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PRE – STRESSED CONCRETE BRIDGE GIRDER ANALYSIS AND DESIGN

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ABSTRACT Pre-stressed Concrete bridges nowadays have become the most widely used amongst all other bridges. Analysis and Design of such bridges are done as per various standard codes which gives satisfactory solutions to most of the design engineers. The supremacy tool for Structural engineering, STAAD-Pro is the most well-liked structural engineering product for 3D model generation as well as analysis and design. The design will be carried out as per IRC specifications and load combinations will be kept same for all the girders. Analysis and design will be carried out using STAAD-Pro. Many researches has been done for analysis and design of PSC Girder Bridge. In this paper also one of the methods is used. In view of achieving this aim, spreadsheet is prepares so that it can directly calculate the properties, design bending moments and stresses and it will show whether the section is safe or not.

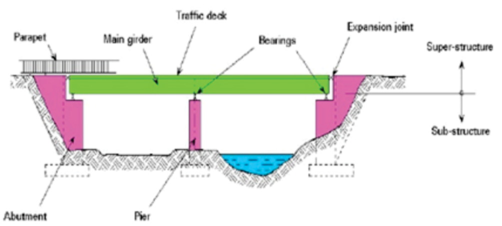
KEYWORDS : Pre-Stressed concrete girder, analysis, design, IRC 112.

I.INTRODUCTION

A bridge is a structure built to span physical obstacles without closing the way underneath such as a body of water, valley, or road, for the purpose of providing passage over the obstacle, usually something that can be detrimental to cross otherwise. There are several designs which serve a particular purpose and be relevant to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it

Conventionally in Bridge analysis, the Super-structure and Sub-structure are analyzed separately. The Super-structure is usually a grid consisting of main girders, transverse diaphragms and deck slab. The deck slab is discretized into a grid of line elements. The supports of the main girders are pinned. The super-structure is analyzed for un-factored Gravity loads and Moving vehicular loads as per IRC-6. The design bending moments due to gravity and moving loads are used to design the main girders and diaphragms. The deck slab is analyzed separately assuming the main girders provide knife edge supports and designed separately. The reactions of the pinned supports for main girders are used to design the sub-structure. In summary, there is no inter-action between superstructure and sub-structure which would have varying degrees of effect on different components of the Bridge. The load combinations are included in the analysis with appropriate limit load factors in the excel sheet.

FIGURE 1 BRIDGE COMPONENTS



(https://www.slideshare.net/reinforced-concrete-deck-girder-bridge)

Terms used in Bridge engineering

The following is a list of bridge terms usually found in bridge plans or referred to in bridge construction:

Abutment - The portion of bridge substructure at both ends of a bridge which passes loads from superstructure in the direction of foundation and serves as lateral support for embankment.

Bearing - Usually, a device which supports the end of a girder and distributes superstructure loads to the abutment or pier. Fixed bearings do not provide for longitudinal movement of the superstructure to compensate for expansion and contraction due to temperature changes.

Parapet - A concrete railing or barrier located on the bridge deck fascia and the tops of retaining walls.

Pier - The portion of the bridge substructure which passes loads from superstructure to foundation. It serves the purpose of intermediate support for multi-span bridges.

Piles - Shafts of concrete, timber, or steel which are used to transfer foundation loads through subsurface materials.

Diaphragm - Channel, angle steel or cast-in-place concrete cross bracing between girders.

Flange - The projecting portion of a beam or channel. It is the top or the bottom plate of a steel girder.

Girder - A horizontal supporting structural member. (Beam, Stringer)

Section View – It is an internal view. In Bridge Plans, sections are usually shown through all parts of the structure.

Substructure - The part of a structure below the superstructure.

Superstructure - In a bridge, the superstructure consists of bearings, girders, decks, sidewalks, etc.

II.ANALYSIS OF SUPERSTRUCTURE

The box girder superstructure shall be analyzed as simply supported line beam and grillage analysis shall be done for 'I' girder superstructure and for steel superstructures in STAADPRO for SIDL & live loads. In this chapter modeling has been done for simply supported superstructure for which grillage model has been prepared in Staad-Pro and analysis has been done using spreadsheet.

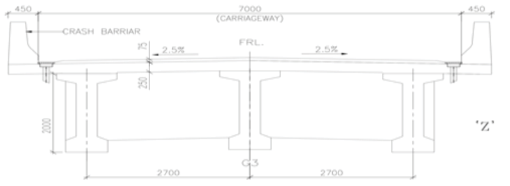


FIG. 2 SECTION OF BRIDGE WITH ITS DIMENSIONS

Figure 2 shows the cross section of bridge which has been considered as the base model. It is a simply supported 30m span bridge which consists of three PSC I-girders having 7m carriageway with wearing coat of 75mm and a crash barrier.

In this section modeling has been done for simply supported superstructure for which grillage model has been prepared in Staad-Pro and design has been done using spreadsheet.

Data for analysis

The superstructure carries 7m carriageway. Superstructure is simply supported. Total span length = 30.00m. Figure 3 alongside shows the original dimensions of the section at support and section at mid. Following loads are considered in the design with appropriate stages.

1. Self weight.
2. SIDL
3. Live load trains as per IRC 6

I)Class 70R - One lane
II)Class A - Two lanes
Concrete Grade Fck - 45Mpa Characteristic compressive strength
Steel Grade Fy - 500Mpa Characteristic yield strength
Pre-stressing Cables Fp - 1860 Ultimate tensile strength
Modulus of Elasticity

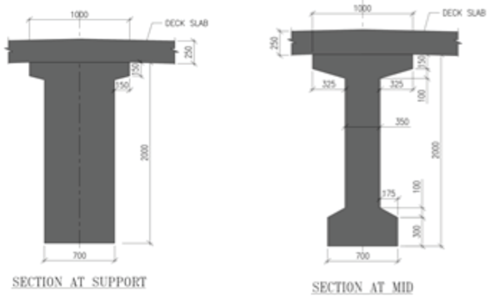


FIG. 3 SECTION AT MID & SECTION AT SUPPORT

Concrete -34000Mpa At 28 days (IRC: 112-2012)
Steel- 200000Mpa
Prestressing Cables-195000Mpa
Corrugated HDPE sheathing is used for the cable.

As per Table 7.1 of IRC 112:2011, wobble coefficient and coefficient of friction are as follow.

Wobble coefficient k	-	0.002 per m
Friction coefficient m	-	0.17 per rad
Cables used in webs.	-	19T15
Cable dia. of 19T15 (Duct OD) manufacturer's schedule)	-	120mm (As per
Cover reinforcement	-	75mm to any

Permissible stresses

Concrete

As per IRC 112:2012; Cl. 12.2.1, allowable compressive stress in concrete

under rare combination of loads	-	0.48fck
for jth days	-	0.48fcj
under quasi-permanent loads	-	0.36fck
for jth days	-	0.36fcj
allowable tensile stress in concrete	-	-3.5Mpa
For 8 Days	-	-2.815Mpa

Steel Fe 500

Max allowable tensile stress - 0.8 fyk (IRC 112:2012; Cl. 12.2.1)

Deck System of Superstructure

Overall deck width of the superstructure is 14.5m. The deck consists of 7m wide carriageway with crash barrier on the edges as shown in Fig below:

MATERIALS

Different materials with its specifications have been mentioned in this section.

Grade of Concrete

Material properties of concrete shall be as per IRC 112:2011 specifications. The grades of concrete are based on 28 days characteristic compressive cube strength. For Reinforced concrete, the preferred nominal aggregate is 20mm. The strength of cast in situ deck slab is M35.

Modulus of elasticity of concrete for shall be taken as per Clause 604.3 of IRC 22-2015

$E_{cm} = 5000\sqrt{f_{ck}} = 29581$ Mpa

The Poisson's ratio of un-cracked concrete is taken as 0.2 and that of cracked as zero as per Cl 6.4.2.5 (4) (ii) of IRC 112-2011.

Grade of Concrete as per component:
PSC Girder = M45
Deck slab and diaphragm = M35
Crash Barrier = M35

REINFORCEMENTS

All reinforcement shall be high yield strength deformed steel bars (HYSD steel), Grade Fe500 conforming to IS 1786-2000 and Table 18.1 of IRC: 112-2011 for all structures. The characteristic strength (f_{yk}) of reinforcement shall be 500 MPa with modulus of elasticity 200 Gpa.

Superimposed Dead Load (SIDL)

Superimposed Dead Load consists of load due to Wearing Coat (surfacing coat) and Crash Barrier

Wearing Coat (Variable Load)

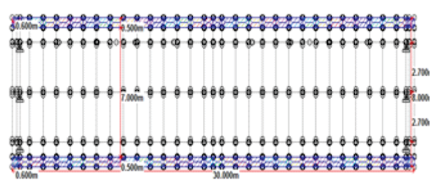
The wearing coat over the superstructure will be 75mm thick. Weight of wearing coat = 0.075 x 22 = 1.65 kN/m2

Load Combinations

It is proposed to adopt Limit State of Design as per IRC: 22-2015 & IRC 112-2011, therefore combination of loads shall be as per Annexure B of IRC: 6-2017. Load combination for checking structural strength, crack width etc are given in the table.

Load Combination for Checking the Structural Strength (ULS)

For checking the Structural strength of the structure the partial safety factor for loads are taken from Table B.2 of IRC: 6 2017. These combinations can be used directly in staad to calculate design bending moment or it can be used separately as done in this design process.



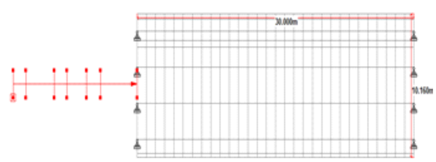


FIG. 4(B) ONE VEHICLE OF CLASS 70R WHEELED

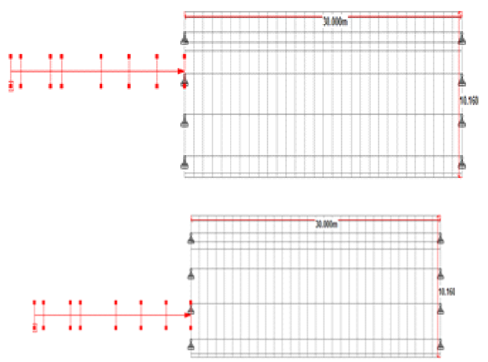


FIG. 4© & 4(D) TWO VEHICLES OF CLASS A

Figure 4(A), shows the Staad model for DL in which all the dimensions such as length of bridge, crash barrier, span, cantilever, girder spacing etc. ahs been shown. SIDL load assigned to the model which are loads for crash barrier and wearing coat. The section properties taken for this case is of composite section properties.

Figure 4(B), shows the assignment of live load for 70R wheeled vehicle on the superstructure whereas figure 4(C) and 4(D) shows the two vehicles of Class A for 7m of carriageway according to IRC code.

Structure is analyzed using grillage model for longitudinal BMs and SFs at various sections using STAAD Pro.

DL denotes self weight of girder, slab and diaphragm.

SIDL due to crash barrier and wearing coat are applied on grillage model

Impact factor as calculated below is applied to LL. Also LL(max) and LL(min) load cases are taken separately.

Impact factor: As per IRC: 6-2000, Cl. 211;
For Class A:
Impact factor fraction=4.5 / (6 + L) = 0.1293(where, L is effective Length of girder)
i.e. Impact factor=1.129
For 70 R wheeled vehicles:
Impact factor fraction=0.1293(i.e. 12 % as per Fig. 5 of IRC: 6-2014)
i.e. Impact factor= 1.129
Construction Load Assumed=1kN/m2= 1*2.7 = 2.7 kN/m

III.DESIGN OF SUPERSTRUCTURE

Following are the dimensions for the base model which has been selected for the present work in which the values which are highlighted are taken as the design variables.

Top slab thickness	-	0.25	m
Over all depth of precast girder	-	2	m
Over all depth of composite girder		2.25	m
Web thickness at support	-	0.7	m
Web thickness at mid span	-	0.35	m

TABLE 1 SECTION AT MID SPAN

Total Height		2.00	
Bottom flange	0.70	0.30	m
Bottom triangle	0.175	0.10	m
Web	0.35	1.350	m
Top triangle	0.325	0.10	m
Top flange	1.00	0.15	m
Deck slab	2.70	0.25	m

Table 1 shows width and height as per shape of section of I-girder and the values which are highlighted are the design variables taken for optimization process.

TABLE 2 SECTIONAL PROPERTIES OF I - GIRDER MID-SECTION

Section Properties	Precast Girder	Composite Girder	Unit
Area	0.953	1.628	m^2
Depth	2.000	2.250	m
CG From Bottom	1.017	1.476	m
CG From Top	0.983	0.774	m
Ixx	0.423	0.912	m^4
Iyy	0.030	0.440	m^4
Zb	0.416	0.618	m^3
Zt	0.430	1.178	m^3
Z @girder top	-	1.741	m^3
Area above CG	-	0.988	m^2
CG from Cg of section	-	0.54708	m

Table 2 consists of section properties such as cross sectional area, moment of inertia, depth of girder, CG from top and bottom, section modulus which are calculated as per the dimensions of girder section.

TABLE 3 DESIGN BENDING MOMENTS (KNM)

Section	DL	DECK	SIDL CB	SIDL WC	Constr. Load	LL MAX	LL MIN	LL MAX Wo impact	LL MIN Wo impact
0	0	0	0	0	0	0	-3.509	0	-3.19
2.88	929.29	676	345	166	101	894.74	-98.91	813.4	-89.92
5.76	1609.5	1214	568	294	179	1677.5	-168.4	1525	-153.13
7.2	1876.1	1431	632	344	210	2027.3	-203.5	1843	-185
8.64	2094.2	1615	669	385	235	2345.2	-270.4	2132	-245.78
11.52	2385.1	1878	649	437	269	2861.1	-335.2	2601	-304.77
14.4	2482.1	2004	507	451	280	3214.2	-422.5	2922	-384.06
17.28	2385.1	1878.08	649	437	269	2861.1	-335.2	2601	-304.77
20.16	2094.2	1614.69	669	385	235	2345.2	-270.4	2132	-245.78
21.6	1876.1	1431.46	632	344	210	2027.3	-203.5	1843	-185
23.04	1609.5	1213.88	568	294	179	1677.5	-168.4	1525	-153.13
25.92	929.29	675.651	345	166	101	894.74	-98.91	813.4	-89.92
28.8	0	0	0	0	0	0	-3.509	0	-3.19

TABLE 4 SHEAR FORCES (KN)

Section	DL	DECK	SIDL CB	SIDL WC	LL MAX	LL MIN	LL MAX Wo impact
0	374.03	258.46	129.00	54.40	457.6	457.6	416
2.88	273.23	210.74	97.80	45.90	419.1	419.1	381
5.76	202.00	163.03	50.40	33.70	353.1	353.1	321
7.2	168.33	139.17	34.80	29.20	328.9	328.9	299
8.64	134.66	115.31	19.28	24.60	304.7	304.7	277
11.52	67.33	67.60	27.60	12.50	228.8	228.8	208
14.4	0.00	19.88	63.00	3.69	211.2	211.2	192
17.28	67.33	67.60	27.60	12.50	257.4	257.4	234
20.16	134.66	115.31	19.28	24.60	334.4	334.4	304
21.6	168.33	139.17	34.80	29.20	359.7	359.7	327
23.04	202.00	163.03	50.40	33.70	382.8	382.8	348
25.92	273.23	210.74	97.80	45.90	452.1	452.1	411
28.8	374.03	258.46	129.00	54.40	495	495	450

Table 3 & 4 contains design bending moments and shear forces which has been calculated from the loading diagram using excel spreadsheet except for the SIDL and vehicular loads i.e., 70R wheeled and Class A loading which has been directly taken from the Staad model. LL(max) & LL(min) moments are further multiplied by impact factor as specified in IRC code and congestion factor can be taken if necessary.

TABLE 5 STRESS CHECK SUMMARY

Load case		Max Stress	Permissible Max Stress	Min Stress	Permissible Min Stress	Remark
		Mpa	Mpa	Mpa	Mpa	
1	At transfer of P1	5.179	17.28	1.429	-2.82	SAFE
2	On 28th Day	4.832	21.60	1.372	-3.5	SAFE
3	At transfer of P2	18.164	21.60	1.278	-3.5	SAFE
5	At 28 days with Self wt of slab + Construction Load	14.038	21.60	3.747	-3.5	SAFE
4	On infinity	10.996	21.60	-0.321	-3.5	SAFE
6	with SIDL WC	9.505	16.20	-0.321	-3.5	SAFE
7	Service with LLMax	9.669	21.60	-0.605	-3.5	SAFE
8	Service with LLMin	9.583	21.60	-0.607	-3.5	SAFE
9	Comb(1)+ LL(max) *1+Temp Rise*0.6	8.678	21.60	-1.595	-3.5	SAFE
10	Comb(1)+ LL(min) *1+Temp Rise*0.6	11.081	21.60	-1.597	-3.5	SAFE
11	Comb(1)+ LL(max) *0.75+Temp Rise*1	9.769	21.60	-2.255	-3.5	SAFE
12	Comb(1)+ LL(min) *0.75+Temp Rise*1	12.011	21.60	-2.257	-3.5	SAFE
13	Comb(1)+ LL(max) *1+Temp Fall*0.6	10.539	21.60	-1.800	-3.5	SAFE
14	Comb(1)+ LL(min) *1+Temp Fall*0.6	8.450	21.60	-1.803	-3.5	SAFE
15	Comb(1)+ LL(max) *0.75+Temp Fall*1	10.658	21.60	-2.743	-3.5	SAFE
16	Comb(1)+ LL(min) *0.75+Temp Fall*1	9.091	21.60	-2.745	-3.5	SAFE
17	Comb(1)+ LL(max)*1+Wind downward*0.6	9.746	21.60	-0.605	-3.5	SAFE
18	Comb(1)+ LL(min) *1+Wind upward*0.6	9.725	21.60	-0.607	-3.5	SAFE
19	Comb(1)+LL(max)*0.75+Winddownward*1	9.336	21.60	-0.605	-3.5	SAFE
20	Comb(1)+ LL(min)* 0.75+Wind upward*1	9.751	21.60	-0.606	-3.5	SAFE

The stresses for various load cases are mentioned in the table 5 for various pre-stressing stages as well as for different load combinations. It shows whether the section is safe or unsafe while carrying out the iterations.

Ultimate strength (Check for Design Bending Moment and Ultimate Moment of Resistance)
The moment of resistance of section at Ultimate state is calculated as Cl.8.1, IRC: 112-2011.
As per IRC 112:2011 clause 6.2.2 & 6.3.5, sections are checked for factored load.

Partial factor of safety for concrete (basic and seismic)	=	Ym	=	1.50
Partial factor of safety for concrete (Accidental)	=	Ym	=	1.20
Partial factor of safety for steel (basic and seismic)	=	Ym	=	1.15
Partial factor of safety for steel (Accidental)	=	Ym	=	1.00

The ultimate moment is calculated assuming x_u and then calculating corresponding total compressive and tensile forces. For exact x_u, the total compressive and tensile forces should be equal. Thus, x_u is further iterated to get the desired result. The ultimate moment of the section is further calculated taking this new xu into consideration.

For calculating moment of resistance rectangular stress block is considered as per IRC 112-2011 Fig.A2-4

Max strain in compression = 0.0035

Max strain in steel = 0.0083 (As per IRC 112-2011 cls-6.2.2 & 6.3.5)

$$\frac{x_{u\,lim}}{d - x_{u\,lim}} = \frac{0.0035}{0.0118} \qquad \frac{x_{u\,lim}}{d} = \frac{0.0035}{0.0118} \qquad x_{u\,lim} = 0.297\,d$$

Assume neutral axis within flange, $x_u \leq D_f$ & $x_u \leq x_{u\,lim}$

A_p = Area of pre-stress
d = Effective depth of composite section
x = Depth of neutral axis
T_u = Pre-stress Force
A_c = Area under compression
C_u = Compressive Force
Z = Lever arm
M_{ur} = Ultimate moment of resistance

Considering force equilibrium

$C_u = 0.362 \times f_{ck} \times b_f \times x_u$ &

$T_u = f_{pk} \times A_p$

$= 0.362 \times 45 \times b_f \times x_u$

$= 16.29 \times b_f \times x_u$

If neutral axis lies in the flange and x_u is less than x_{ulim}, then M_{ur} is given by the following equation.

$M_{ur} = C_u \times (d-0.416\,x_u)$

$M_{ur\,steel} = T_u \times (d-0.416\,x_u)$

TABLE 6 COMPARISONS BETWEEN ULTIMATE MOMENT OF RESISTANCE AND DESIGN BENDING MOMENTS

Sections	xu position	A_c	Cu	Z	Mur	Mur d	Remark
		m2	kN	M	kNm	kNm	
0.00	Outside flange	0.451	9062	1.218	11996	0	OK
2.88	Outside flange	0.451	9062	1.520	14973	4339	OK
5.76	Outside flange	0.451	9062	1.700	16744	7740	OK
7.20	Outside flange	0.451	9062	1.736	17100	9115	OK
8.64	Outside flange	0.451	9062	1.772	17455	10274	OK
11.52	Outside flange	0.451	9062	1.799	17721	11883	OK
14.40	Outside flange	0.451	9062	1.799	17721	12553	OK
17.28	Outside flange	0.451	9062	1.799	17721	11883	OK
20.16	Outside flange	0.451	9062	1.772	17455	10274	OK
21.60	Outside flange	0.451	9062	1.736	17100	9115	OK
23.04	Outside flange	0.451	9062	1.700	16744	7740	OK
25.92	Outside flange	0.451	9062	1.520	14973	4339	OK
28.80	Outside flange	0.451	9062	1.218	11996	0	OK

Table 6 gives the remark whether the section is okay or not after comparing the ultimate moment of resistance and design bending moments for each section. By using spreadsheet, moments are calculated and checked for the ultimate moment of resistance and the position of neutral axis is also known. Stresses are checked to find out whether the section is safe at every load case and if it is not then it will be said that the section is unsafe and can't be used further for which the section is to be re-design again.

I.CONCLUSIONS

From the analysis and design of superstructure of PSC Girder Bridge following observations are made.

- Depending upon the design bending moments calculated in table 3.3, a parabolic profile is provided to cables.
- For box girder, line model is to be analysed in Staad whereas for I-girder, grillage model should be analysed.
- Results tabulated shows that at different section of each girder, values of bending moment changes.
- The difference between the bending moments at every section of girder is not so high, hence a cable profile should also be smooth in nature at every point of girder.
- For same dimensions and cross section, it was found that, if design is done by WSM method it consumes more steel which using LSM becomes more effective.

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