the bottom flange of box girder shall be not less than 1/20 th of the clear web spacing at the junction with bottom flange or 200 mm whichever is more.

Thickness of Top Flange:

The minimum thickness of the deck slab including that at cantilever tips be 200 mm. For top and bottom flange having prestressing cables, the thickness of such flange shall not be less than 150 mm plus diameter of duct hole.

Losses in Prestress:

While assessing the stresses in concrete and steel during tensioning operations and later in service, due regard shall be paid to all losses and variations in stress resulting from creep of concrete, shrinkage of concrete, relaxation of steel, the shortening (elastic deformation) of concrete at transfer, and friction and slip of anchorage.

Calculation of Ultimate Strength:

Ultimate moment resistance of sections, under these two alternative conditions of failure shall be calculated by the following formulae and the smaller of the two values shall be taken as the ultimate moment of resistance for design.

Failure by Yield of Steel

$M_{ult} = 0.9 \, d_b \, As \, F_p$

Failure by Crushing of Concrete

$M_{ult} = 0.176 \, b \, d_b^2 \, f_{ck}$ (5.1)

6. ANALYSIS AND DESIGN OF POST TENSIONED DECK TYPE BOX GIRDER BRIDGE

A post tensioned deck type box girder bridge of clear span 30 m and width of roadway is 7.5 m is considered for the analysis. Live loads are taken as per IRC:6. Cross section of box girder is shown in Figure 6.1 and mathematical modeling is done using SAP2000 and is shown in Figure 5.3. The overhang face of the girder is 1.2 m and deck slab thickness is 0.25 m. Bottom slab thickness is 0.25 m and girder thickness is 0.35 m. Material properties used are M50 grade of concrete and Fe415 grade steel. The tendon profile considered is parabolic in nature. The Bridge analysis for different span to depth ratios (L/d) ratio starting from 15 to 19 and different span to depth ratios (L/d) are considered as follows.

Case1 L/d= 15, d= 2.0

Case2 L/d=16, d= 1.9

Case3 L/d=17, d= 1.8

Case4 L/d= 18, d= 1.7

Case5 L/d= 19, d= 1.6 (5.2)
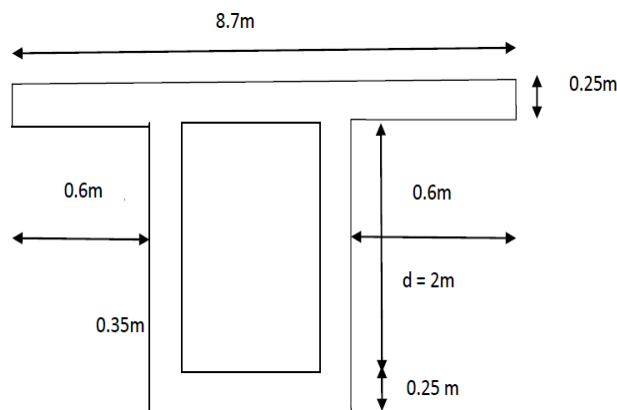
6.1Cross Section of Box-Girder

6.1. Mathematical Modeling

The mathematical model of a box girder bridge having a span of 30 m is shown in Figure6.2
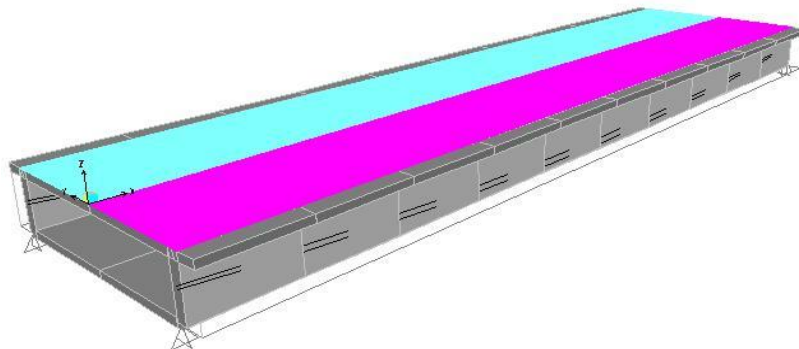

Fig6.2. *Modeling of box girder bridge*

The tendon profile considered for the design of post tensioned box girder bridge is parabolic and mathematical model is shown in Figure 6.3
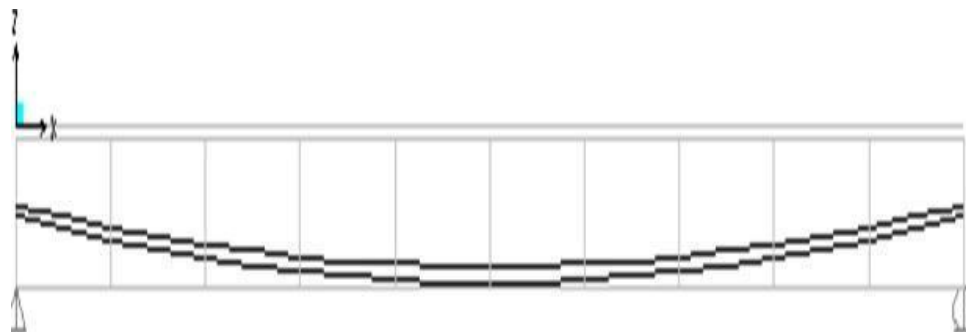
Fig6.3. *Tendon profile*

6.2. Validation of Results

The bending moment, shear force and deflection results are obtained by using SAP2000. The bending moment and shear force are obtained by considering different loading conditions consisting of dead load, super imposed dead load and live load. The results are shown below for case 1. The variation of bending moment and shear force along the length up to mid span is shown in Tables 6.1 and 6.2.

Table 6.1. *Bending moment variation along span (tm)*

Span (m)	0L	0.1L	0.2L	0.3L	0.4L	0.5L
DL	0	526	934	1226	1400	1459
LL	0	218	381	495	565	588
SIDL	0	62	110	145	165	172
Total	0	806	1425	1866	2130	2219

Table 6.2. *Shear variation along span (kN)*

Span (m)	0L	0.1L	0.2L	0.3L	0.4L	0.5L
DL	194	156	117	78	39	0
LL	80	72	57	41	23	0
SIDL	23	18	14	9	5	0
Total	297	246	188	128	67	0

Moment due to DL+SIDL (M_g) = 1631 tm

Total Maximum moment (M_t) = 2219 tm

Initial Stresses:

f_{ck} = 50 MPa

fci= 40 MPa

fct= 20 MPa

f_{cw} = 16.5 MPa

ftt= 2 MPa

f_{tw} = 0 MPa

fbr= 16 MPa

Loss ratio= 0.8

The variation of prestress force, eccentricity and number of cables with respect to span to depth ratios are summarized in Table6.3

Table 6.3. *Calculation of prestress force and eccentricity*

L/d	15	16	17	18	19
f_{sup} (MPa)	1.57	1.59	1.6	1.62	1.64
f_{inf} (MPa)	0.81	0.78	0.76	0.73	0.7
Prestressing Force P (kN)	5428	5370	5309	5251	5194
e (mm)	850	800	750	700	650
using the freyssinet system, anchorage type 7K-15 in 65mm cable ducts (IS:6006-1983)					
No of Cables	4	4	4	4	4

The following checks are performed for the above mentioned case1.

Check for Section Modulus:

Required section modulus Z_{req} = 571 x 10^6 mm^3

Provided section modulus Z_{pro} =341 x 10^8 mm^3

Z_{pro}> Z_{req}, Hence the section provided is adequate.

Check for Stresses:

At transfer stage

Stress at top = 1.52 MPa < f_{ct}

Stress at bottom = 0.87 MPa < f_{tt}

At working stage

Stress at top = 1.4 MPa < f_{cw}

Stress at bottom = 0.48 MPa (As per IS1343:1980 there is no tensile stress)

All the stresses at top and bottom fibers at transfer and service loads are well within the permissible limits.

Check for Flexural Strength:

For the centre of span section

According to IRC: 18-2000,

$M_u = 1.5 M(G) + 2 M(SG) + 2.5 M(Q)$

$M_u = 40025$ kNm

The ultimate flexural strength is calculated as follows

Failure by Yielding of Steel

$M_u = 0.9 d_b A_p f_p$

$M_u = 118244$ kNm

Failure by Crushing of Concrete

$M_u = 0.176 b_w d^2 f_{ck} + (2/3) 0.8 (b-b_w) (d-0.5D_f) D_f f_{ck}$

$M_u = 234556$ kNm

The ultimate flexural strength $M_u = 118244 > 40025$ kNm, Hence safe.

Deflection Check:

Table 6.4. *Check for deflection*

Span/Depth	Prestressing Force (kN)	Eccentricity (mm)	Deflection (mm)		
			DL+SIDL	DL+SIDL+PRE	DL+LL+PRE+SIDL
15	5428	850	14	11	18

Maximum permissible deflection according to IS: 1343-1980, Deflection due to self weight + prestress + live load = span / 350 or 20 mm, whichever is less Permissible deflection = minimum of (86 or 20) =20 mm > 18 mm Hence safe.

6.3. Design of Reinforcement in Box Girder Bridge

Design of End Block

P=5428 kN

b_w=350 mm

d=1800 mm

Assume 200 mm wide and 200 mm deep distribution plate, located concentrically at center.

$Y_{po}/y_o = 0.57$

As per IRC18:2000, from table 8. $F_{bst}/P_k = 0.149$

$F_{bst} = 404$kN

$A_{st} = 1119$mm^2

Provide 12 mm diameter bars @ 100 mm c/c in horizontal direction and in vertical direction also same reinforcement provided up to 750 mm in longitudinal direction and same reinforcement to other web also.

Side Face Reinforcement

Ast = 315 mm^2

Provide 6-12 mm diameter on each face of web.

Design of Deck Slab

Bending moment = 2219 kNm

Depth required= 201 mm

Depth provided= 250 mm safe.

Main Reinforcement

Ast = 4256 mm^2

Providing 16 mm diameter bars 100 mm c/c

Design of Transverse Reinforcement

M = 0.3 ML + 0.2 (MDL + MSIDL) M = 503 kNm

Ast = 1235 mm^2

Providing 12 mm diameter bars @ 160 mm c/c

The detailing of side face reinforcement as shown in Figure 6.4 and cross sectional detailing as shown in Figure .6.5
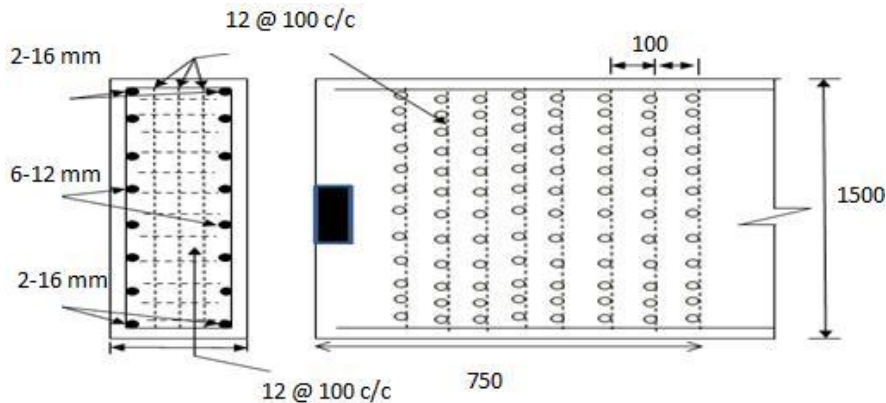
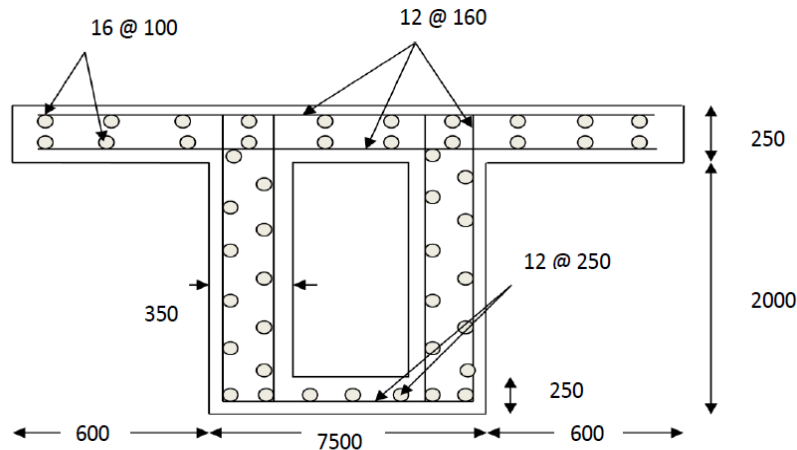

Figure6.4. *Side face reinforcement detailing*

Figure6.5. *Cross sectional view (all dimensions are in mm)*

6.4. Comparison of Results for Various Span to Depth Ratio

The comparison of prestress force, deflection and stresses values are obtained for various span/depth ratios for box girder bridge as shown in Table 6.5.

Table6.5. *Comparison of prestress force and deflection for various span to depth ratio*

Span/Depth	Prestressing Force (kN)	Eccentricity (mm)	Deflection (mm)		
			DL+SIDL	DL+SIDL+PRE	DL+LL+PRE+SIDL
15	5428	850	14	11	18
16	5370	800	16	12	20
17	5309	750	17	13	23
18	5251	700	19	16	26
19	5194	650	22	18	29

The comparison of stresses at transfer and working stage for various span to depth ratios for box girder bridge as shown in Table 6.6.

Table 6.6. *Comparison of stresses for various span/ depth ratio*

Span/Depth	15	16	17	18	19	units
	At the Transfer Stage					
Stress at Top	1.52	1.51	1.5	1.49	1.48	Mpa
Stress at Bottom	0.87	0.87	0.87	0.87	0.88	Mpa
	At the Working Stage					
Stress at Top	1.41	0.43	0.43	0.42	0.41	Mpa
Stress at Bottom	0.48	-0.48	-0.47	-0.46	-0.45	Mpa

7. CONCLUSIONS

From the analysis and design of post tensioned box girder bridge for various span to depth ratios the following observations are made.

- The various span to depth ratio are taken for the analysis of box girder bridges, and for all the cases, deflection and stresses are within the permissible limits.

- As the depth of box girder decreases, the prestressing force decreases and no of cables decreases. Because of prestressing, more strength of concrete is utilized and also well governs serviceability.

- New code (IRC:112) requires increased cover for pre tensioned strands as well as post tensioned ducts, which will lead to increased thickness of webs and deck slab / soffit slabs for PSC girders / PSC box girder bridges.

- For the same cross section and same applied moment, steel difference is quite noticeable compare to WSM, LSM consumes less steel than WSM and its better to change grade of steel rather increasing grade of concrete for more %p steel difference.

REFERENCES

[1] Barr, P.J. (2008). "Comparison of prestress losses for a prestress concrete bridge made with high performance concrete", *J. Bridge Eng.*, ASCE, 13 (5), 468-475.

[2] Byung Hwan Oh, In Hwan Yang (2001). "Realistic long term prediction of prestress forces in psc box girder bridges", *J. Structural Eng.*, ASCE, 127 (9), 1109-1116.

[3] Chang-Su Shim, Pil-Goo Lee, Sung-Pil Chang (2001). "Design of shear connection in composite steel and concrete bridges with precast decks", *J. Bridge Eng.*, ASCE, 15 (3), 725-733.

[4] Dereck J. Hodson, Paul J. Barr, and Marvin W. Halling (2012). "Live-Load Analysis of Post-tensioned Box-Girder Bridges", *J. Bridge Eng.*, ASCE, 17(4), 644-651.

[5] Gonzalo R., Angel, C. A., Gonzalo R. and Juan R.C. (2000). "Externally prestressed high strength concrete viaduct", *J. Bridge Eng.*, ASCE, 26 (4), 337-345.

[6] IRC: 18.(2000). Design criteria for prestressed concrete road bridges (post tensioned concrete), IRC, New Delhi, India.

[7] IRC: 6. (2010). Loads and stresses, IRC, New Delhi, India.

[8] IRC:112. (2011). Code of practice for concrete bridges, IRC, New Delhi, India.

[9] IS1343.(1980). Indian Standard code of practice for prestressed concrete (First Revision), BIS, New Delhi,India.

[10] Jarret Kasan, s. m., Kent, A. H. (2011). "Redevelopment of prestressing force in severed prestressed strands*", J. Bridge Eng.*, ASCE,16 (3), 431-437.

[11] John B. Kennedy and Mohamed H. Soliman (1987). "Temperature distribution in composite bridges" *J. Structural Eng.*, ASCE, 113 (3), 475-482.

[12] Krishna Raju, N. (1995). *Prestressed Concrete*, Tata McGraw- Hill Publishing company Limited, New Delhi.

[13] Leo E. Rodriguez, Paul J. Barr, Marv W. Halling (2013). "Temperature effects on a box girder, integral abutment bridge", journal of performance of constructed facilities, ASCE, 16(7), 548-553.

[14] Raina, V.K. (1994). *Concrete Bridge Practice-Analysis*, Design and Economics, McGraw- Hill Publishing Company Limited, New Delhi.

[15] S. Maleki (2002). "Effect of deck and support stiffness on seismic response of slab girder bridges", Engineering Structures, 24, 219-226.

[16] Vikash Khatri, Pramod Kumar Singh and P.R.Maiti (2012). "Comparative study of prestressed steel concrete composite bridge of different span length and girder spacing", International Journal of Modern Engineering Research, 2(5), 3917-3922.

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