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To Study Alternative to Segmental Box Girder Superstructure

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Abstract—*Performance based selection of bridge superstructure is important for economy and longevity of structure and ease of construction. It is observed that construction resources influence the execution of a bridge and time of construction.*

In this project a case study of a Bridge at Sarai Kale Khan area of New Delhi, on Barapullah Nallah has been taken for the academic purpose. Study of the existing Segmental Box girder Superstructure has been done and Alternatives are given as below:

- *Alternative: 4 number of girder Simply Supported structure.*

The structures are modeled in MIDAS Civil software and studied for various loading conditions as per IRC:6-2014 and IRC:112-2011. The construction stages analyses and time dependent analyses are also done using MIDAS Civil.

Index Terms*—Segmental Box Girder Superstructure, Simply Supported Girder, Construction Stages, MIDAS Civil Software.*

1. Introduction

The various construction stages are considered for analysis in MIDAS for Simply Supported Structure:

Stage (1,1) represents Self-weight of girder and first stage of prestressing before launching of the girder. (at Transfer stage).
Stage (1,2) represents casting of deck slab after launching of the Girder.
Stage (2,1) represents after 7 days of deck slab casting.
Stage (2,2) represents second stage of prestressing on composite structure after 28 days of deck slab casting.
Stage (3,1) represents placing of SIDL fix and variable after second stage of prestressing done. (@ Service stage).
Stage (3,2) represents after 30 years of the bridge constructed.

2. Existing Segmental Box Girder Super structure.

The Barapullah Phase II: consists of a 3 span continuous prestressed bridge. It is a precast segmental bridge structure consisting of five post tensioned prestressing tendons (in each web). Three out of which are placed throughout the length and remaining two are placed at support to minimize the support negative moments.

Construction Methodology:

The stages of construction as well as the longitudinal arrangement of the segments are represented in Figure 2.1 It also shows the bearing types at different piers.

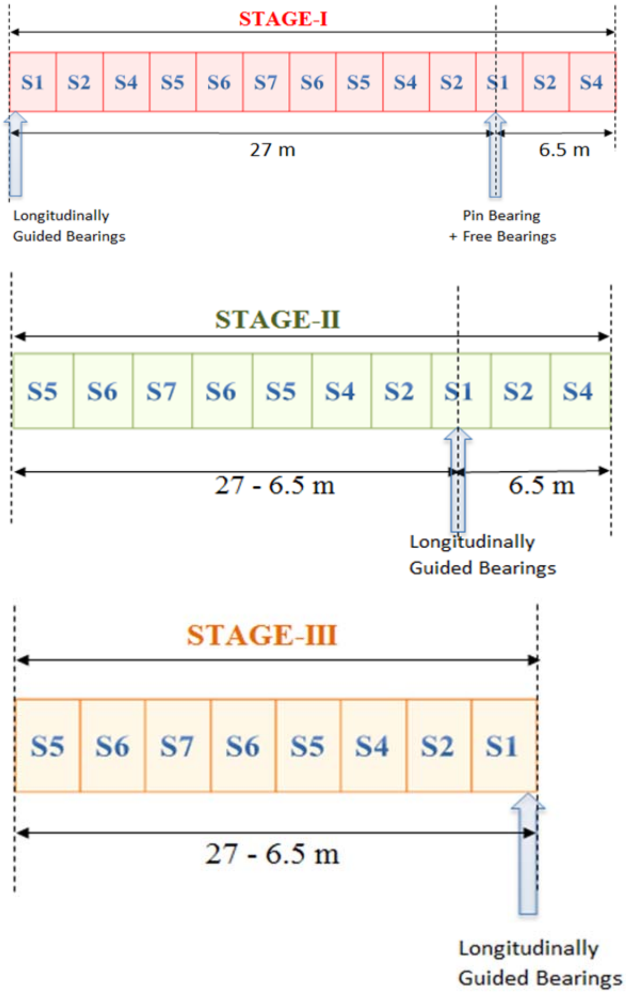


Figure 2.1 **Construction Stages for 3-span continuous bridge**

Definition of Cable Profile:

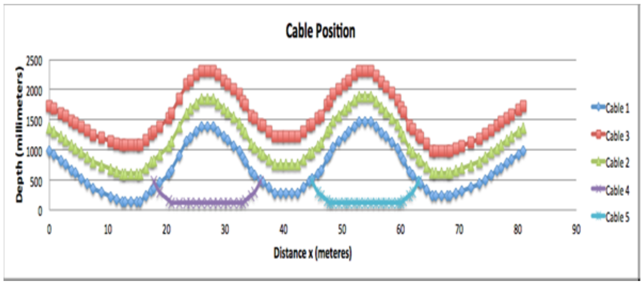
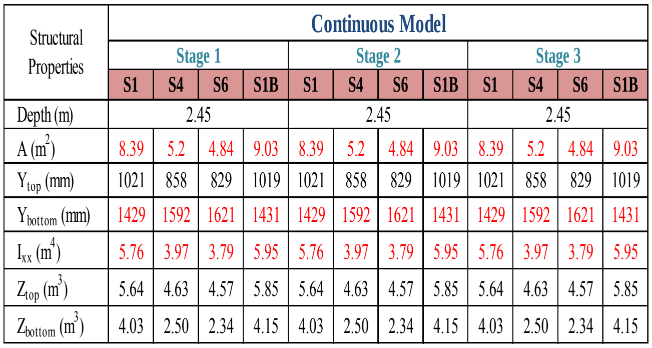


Figure 2.2 Cable Positioning according to the depth of Box Girder.



Structural Properties	Continuous Model											
	Stage 1				Stage 2				Stage 3			
	S1	S4	S6	S1B	S1	S4	S6	S1B	S1	S4	S6	S1B
Depth (m)	2.45				2.45				2.45			
A (m^2)	8.39	5.2	4.84	9.03	8.39	5.2	4.84	9.03	8.39	5.2	4.84	9.03
Y_{top} (mm)	1021	858	829	1019	1021	858	829	1019	1021	858	829	1019
Y_{bottom} (mm)	1429	1592	1621	1431	1429	1592	1621	1431	1429	1592	1621	1431
I_{xx} (m^4)	5.76	3.97	3.79	5.95	5.76	3.97	3.79	5.95	5.76	3.97	3.79	5.95
Z_{top} (m^3)	5.64	4.63	4.57	5.85	5.64	4.63	4.57	5.85	5.64	4.63	4.57	5.85
Z_{bottom} (m^3)	4.03	2.50	2.34	4.15	4.03	2.50	2.34	4.15	4.03	2.50	2.34	4.15

Table 2.1 Sectional Properties of Continuous Segmental Box Girder:

Prestress Force:

Prestressing force as per cable profile including the losses has been applied. The high tensile steel for prestressing shall consist of uncoated, stress relieved, low relaxation strands conforming to class II of IS: 14268-1995 (with a breaking load of 260.7 kN for 15.2 mm strand).

Table 2.2 Prestressing Cable properties:

Wobble coefficient of the sheathing duct/strand	k = 0.002 per meter
Friction coefficient of the sheathing duct/strand	m = 0.17 per radian
Wedge slip at decking end	6 mm
Type of cable	19K15
Type of sheaths	HDPE
Duct diameter	105 mm
Minimum c/c distance between cables	210 mm
Minimum distance of centre of cable from surface of concrete	130 mm

Mathematical Modelling:

The mathematical modeling of segmental PSC box Girder Bridge having span of (27+27+27) m is shown in Figure 3.15. The modeling of the bridge structure is done in MIDAS Civil Software (2016 version) and Beam Element is used for geometry and PSC single cell box is chosen as the cross section. Type of model is Linear Elastic modeling. Rigid links are used to transfer the forces to the supports.

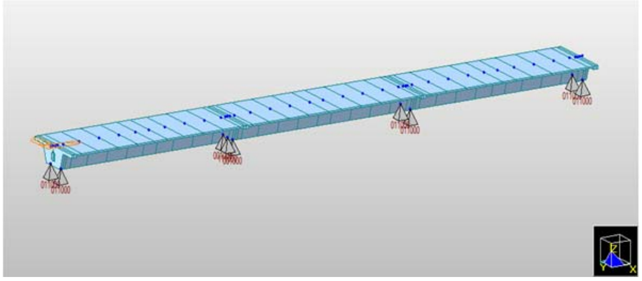


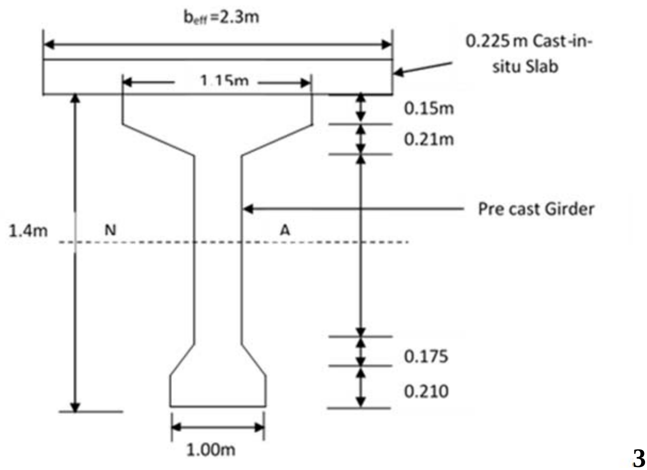
Figure 2.3 Modeling of Segmental Box Girder Superstructure in MIDAS Civil.

Table 2.3 Deflection Check:

Deflection (mm)		At Transfer	At Service
Stage 1	S1	0	-
	S4	0.731	
	S6	1.19	
	Couplers	-1.275	
Stage 2	S1	0	
	S4	0.913	
	S6	1.045	
	Coupler	-1.032	
Stage 3	S1	0	0
	S4	3.17	0.98
	S6	4.27	-1.05

Table 2.4 Check for stresses at top and bottom at both transfer and service stage:

Design Output Stresses (MPa)		Stage 1				Stage 2				Stage 3			
		S1	S4	S6	S1B	S1	S4	S6	S1B	S1	S4	S6	S1B
At Transfer	σtop	1.3	2.7	2.8	1.2	1.3	2.6	2.6	0.8	1.9	3.1	2.9	1.4
	σbott	1.5	0.7	0.3	1.2	1.5	1.0	0.8	1.8	2.2	2.8	3.1	2.9
At Service	σtop	-								1.9	4.3	4.4	0.7
	σbott									2.2	0.6	0.2	3.9



3. Validation of MIDAS Civil Modeling:

Validation of modelling done in MIDAS Civil software with STAAD Pro software and Manual calculation in which distribution factor is calculated by using Courbon's methodq is done.

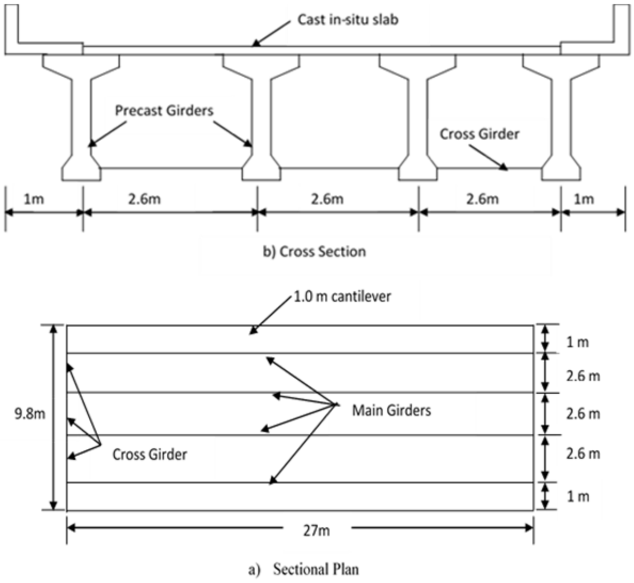


Figure 3.1 Plan and Cross section of Bridge Structure.

	Class A (Edge)	Class A (Centre)	Class 70R (Centre)	Class 70R (Edge)	2 lane Class A (Edge)
Maxi. B.M. (kN-m) Manual	1642	1147	2489	2565	2025
Maxi. B.M. (kN-m) MIDAS	1520	1119	2436	2394	1795
Maxi. B.M. (kN-m) STAAD	1522	1078	2300	2471	1962

Table 3.1 Maximum Bending Moment (kN-m) comparison:

Table 4.4 Shows that there is maxi. Variation between MIDAS and STAAD results is 8.5%.. Variation between MIDAS and Manual calculation result is 11.35%. it means that modeling in MIDAS is correct.

4. Alternative 4 number of girder Simply Supported structure:

Vehicular Live Load for clear carriageway of 9m is applied as per IRC: 6-2014. Following options were considered for the analysis of present problem.

- Class A Wheeled Vehicle – 1 Lane
- Class A Wheeled Vehicle – 2 Lane
- 70R Wheeled Vehicle – 1 Lane.
  The impact factor for the appropriate loading class is considered as per IRC: 6-2014.

Figure 4.1 Cross section of Exterior Girder.

Table 4.1 Section Properties of exterior I-girder:

Section Properties	I-Girder		Composite I-Girder	
Locations	Support	Mid-span	Support	Mid-span
Area (m^2)	1.454	0.845	1.972	1.363
Depth (m)	1.40	1.40	1.625	1.625
Y_b (m)	0.72	0.71	0.93	1.01
I_{xx} (m^4)	0.243	0.200	0.486	0.409
Z_t (m^3)	0.357	0.290	0.700	0.665
Z_b (m^3)	0.337	0.282	0.522	0.405

Table 4.2 Variation of Moment and Shear Force along span for exterior I-girder:

Exterior I-Girder						
Properties	Values					
Section from end	0L	0.1L	0.2L	0.3L	0.4L	0.5L
	0	2.7	5.4	8.1	10.8	13.5
M_{DL}	0	1296	2034	2743	3071	3229
SF_{DL}	493	367	287	183	105	0
$M_{SIDL-Fix}$	0	239	350	456	499	520
$SF_{SIDL-Fix}$	82	70	54	33	15	0
$M_{SIDL-Vari}$	0	152	242	326	365	383
$SF_{SIDL-Vari}$	58	44	35	22	13	0
M_{Live}	0	760	1260	1712	1910	2034
SF_{Live}	342	310	223	188	119	79

Table 4.3 Details of prestressing cable profile:

Cable no.	Strand Type	Sheating Dia. (mm)	Jacking Stress (Mpa)	Y_{bottom} at sup. (mm)	Y_{bottom} at mid (mm)
C1	7PLY15	110	1267	1100	150
C2	7PLY15	110	1267	700	150
C3	7PLY15	110	1267	300	150

Table 4.4 Permissible stresses in concrete:

Stress in concrete	Expression
Compressive strength of concrete at transfer (f_{ci})	0.8 f_{ck} (32)
Permissible compressive stress in concrete at transfer (f_{ct})	0.5 f_{ci} (16)
Permissible tensile stress in concrete at transfer (f_{tt})	0
Permissible compressive stress in concrete at working (f_{cw})	0.4 f_{ck} (12.8)
Permissible tensile stress in concrete at working (f_{tw})	0

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.70	5.68	4.17	3.39	3.97	4.30
σ_{bottom}	4.34	8.12	9.86	10.95	10.48	10.26

Table 4.5 Check for stresses at construction stage (1,1) in exterior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.59	7.29	6.95	7.22	8.22	8.75
σ_{bottom}	4.14	5.80	6.31	6.30	5.42	4.99

Table 4.6 Check for stresses at construction stage (1,2) in exterior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	4.57	7.94	7.16	7.07	7.97	8.46
σ_{bottom}	6.65	11.1	12.8	13.6	12.9	12.5

Table 4.7 Check for stresses at construction stage (2,2) in exterior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	4.60	8.27	7.66	7.74	8.69	9.20
σ_{bottom}	6.50	9.91	11.0	11.3	10.4	10.0

Table 4.8 Check for stresses at construction stage (2,3) in exterior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.36	5.83	5.60	5.78	6.40	6.74
σ_{bottom}	6.17	8.80	9.33	9.33	8.59	8.22

Table 4.9 Check for stresses at construction stage (3,1) in exterior I-girder:

Table 4.10 Check for stresses at service stage (SLS) in exterior I girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.35	5.82	5.59	5.77	6.39	6.74
σ_{bottom}	6.14	6.92	6.26	5.14	3.91	3.24

As all stress values in all construction stages are within permissible limit i.e. 16 Mpa and 12.8 Mpa compressive stresses in transfer stage and working stage respectively. 0 Mpa tensile stresses in all construction stages or there is no tensile stress at all in any stage.

Table 4.11 Check for deflection at various stages in exterior I girder:

Stages	Deflection (mm)					
Section from end (m)	0L	0.1L	0.2L	0.3L	0.4L	0.5L
	0	2.7	5.4	8.1	10.8	13.5
Stage (1,1)	0	4.67	8.78	11.55	12.81	12.80
Stage (1,2)	0	2.40	4.53	5.72	6.04	6.03
Stage (2,2)	0	4.97	9.15	11.67	12.60	12.59
Stage (2,3)	0	5.07	9.27	11.76	12.65	12.64
Stage (3,2)	0	8.40	14.98	18.89	20.38	20.37

The above all deflection values are within limits 34mm i.e. (span/800) so, it is safe in deflection criteria.

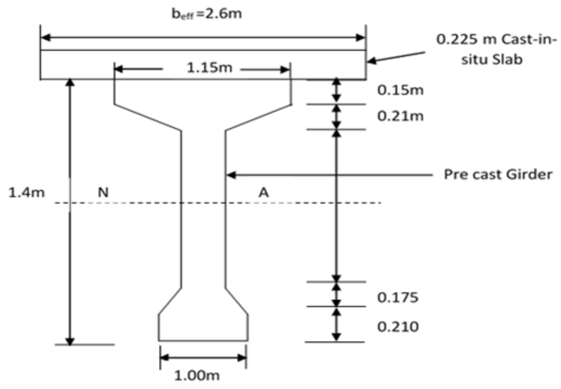


Figure 4.1 **Cross section of Interior Girder**

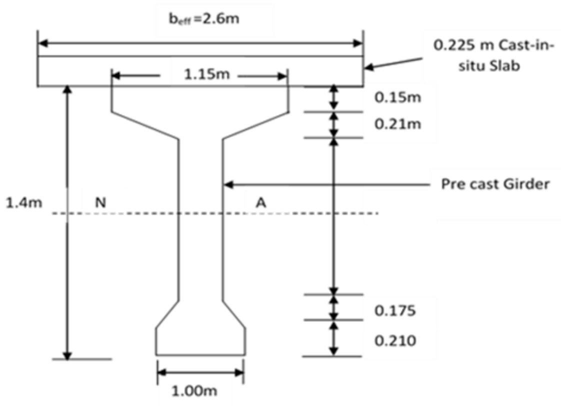


Table 4.12 Section Properties of Interior I-girder:

Section Properties	I-Girder		Composite I-Girder	
Locations	Support	Mid-span	Support	Mid-span
Area (m^2)	1.454	0.845	2.039	1.430
Depth (m)	1.40	1.40	1.625	1.625
Y_b (m)	0.72	0.71	0.95	1.04
I_{xx} (m^4)	0.243	0.200	0.508	0.425
Z_t (m^3)	0.357	0.290	0.753	0.726
Z_b (m^3)	0.337	0.282	0.535	0.409

Table 4.13 Variation of Moment and Shear Force along span for interior I-girder:

Exterior I-Girder						
Properties	Values					
Section from end	0L	0.1L	0.2L	0.3L	0.4L	0.5L
	0	2.7	5.4	8.1	10.8	13.5
M_{DL}	0	1286	2038	2757	3084	3244
SF_{DL}	503	373	295	187	107	0
$M_{SIDL-Fix}$	0	55	106	162	191	206
$SF_{SIDL-Fix}$	14	12	11	10	8	0
$M_{SIDL-Vari}$	0	150	239	325	365	384
$SF_{SIDL-Vari}$	55	44	35	22	13	0
M_{Live}	0	964	1473	1926	1982	2109
SF_{Live}	363	320	272	244	210	173

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.70	5.68	4.17	3.39	3.97	4.30
σ_{bottom}	4.34	8.12	9.86	10.9	10.5	10.3

Table 4.14 Check for stresses at construction stage (1,1) in interior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.55	7.28	6.90	7.09	8.08	8.61
σ_{bottom}	4.13	5.72	6.32	6.41	5.54	5.09

Table 4.15 Check for stresses at construction stage (1,2) in interior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	4.53	7.95	7.21	7.06	7.95	8.43
σ_{bottom}	6.75	11.2	12.9	13.8	13.1	12.7

Table 4.16 Check for stresses at construction stage (2,2) in interior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	4.57	8.06	7.43	7.40	8.32	8.81
σ_{bottom}	6.55	10.4	11.6	12.3	11.4	10.9

Table 4.17 Check for stresses at construction stage (2,3) in interior I-girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.41	5.74	5.52	5.68	6.29	6.61
σ_{bottom}	6.25	9.14	9.73	9.77	9.00	8.62

Table 4.18 Check for stresses at construction stage (3,1) in interior I-girder:

Table 4.19 Check for stresses at service stage (SLS) in interior I girder:

Properties	Values (Mpa)					
Section from end (m)	0	2.7	5.4	8.1	10.8	13.5
σ_{top}	3.38	5.74	5.52	5.68	6.29	6.61
σ_{bottom}	6.25	6.82	6.19	5.13	4.23	3.53

As all stress values in all construction stages are within permissible limit i.e. 16 Mpa and 12.8 Mpa compressive stresses in transfer stage and working stage respectively. 0 Mpa tensile stresses in all construction stages or there is no tensile stress at all in any stage.

Table 4.20 Check for deflection at various stages in interior I girder:

Stages	Deflection (mm)					
Section from end (m)	0L	0.1L	0.2L	0.3L	0.4L	0.5L
	0	2.7	5.4	8.1	10.8	13.5
Stage (1,1)	0	4.96	9.37	12.38	13.76	13.76
Stage (1,2)	0	2.71	5.18	6.64	7.09	7.09
Stage (2,2)	0	5.28	9.79	12.56	13.62	13.62
Stage (2,3)	0	6.10	11.22	14.38	15.61	15.60
Stage (3,2)	0	9.64	17.31	21.99	23.86	23.86

The above all deflection values are within limits 34mm i.e. (span/800) so, it is safe in deflection criteria.

5. Conclusion:

An attempt has been made in the present study to understand the current design practice of PSC I-type Girder Superstructure bridge using MIDAS civil software in which construction stage wise analysis are carried out as per construction sequences of the bridge. The following observations and conclusions are made from this project work.

Alternative 4 numbers of longitudinal girders of 1.4m depth with 3 nos. of prestressing cable 19K15 used in simply supported structure.

- it is found that compressive stress value is 3.24 Mpa in exterior girder and no tensile stress at any stages. maximum deflection is 20mm.
- it is found that compressive stress value is 3.53 Mpa in interior girder and no tensile stress at any stages. maximum deflection is 24mm.

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