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Finite Element Analysis of I-Girder Bridge

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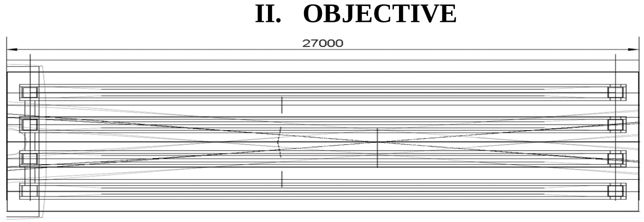
Abstract: In India railway bridge structures are widely designed with the method suggested by IRS – Concrete bridge code 1997. This Code of Practice applies to the use of plain, reinforced and prestressed concrete in railway bridge construction. It covers both in-situ construction and manufacture of precast units. The Code gives detailed specifications for materials and workmanship for concrete, reinforcement and prestressing tendons used in the construction of railway bridges. After defining the loads, forces and their combinations and requirements for the limit state design, particular recommendations are given for plain concrete, reinforced concrete and prestressed concrete bridge construction. The design of I-Girder bridge superstructure (deck slab and PSC I-beam) are done by calculating bending moments, shear forces, bending resistance in transverse direction, bending resistance in longitudinal direction, checking flexural cracking. The Design of PSC I-Girders is done for Bending moments and Shear forces by Dead Load, Super Imposed Dead Load (SIDL) and Live Loads (LL). The Shrinkage strain, Creep Strain and effect of Temperature rise and fall are also determined. The design is complete for Pre-stressing cables, un-tensioned reinforcements, End cross girder, Shear connectors. I-girder superstructures are the most commonly used superstructures at cross-over location in metro bridges in india, as it has the wide deck slab and it easily permits metro's to change tracks. I-Girder superstructure construction is component wise construction unlike U-Girders. I-Girders are constructed in casting yard and its deck slab is cast in situ, parapets are also installed on later stage.

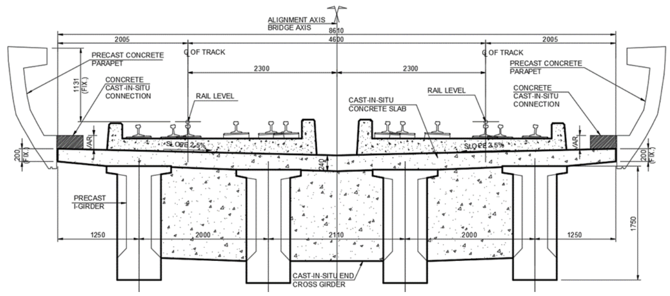
Keywords: SIDL effects, Live Load effects, Derailment effect, with or without 15% future PT margin

I. INTRODUCTION

A bridge is a structure designed to cross physical barriers, such as water, a water body, a valley, or a highway. Bridge designs vary depending on the function of the bridge, the nature of the land on which the bridge is built and established, the materials used to build it, and the funds available for its construction. Building a bridge is of global importance today. 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. Bridges are nation's lifelines and backbones in the event of war. These include barriers that divide people, societies, and nations, and bring them closer together. They shorten distances, speed transportation and facilitate commerce. Building bridges is very important in communication and an important element in the development of civilization. Bridges stand as an illustration of the work of civil engineers. In order to supply safer and larger speed of traffic, the route is made as straight as possible. Box girder bridges have gained wide acceptance in superhighway and bridge systems owing to their structural potency, higher stability, use ableness, economy of construction and pleasing aesthetics. In U.S, Bridge Engineers use the code of AASHTO "American Association of state highway and Transportation Officials"; this code will be adopted for style of the highway bridges with special needs. Similarly, Indian bridge engineers seek advice from the IRC (Indian Road Congress) commonplace to try to the planning. But the AASHTO commonplace Specification is adopted by several countries because the typically accepted code for bridge styles. The design parameters are check and verify by the structural analysis program (Cosi BRIDGE). Design is a very important part of the bridge that determines the safety of the general context and the basic cost of the project. Therefore, the choice of the correct and appropriate code will save ahigh value of the cost of construction, in addition to the safe and successful design. To decide the size (dimension) of the member and the amount of reinforcement required. To check the weather adopted section will perform safely and satisfactorily during the life time of the structure. Design philosophy, loading and unloading patterns and safety factors. Shear force and Bending Moment induced in the components, Reinforcement required for each design, from these comparative studies, we can have idea about the best design standards.

II. OBJECTIVE

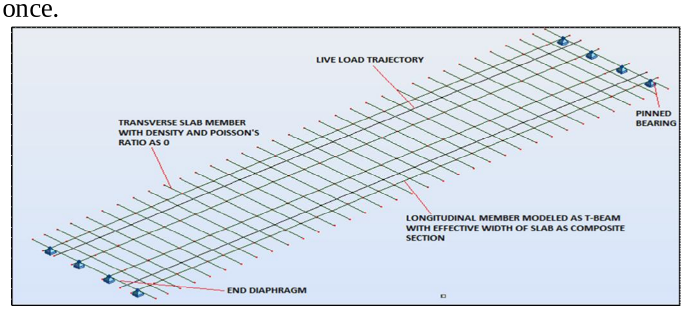




To design and analyse the I-Girder bridge superstructure. It is a component wise design system.
The design is done by considering the loads such as dead load, super imposed dead load and live load.
PSC I-Girders are being analysed by considering 15% margin for future PT.
Deck slab to be designed for normal live load cases and for derailment cases.

III. METHODOLOGY

The 3D model for the superstructure to be modelled in AUTODESK ROBOT software and is modeled as bar element taking into account the exact properties of I-Beam (at the support section and mid-section along with the properties of slab i.e. composite section) , diaphragm, and deck slab (modeled as bar element with unit weight=0 & Poisson's ratio=0), as per final design. In order to transfer loads from one I-Beam to the other transverse rigidity is provided in the form of transverse members which include diaphragms and slab. Bearing (whichever applicable) is provided underneath the I-Girder in order to extract the exact forces under each bearing. Longitudinal spacing of bars is as per the spacing of the I-girders and transverse spacing of bars varies depending on the section. Since cross girders are present here in the structure, in the modeling slab has been omitted from those portions. The clear reason being the rigidity of slab should be taken into account only once.

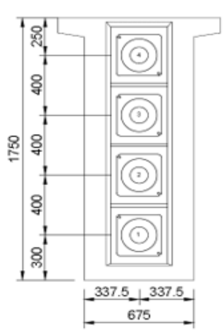


A. Longitudinal Analysis

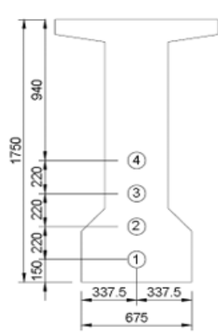
The extracted bearing forces and moments from AUTODESK ROBOT shall be applied on ST1 software and perform the longitudinal analysis for PSC I-Girder.
ST1 is a Finite elements Method programme. It takes into account the phenomena specified below:

1) *Actual Construction Stages:* Time variations of both topology and loading.
2) *Effect of Time on materials:* Creep, Shrinkage of concrete and Prestressing losses (instantaneous and long term losses)

The prestressing layout for I – Beam are shown below.



At Support



At Mid

B. Construction Sequence

The following are the construction stages which are considered for the verification of I-Beam.

STAGE	ACTION	WITH SECTION PROPERTIES
1.	Casting of I-beam in casting yard	Single I-beam only
2.	SW(Single I-beam) + PT(After Short term Losses due to PT)	Single I-beam only
3.	Stage 2 + Self Weight of slab + Diaphragm	Single I-beam only
4.	Stage 3 + SIDL	Composite Section :- I-beam + Slab
5.	Stage 4 + LL + Impact	Composite Section :- I-beam + Slab

C. Load Combinations

IRS CBC-1997 Table 12

LOAD		LIMIT STATE	γ_{fL} TO BE CONSIDERED IN COMBINATION				
			1	2	3	4	5
Dead weight of concrete		ULS SLS	1.25 1.00	1.25 1.00	1.25 1.00	1.25 1.00	1.25 1.00
Superimposed dead load		ULS SLS	2.00 1.20	2.00 1.20	2.00 1.20	2.00 1.20	2.00 1.00
Wind	During erection	ULS SLS	- -	1.25 1.00	- -	- -	- -
	with dead and superimposed dead loads only and for members primarily resisting wind loads.	ULS SLS	- -	1.60 1.00	- -	- -	- -
	With dead plus superimposed dead plus other appropriate combination 2 loads.	ULS SLS	- -	1.25 1.00	- -	- -	- -
	Relieving effect of wind	ULS SLS	- -	1.00 1.00	- -	- -	- -
Earth quake	During erection	ULS SLS	- -	1.25 1.00	- -	- -	- -
	With dead and superimposed dead loads only	ULS SLS	- -	1.60 1.00	- -	- -	- -
	With dead plus superimposed dead plus other appropriate combination 2 loads.	ULS SLS	- -	1.25 1.00	- -	- -	- -
Temperature	Restraint against movement except frictional	ULS SLS	- -	- -	1.50 1.00	- -	- -
	Frictional restraint	ULS SLS	- -	- -	- -	1.50 1.00	- -
	Differential temperature effect	ULS SLS	- -	- -	1.15 0.80	- -	- -
Differential settlement		ULS SLS	As specified by engineer				
Earth Pressure	Fill retained and or live load surcharge	ULS SLS	1.70 1.00	1.70 1.00	1.70 1.00	1.70 1.00	- -
	relieving effect	ULS	1.00	1.00	1.00	1.00	-
Erection temporary loads (when being considered)		ULS	-	1.30	1.30	-	-
Live load on foot path		ULS SLS	1.50 1.00	1.25 1.00	1.25 1.00	- -	- -
Live load		ULS SLS	1.75 1.10	1.40 1.00	1.40 1.00	- -	- -
Derailment loads		(As specified by bridge rules for combination 5 only)					

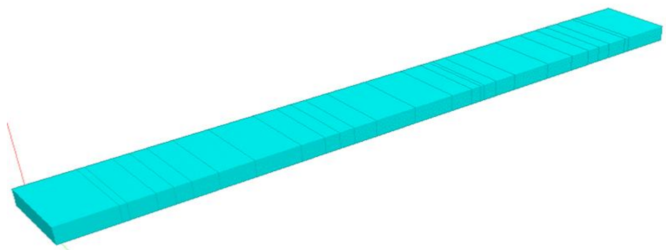
PSC I-Girders are design for load combination 1 as it is the critical case.

D. Design Criteria

Stage	*Allowable compressive strength*	*Value*	*Allowable tensile stress*	*Reference*
Construction	*0.5 fci but < 0.4 fck*	*24 MPa*	*-1 MPa*	*IRS*
Service	*0.4 fck*	*24 MPa*	*No tension*	

E. *Transverse Analysis*

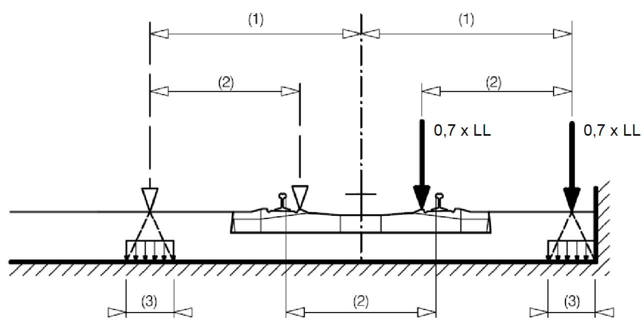
The transverse analysis is done for the most critical section of deck slab in STAAD Pro. Slab is designed as per meter width element choosing the most critical position of live load. The analysis is for the normal case and derailment cases.



F. *Derailment Load*

Vertical derailment load is calculated According to EN 1991-2 §6.7, two design situations shall be considered:

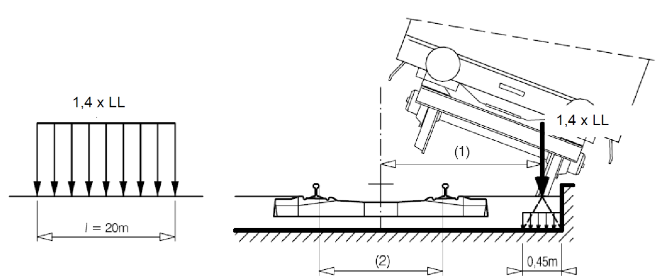
1) *Design Situation I:* derailment of railway vehicles, with the derailed vehicles remaining in the track area on the bridge deck with vehicles retained by the adjacent rail or an upstand wall. The part of the structure concerned shall be designed for the following design loads in the Accidental Design Situation: 1.4*LL parallel to the track in the most unfavourable position inside an area of width 1.5 times the track gauge on either side of the center-line of the track, as shown in the figure below:



a) : max 1.5s or less if against wall
b) : Track gauge (s)
c) : The point forces may be assumed to be distributed on a square of side 450mm at the top of the deck if vehicle remains on track plinth. If not, the point forces will be directly applied to the deck.

2) *Design Situation II:* derailment of railway vehicles, with the derailed vehicles balanced on the edge of the bridge of the bridge and loading the edge of the superstructure (excluding non-structural elements such as walk ways).

For this Design situation, the bridge should not overturn or collapse. For the determination of overall stability, a maximum total length of 20m of 1.4*LL(AW0) shall be taken as a uniformly distributed vertical line load acting on the edge of the structure under consideration, as shown in the figure below:



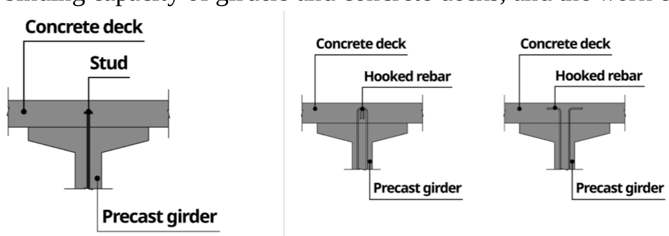
a) Load acting on edge of structure
b) Track gauge (s)

G. Design Criteria

M/Mu	ALLOWABLE Fc (Mpa)	ALLOWABLE Fs (Mpa)	ALLOWABLE CRACK WIDTH (mm)
M/Mu < 1	0.5 Fck	0.75 Fy	0.25

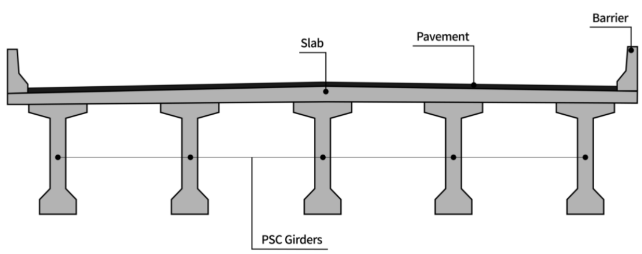
H. Shear Connectors

The shear connector is installed on the girder and integrated with the concrete deck so that girder and the concrete deck work together. It is mainly installed by embedding the shear connector in the concrete girder. As for the forms of the shear connectors have been proposed and studied in consideration of the binding capacity of girders and concrete decks, and the work efficiency of construction workers.



IV. CONCLUSION

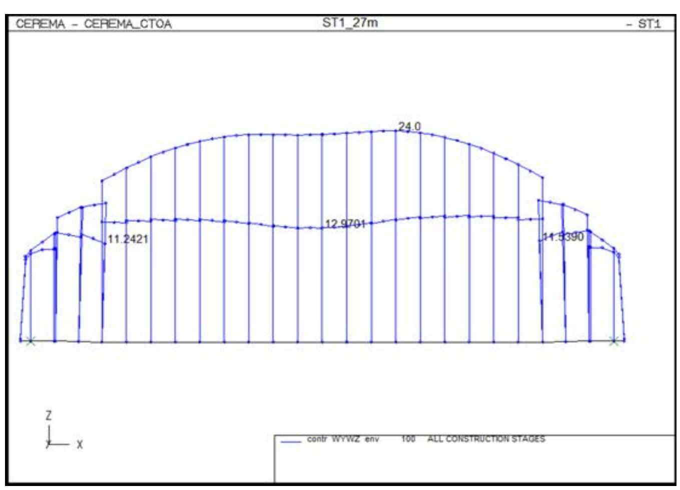
The bridge can be composed of 1 span or multi span with 20~40m per span. Depending on the shape and construction method of the beam, the length of one span can be as long as 50m.



The grillage model distributes the loads through transverse members.
Depending upon the bending moment diagram obtained from AUTODESK ROBOT software a parabolic cable profile is provided.

A. Stresses in Construction stage (with 15% margin)

1) Beam Bottom



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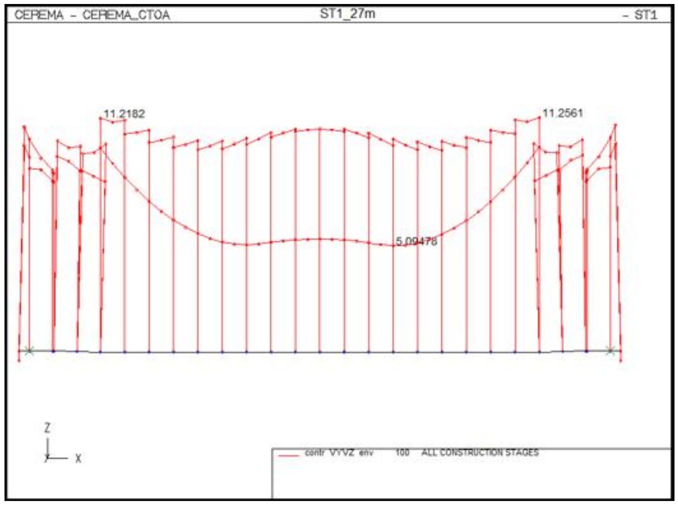
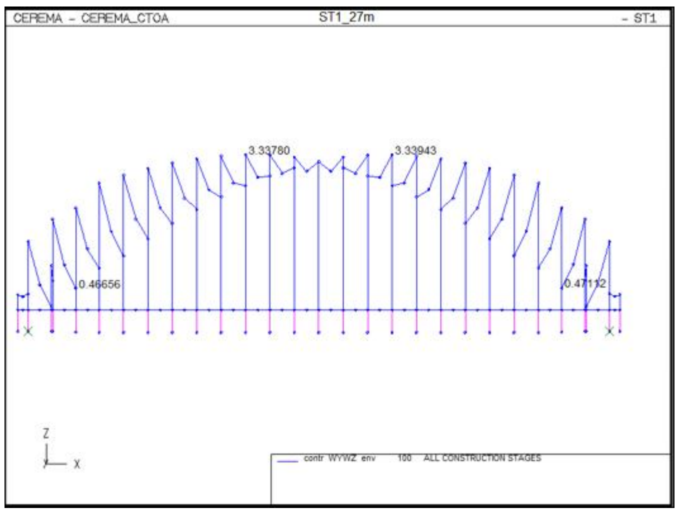
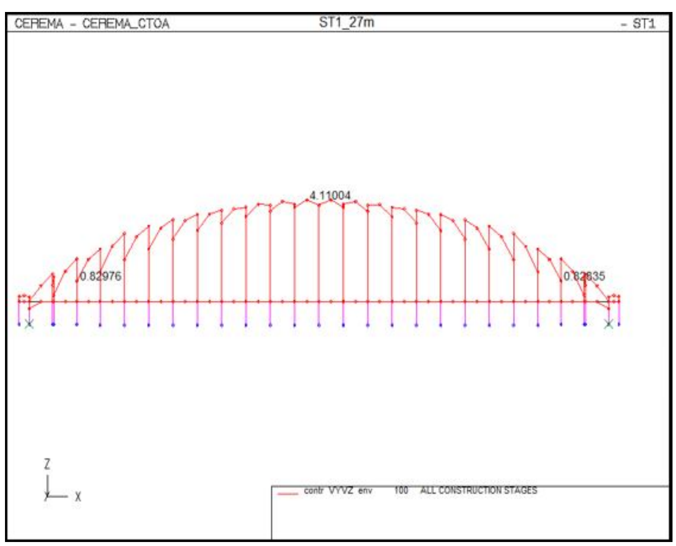
2) Beam Top



3) Slab Bottom



4) Slab Top



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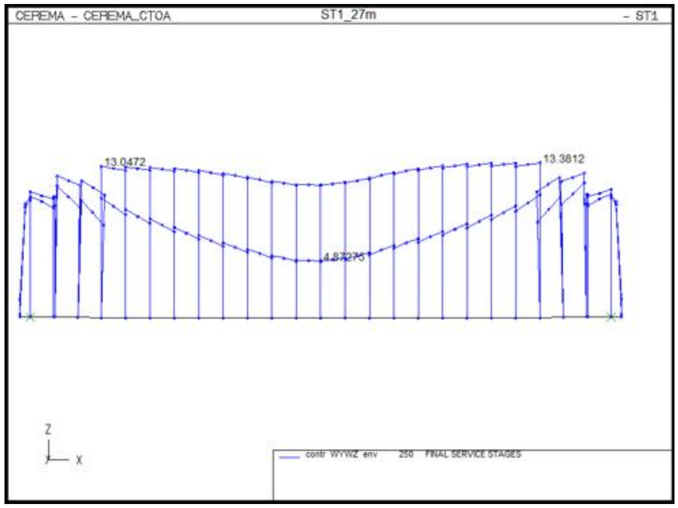
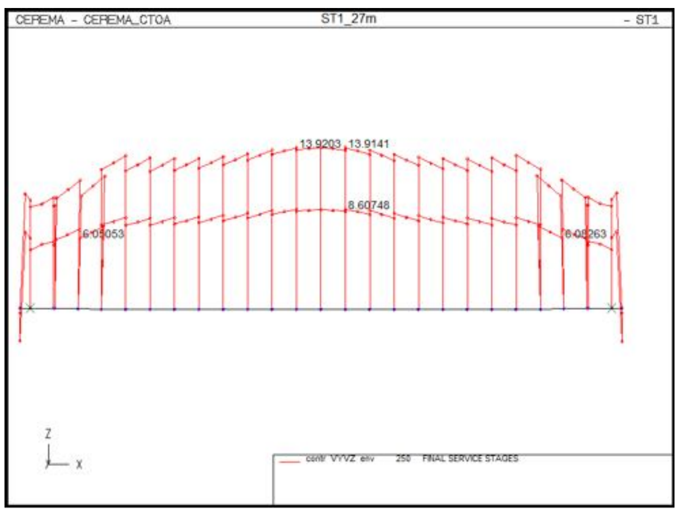
B. Stresses in service stage (with 15% margin)

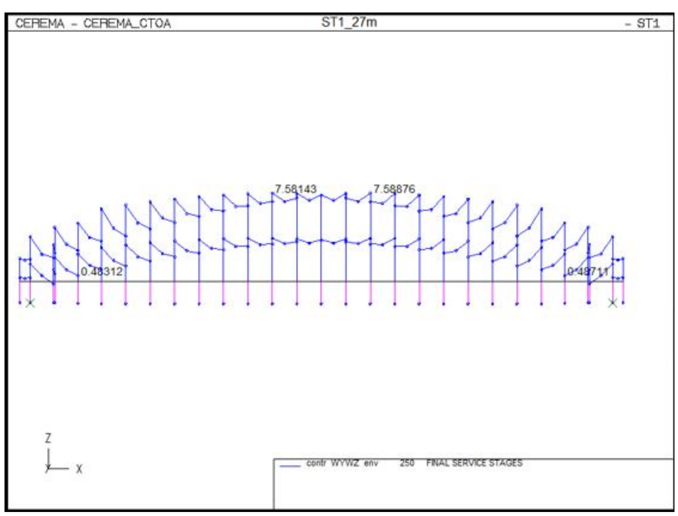
1) Beam Bottom



2) Beam Top



3) Slab Bottom



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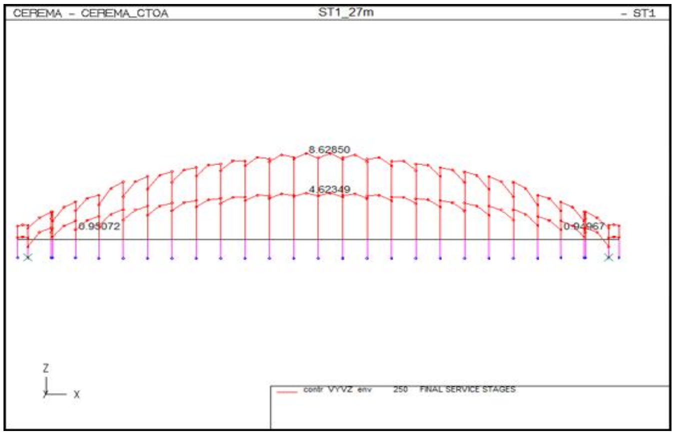
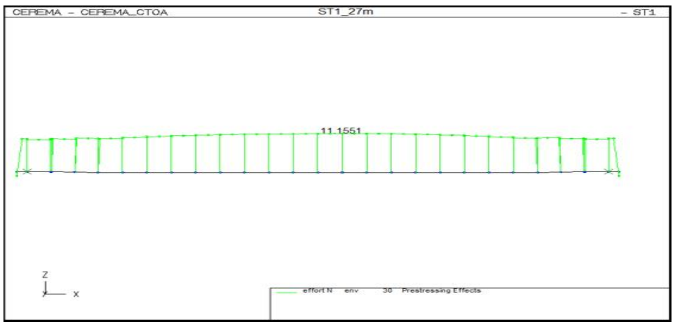
4) Slab Top



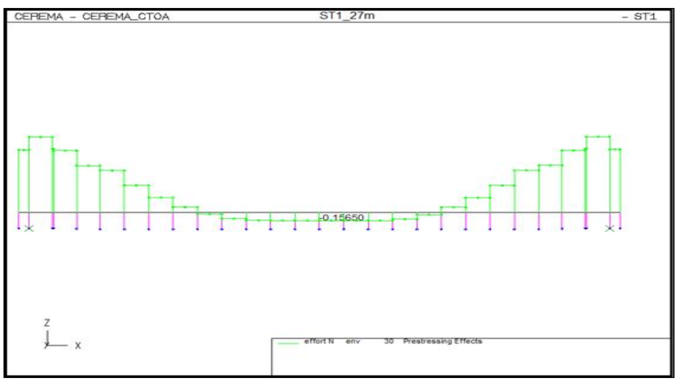
The above stresses are in limit as per the design criteria.

C. Prestressing Losses

1) Beam



2) Slab



Therefore,

Total Prestressing force at Ultimate Stage (After all losses) = (11.1551-0.15650) = 10.999 MN

Total Prestressing Losses: -

Total Actual Jacking Force = 72 * (0.765 * 1860) * 140/10^6 = 14.343 MN

After all losses, effective pre-stressing force at long term = 10.999 MN (Refer above sketches)

Losses due to Prestressing: -

= (1- (10.999/14.343))

= 23.3%

D. Flexure Verification

ULTIMATE LIMIT STATE : FLEXURE (IRS Concrete Bridge Code 1997, Cl. 16.4.3)

1.) Materials Parameters :

f_{ck}	=	60	N/mm²	: Characteristic Compresive Strength of Concrete
f_{pu}	=	1860	N/mm²	: Characteristic Strength of Prestressing Tendons
E_p	=	195000	MPa	: Modulus of Elasticity of Prestressing Tendons

2.) Section Properties :

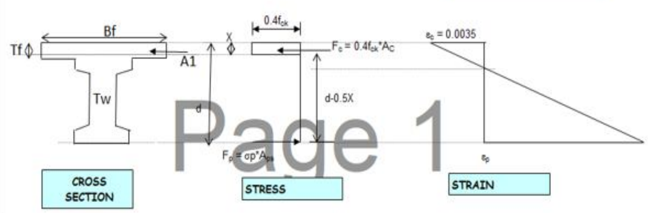
S_x	=	1.358	m²	: Cross Sectional Area
I	=	0.594	m^4	: Inertia of Section
Y_g	=	1.211	m	: Distance from Bottom fiber to the Center of Gravity of Section
T_f	=	0.240	m	: Average Thickness of Flange
B_f	=	2.055	m	: Average Width of Flange
H	=	1.990	m	: Total Height of Section
T_w	=	0.390	m	: Thickness of Web
d	=	1.491	m	: Distance from Top fiber to the COG of Tendons
A_1	=	0.660	m²	: Area of Flange (See Fig. below)

3.) Prestressing Layout :

No. of Strands	Eccentricity from Bottom Fiber (m)
16	0.150
16	0.370
19	0.590
19	0.810

A_s	=	0.00014	m²	: Area of Strand
N_s	=	70		: Total no. of Strands
e_p	=	0.499	m	: C.O.G of Strands from Bottom Fiber of Section
$N_{p\,eff}$	=	10.365	MN	: Effective Normal Force due to prestressing after all Losses

3.) Analysis : *Assumption : Position of Neutral Axis ' y ' lies within the Flange* ⟹ **X = 0.321 m**



⟹ **Calculation of Fc :**

$F_c = F_1 = 0.4f_{ck}{*}A_1$

F_1	=	15.847	MN	: F_c due to A_1
M_1	=	21.084	MN-m	: M_c due to A_1

F_c = 15.847 MN
M_c = 21.084 MN-m

⟹ **Calculation of F_p :**

ε_0	=	0.00542		: Initial Strain due to prestress after all Losses

OK, in the elastic domain

ε_p	=	0.01274		: Strain due to prestress
$\varepsilon_p+\varepsilon_0$	=	0.0182		: Total Strain due to prestressing
σ_p	=	1617	N/mm²	: Stress due to prestressing (Corresponding to Total Strain,$\varepsilon_p+\varepsilon_0$)
F_p	=	15.847	MN	: F_p due to prestress

⟹ **F_c - F_p :** 0.00

4.) Check :

M	=	21.084	MN-m	: Capable Ulimate Moment of the Section
M_u	=	12.892	MN-m	: Applied Ulimate Moment (ULS-GI :- 1.25DL+2SIDL+1.75LL)

	Mu (MN-m)
DL	2.784
SIDL	2.822
LL	2.152
	12.892

0.005+fpu/Es γs	=	0.0133		
α	=	1.00		: Implification Factor (Refer Cl 16.4.3.1,e)
$M_{u\,final} = M_u{*}\alpha$	=	12.892	MN-m	: Applied Ulimate Moment (ULS-GI :- 1.25DL+2SIDL+1.75LL)

IS M>$M_{u\,final}$?? ⟹ **Yes, Section is able to Resist Applied Moment**

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E. Shear Verification

ULTIMATE SHEAR RESISTANCE (IRS Concrete Bridge Code.1997, Cl. 16.4.4)

1.) Input Data :

b	=	0.317	m	: Thickness of Web
H	=	1.990	m	: Total Height of Section
A	=	1.358	m²	: Cross Sectional area of I - Girder
f_{ck}	=	60	N/mm²	: Characteristic Compresive Strength of Concrete
d	=	1.491	m	: Distance from Top fiber to the COG of tendons
I	=	0.594	m4	: Inertia of Section
Y_g	=	1.171	m	: Distance from Bottom fiber to the Center of Gravity of Section
W_g	=	0.819	m	: Distance from Top fiber to the Center of Gravity of Section
e_0	=	0.672	m	: Distance between C.O.G of Section to C.O.G. of Tendons
f_{yv}	=	415	N/mm²	: Characteristic Strength of Link Reinforcement
V_u	=	1.583	MN	: Applied Ulimate Shear Force (ULS-GI :- 1.25DL+2SIDL+1.75LL)

	V_u (MN)	Mu (MN - m)
DL	0.308	0.647
SIDL	0.317	0.651
LL+I	0.322	0.662
	1.583	3.271

2.) Section Uncracked in Flexure :

f_t	=	1.859	N/mm²	: Maximum principal tensile stress at the centroidal axis
N	=	9.018	MN	: Normal Force due to Prestressing after all losses (with 0.87 factor)
f_{cp}	=	6.641	N/mm²	: Compressive Stress at the Centroidal axis due to PT
V_{co}	=	1.678	MN	

3.) Section Cracked in Flexure :

f_{pt}	=	18.596	N/mm²	: Stress at the Tensile Fiber due to PT only with 0.87 factor
M_{cr}	=	10.881	MN-m	: Cracking Moment at the Section Considered
V_{cr}	=	5.401	MN	: Maximum Shear and Corresponding Bending Moment (At Support)

Section is Uncracked

4.) Shear Reinforcement :

V_u	=	1.583	MN	: Applied Ulimate Shear Force (ULS-GI :- 1.25DL+2SIDL+1.75LL)
V_c	=	1.678	MN	: Minimum of V_{co} and V_{cr}
A_{sv}/S_v	=	3.51	Cm²/m	: Reinforcement for Webs

5.) Maximum Shear Stress :

v	=	3.352	N/mm²	: Applied Shear Stress
v_{max}	=	5.300	N/mm²	: IRS, Table 26: Maximum Shear Stress

O.K.

F. Shear Connector at support Verification

CALCULATION OF LONGITUDINAL SHEAR : IRC-22-1986,CLAUSE : 608.2.2

V_1	=	23.237	Ton	:Ultimate Vertical Shear due to Dead load of slab (Ult. Factor = 1.25)
V_2	=	82.705	Ton	:Ultimate Vertical Shear due to SIDL, (From ST1), (Ult. Factor = 2)
V_3	=	106.397	Ton	:Ultimate Vertical Shear due to Live Load, (From Robot), (Ult. Factor = 2.5)
V	=	212.339	Ton	:Total Ultimate Vertical Shear force
A_C	=	0.540	m²	:Transformed Compressive area of Concrete above the neutral axis
Y	=	0.699	m	:Distance from N.A. to the centroid of area under consideration
I	=	0.646	m⁴	:Moment of Inertia of the whole transformed section
V_L	=	124.166	Ton/lm	:Longitudinal Shear per unit Length, $V_L = V A_C Y / I$

CALCULATION OF RESISTANCE OF THE SECTION

Where,

As	=	0.0042	m²/lm	(Required Reinforcement) = $V_L / (0.7*\sigma_y)$
d	=	0.016	m	:Diameter of shear connector
n	=	4	no. of leg	for T16
S	=	0.150	m	:Spacing of shear connector along the lengths of I-Beam
d	=	0.016	m	:Diameter of shear connector
n	=	2	no. of leg	for T16
S	=	0.300	m	:Spacing of shear connector along the lengths of I-Beam
As	=	0.0067	m²/lm	:Cross sectional area of the shear connector per unit length of I-Beam
			SHEAR CONNECTOR ARE OK	
σy	=	42304	T/m²	:Yield stress of the reinforcing
D	=	0.240	m	:Depth of slab

CHECK FOR SPACING OF SHEAR CONNECTOR : IRC-22-1986,CLAUSE : 612.4.3

The spacing of shear connector shall not be less than 0.7 times the depth of slab and shall not be greater than two times the depth of slab : SPACING IS OK

CHECK FOR MINIMUM REINFORCEMENT : IRC-22-1986,CLAUSE : 612.2.2

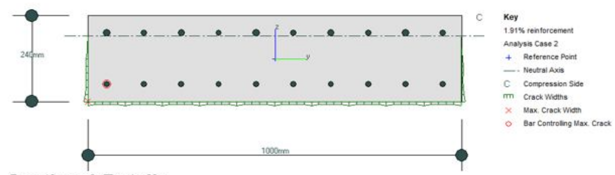
The vertical reinforcement from web and flange of the precast element shall be extended into the cast-in-situ concrete slab. Such reinforcement shall not be less than 0.15 percent of the contact area or 130 sq. mm per meter of the span.

$A_{CONTACT}$	=	0.875	m²	: Contact Area

MIN. REINFORCEMENT IS OK

G. *Deck Slab*

1) *Flexure Verification*



Section 1 Details

```
1.91% reinforcement in section 1 (Section 1). Check this against code requirements.
```

Serviceability Analysis - Loads

```
Case   N     Myy     Mzz    M       θ
      [kN]  [kNm]   [kNm]  [kNm]   [°]
   1   0.0  -76.90    0.0  76.90  -180.0
   2   0.0   14.94    0.0  14.94     0.0
```

Section Material Stresses/Strains at SLS Loads

```
Case Point  Coordinates                                    Notes
              y       z          Strain      Stress
             [mm]    [mm]         [-]        [N/mm²]
Maxima
   1     2   500.0 -120.0       428.0E-6      13.45
   1     2   500.0 -120.0       428.0E-6      13.45
Minima
   1     4  -500.0  120.0      -0.001212       0.0
   1     1   500.0  120.0      -0.001212       0.0
```

Reinforcement Stresses/Strains at SLS Loads

```
Case Bar   Coordinates                                     Notes
             y       z          Strain      Stress
            [mm]    [mm]         [-]        [N/mm²]
Maxima
   1    15  450.0  -72.00      100.1E-6     20.02 FE-500
   1    15  450.0  -72.00      100.1E-6     20.02 FE-500
Minima
   1     6 -450.0   72.00     -883.7E-6    -176.7 FE-500
   1     6 -450.0   72.00     -883.7E-6    -176.7 FE-500
```

Crack Widths at SLS Loads

```
Crack widths calculated at 20mm intervals

Case Face Point Coordinates Strain Em Strain E1  bt   Control Bar  acr        Cover        h
x   Crack

Width
                   y      z                                                  cmin     From
                 [mm]   [mm]                                          [mm]   [mm]               [mm]
[mm]   [mm]
Maxima
   1    4   110 100.0 120.0 -0.001212 -0.001212 1.000           18 61.31 40.00 Face 4
240.0 62.65 0.2229
```

Strength Analysis - Summary

```
Governing conditions are defined as:
    A - reinforcing steel tension strain limit
    B - concrete compression strain limit
Effective centroid is reported relative to the reference point.


Case   Eff.      Eff.      N      M       Mu     M/Mu   Governing   Neutral Neutral
     Centroid  Centroid                                 Condition    Axis    Axis
       (y)       (z)                                                 Angle   Depth
                          [kN]  [kNm]   [kNm]                        [°]     [mm]
Maxima
   1   -0.5731    0.8253  0.0 -156.9 -189.1 0.8295 B: Node 2
Minima
   2   -0.5731    0.8253  0.0  28.74  153.1 0.1877 B: Node 1
```

Fc (Mpa)	Fs (Mpa)	CRACK WIDTH (mm)	M/Mu	ALLOWABLE Fc (Mpa)	ALLOWABLE Fs (Mpa)	ALLOWABLE CRACK WIDTH (mm)	REMARK
13.45	176.7	0.2229	0.8295	22	375	0.25	OK

H. *Cross-Girder*

1) *Summary*

-ve = Sagging

+ve = Hogging

Table 4. Bending Moment

Combination	Load Case	Nature	Max BM (kN-m)
SLS	DL+1.2SIDL	Max + ve	943.391
		Max - ve	-135.605
ULS	1.25DL+2SIDL	Max + ve	1374.85
		Max - ve	-180.179

Table 5. Shear Force

Combination	Load Case	Nature	Max SF (kN)
SLS	DL+1.2SIDL	Max	1413.32
ULS	1.25DL+2SIDL	Max	2059.70

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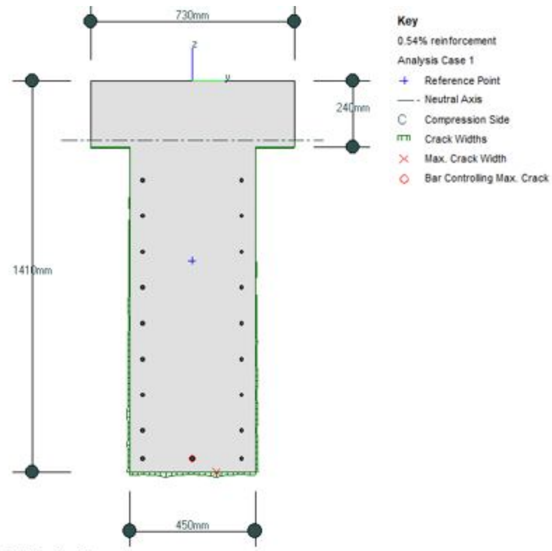
2) Verification for Sagging moment



Section 1 Details

0.54% reinforcement in section 1 (Section 1). Check this against code requirements.

Serviceability Analysis - Loads

Case	N [kN]	M_{yy} [kNm]	M_{zz} [kNm]	M [kNm]	θ [°]
1	0.0	135.6	0.0	135.6	0.0

Section Material Stresses/Strains at SLS Loads

Case	Point	Coordinates y [mm]	z [mm]	Strain [-]	Stress [N/mm²]	Notes
Maxima						
1	1	365.0	0.0	55.87E-6	1.756	
1	1	365.0	0.0	55.87E-6	1.756	
Minima						
1	4	225.0	-1410.	-313.5E-6	0.0	
1	2	365.0	-240.0	-7.002E-6	0.0	

Reinforcement Stresses/Strains at SLS Loads

Case	Bar	Coordinates y [mm]	z [mm]	Strain [-]	Stress [N/mm²]	Notes
Maxima						
1	1	177.0	-360.0	-38.44E-6	-7.688	rebar 500
1	1	177.0	-360.0	-38.44E-6	-7.688	rebar 500
Minima						
1	17	-177.0	-1362.	-300.9E-6	-60.18	rebar 500
1	17	-177.0	-1362.	-300.9E-6	-60.18	rebar 500

Crack Widths at SLS Loads

Maximum Crack Width per Face

Crack widths calculated at 20mm intervals

Case	Face	Point	Coordinates y [mm]	z [mm]	Strain E_m	Strain E_1	b_t	Control Bar	a_{cr} [mm]	c_{min} [mm]	Cover From	h [mm]	x [mm]	Crack Width [mm]
Maxima														
1	4	4	85.00	-1410.	-313.5E-6	-313.5E-6	0.4500	18	89.62	40.00	Face 4	1410.	213.3	0.07783

Strength Analysis - Summary

Governing conditions are defined as:
A - reinforcing steel tension strain limit
B - concrete compression strain limit
Effective centroid is reported relative to the reference point.

Case	Eff. Centroid (y)	Eff. Centroid (z)	N [kN]	M [kNm]	M_u [kNm]	M/M_u	Governing Condition	Neutral Axis Angle [°]	Neutral Axis Depth [mm]
Maxima									
1	-120.9E-9	-25.46	0.0	180.2	1414.	0.1274	B: Node 1		
Minima									
1	-120.9E-9	-25.46	0.0	180.2	1414.	0.1274	B: Node 1		

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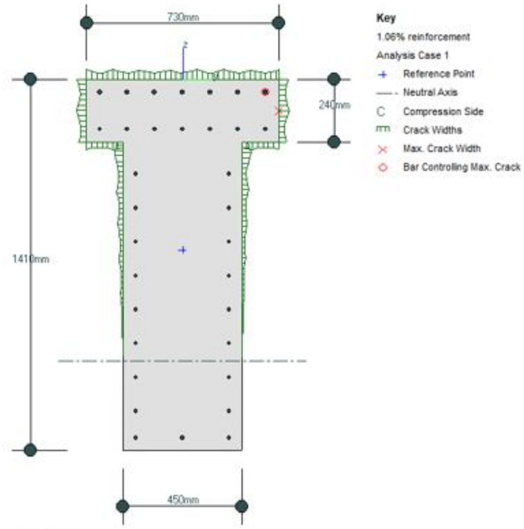
3) Verification for Hogging moment



Section 1 Details

1.06% reinforcement in section 1 (Section 1). Check this against code requirements.

Serviceability Analysis - Loads

Case	N [kN]	M_{yy} [kNm]	M_{zz} [kNm]	M [kNm]	θ [°]
1	0.0	-943.4	0.0	943.4	-180.0

Section Material Stresses/Strains at SLS Loads

Case	Point	Coordinates y [mm]	z [mm]	Strain [-]	Stress [N/mm²]	Notes
Maxima						
1	5	-225.0	-1410.	334.3E-6	10.51	
1	5	-225.0	-1410.	334.3E-6	10.51	
Minima						
1	1	365.0	0.0	-0.001040	0.0	
1	1	365.0	0.0	-0.001040	0.0	

Reinforcement Stresses/Strains at SLS Loads

Case	Bar	Coordinates y [mm]	z [mm]	Strain [-]	Stress [N/mm²]	Notes
Maxima						
1	17	-177.0	-1362.	287.6E-6	57.51	rebar 500
1	17	-177.0	-1362.	287.6E-6	57.51	rebar 500
Minima						
1	20	-315.0	-50.00	-990.8E-6	-198.2	rebar 500
1	20	-315.0	-50.00	-990.8E-6	-198.2	rebar 500

Crack Widths at SLS Loads

Maximum Crack Width per Face

Crack widths calculated at 20mm intervals

Case	Face	Point	Coordinates y [mm]	z [mm]	Strain E_m	Strain E_1	b_t	Control Bar	a_{cr} [mm]	c_{min} [mm]	Cover From	h [mm]	x [mm]	Crack Width [mm]
Maxima														
1	1	1	365.0	-120.0	-922.6E-6	-922.6E-6	0.7300	26	76.02	40.00	Face 1	1410.	343.1	0.1971

Strength Analysis - Summary

Governing conditions are defined as:
A - reinforcing steel tension strain limit
B - concrete compression strain limit
Effective centroid is reported relative to the reference point.

Case	Eff. Centroid (y)	Eff. Centroid (z)	N [kN]	M [kNm]	M_u [kNm]	M/M_u	Governing Condition	Neutral Axis Angle [°]	Neutral Axis Depth [mm]
Maxima									
1	0.0	-27.52	0.0	1375.	2540.	0.5413	B: Node 4		
Minima									
1	0.0	-27.52	0.0	1375.	2540.	0.5413	B: Node 4		

4) Shear Verification at support

ULTIMATE SHEAR RESISTANCE (IRS Concrete Bridge Code.1997, Cl. 16.4.4)

1.) Input Data :

b	=	0.450	m	: Thickness of Web
H	=	1.410	m	: Total Height of Section
A	=	0.702	m²	: Cross Sectional area of End cross girder
f_{ck}	=	55	N/mm²	: Characteristic Compresive Strength of Concrete
d	=	1.350	m	: Distance from Extreme fiber to the COG of Reinforcement
I	=	0.126	m4	: Inertia of Section
Y_g	=	0.761	m	: Distance from Bottom fiber to the Center of Gravity of Section
W_g	=	0.649	m	: Distance from Top fiber to the Center of Gravity of Section
e_0	=	0.000	m	: Distance between C.O.G of Section to C.O.G. of Tendons
f_{yv}	=	415	N/mm²	: Characteristic Strength of Link Reinforcement, fy < 415 Mpa
V_u	=	2.060	MN	: Applied Ulimate Shear Force (ULS-GI :- 1.25DL+2SIDL+1.75LL)

	V_u (MN)	Mu (MN - m)
DL	0.710	0.474
SIDL	0.586	0.391
	2.060	1.375

2.) Section Uncracked in Flexure :

f_t	=	1.780	N/mm²	: Maximum principal tensile stress at the centroidal axis
N	=	0.000	MN	: Normal Force due to Prestressing after all losses (with 0.87 factor)
f_{cp}	=	0.000	N/mm²	: Compressive Stress at the Centroidal axis due to PT
V_{co}	=	0.757	MN	

3.) Section Cracked in Flexure :

f_{pt}	=	0.000	N/mm²	: Stress at the Tensile Fiber due to PT only (with 0.87 factor)
M_{cr}	=	0.455	MN-m	: Cracking Moment at the Section Considered
V_{cr}	=	0.85	MN	: Maximum Shear and Corresponding Bending Moment (At Support)

Section is Uncracked

4.) Shear Reinforcement : s

V_u	=	2.060	MN	: Applied Ulimate Shear Force (ULS-GI :- 1.25DL+2SIDL+1.75LL)
V_c	=	0.757	MN	: Minimum of V_{co} and V_{cr}
A_{sv}/S_v	=	31.72	Cm²/m	: Reinforcement for Webs

5.) Maximum Shear Stress :

v	=	3.390	N/mm²	: Applied Shear Stress
v_{max}	=	5.300	N/mm²	: IRS, Table 26: Maximum Shear Stress

O.K.

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[2] Bridge Deck Behaviour - by Hambly E. Pennells. "Concrete bridge designer's manual".
[3] IRS-CBC-1997 concrete bridge code for railways
[4] BS:5400 Code of practice for Design of Concrete Bridges: Part-4-1990
[5] French Code for Pre-stressed Concrete: BPEL 91
[6] French Code for Reinforced Concrete: BAEL 91
[7] Euro code EN-1991-2, Clause 6.7 for derailment check.
[8] IRC:6-2000, effect of temperature variation in superstructure will be seen in longitudinal direction for both temperature rise as well as temperature fall.

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