https://doi.org/10.15623/ijret.2018.0711006 Received: 13-09-2018, Accepted: 23-10-2018, Published: 15-11-2018

STUDY OF STRUCTURAL ANALYSIS OF PSC BOX GIRDER VIADUCT FOR PUNE METRO

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Abstract

Pune is a developing metropolitan city not only emerging as an international education hub but also as an IT and an ITES research and development centre, which attracts in migration of population in the city. The Population of Pune city is approximately 40 lacs and has registered 10, 70,000 vehicles. The survey which was conducted by PMC shows that volume to capacity ratio of the existing roads is more than 1.00 in peak hours. In this urbanized city, there is growing multi-modal commuting activity (public bus transport, two-wheelers, three wheelers, cars, and others). This activity is largely local, but rapid urbanization is increasing its traffic within the city. It is observed that, road public transport system in Pune city is not efficiently working as estimated because the existing roads do not have the capacity to carry vehicular load and high demand of traffic density. Hence, there is a need to study the traffic density to minimize the traffic congestion for efficient movement of traffic. With the available road width, as there are no chances of road widening possible, constructing a metro bridge at most congested routes is the only option to solve the traffic problems. In this project, the study is mainly focusing on analysis of advanced techniques for design of precast segmental box girder viaduct. The construction of metro rail bridge is one of the long term strategies for safe and efficient movement of commuter's flow which provides fast, safe and non polluting way of transport system. The proposal of a precast segmental viaduct design is technically feasible as there is continuous traffic flow with limited availability of Right Of Way. An extensive study of all the parameters involved in the design of the bridge will be made. The project concisely summarizes the economical design of the bridge.

Keywords: *analysis of PSC Box girder, Pune Metro, Elevated Metro Structure, MIDAS civil*

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1. INTRODUCTION

A viaduct is a bridge composed of several small spans. The viaduct structure which is being used for Metro railway in Pune is the Pre-cast segmental box girder that carries two number of tracks supported on single pier (column). Externally post-tensioned segmental box girder bridges are now making new developments in the field of bridge engineering over the last few years. As compared to 'classical monolithic' constructions in cast in place type structure, precast segmental bridge is having small precast elements which are stressed together as a part of pre-tensioning or post tensioning by using external tendons. Using this type of structure the construction work can be achieved at faster rate without causing disruption at road level. Also the advantage of adopting such structure is the high controlled quality and cost savings which has found to be the preferable solution for many elevated railway projects and road projects like metro railways, flyovers in urban cities etc. Therefore, the superstructure for metro-rail in Pune has opted precast segmental construction over Cast in place RCC construction which will cause minimum inconvenience to the traffic on road during the work execution stage.

In PSC box girder, an initial load on a structure is applied so as to enable it to prevent the stresses arising from upcoming loads during its service period. Pre-stressed concrete is the concrete where in the internal stresses of an appropriate measure are introduced such that the stresses arising from external loads are prevented to desired level. In reinforced concrete members, generally high tensile steel rods or steel cables are used as a pre-stressing tendons.

Metro bridges have two major elements: pier and pre-stressed box girder or beams. In almost all major cities of India metro construction work is going on but still at present nationwide guidelines are not available for the design of metro rail structure. Each metro organization in India has their own design specifications based on Indian Road Congress (IRC) or Indian Railway Standard (IRS) guidelines. The main objective of this study project is to study the design forces calculated for superstructure and substructures of metro rail bridges using IRC, IRS.

2. METODOLOGY

For the structural design, meet all applicable portions of the Indian general laws and regulations, and the codes, manuals, or specifications identified in this Section. The proposed bridge system for precast segmental cantilever construction is a variable depth single cell box girder. The box girder cross section is designed to have thin flanges and thin webs to make efficient use of concrete of high strength and to reduce dead load of the superstructure. The maximum bridge span considered for this study is 30m for practical and visual considerations. As a practical consideration, the maximum depth of the girder segments should be limited to

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accommodate ease of transportation which is constrained by standard vertical clearances for existing overpass structures. As a visual consideration, the depth of the girder should be limited to maintain a reasonable level of slenderness for the design. For design and analysis, provisions of IRS concrete bridge code is followed. The partial load factors and load combinations are considered according to clause 11 and table-12 of IRS CBC.

Table 1: Load factors and load combinations

(Clauses 11.2 and 11.3)

LOAD		LIMIT STATE	γ_{fL} TO BE CONSIDERED IN COMBINATION				
			1	2	3	4	5
Dead weight of concrete		ULS SLS	1.40 1.00	1.40 1.00	1.40 1.00	1.40 1.00	- 1.00
Superimposed dead load		ULS SLS*	2.00 1.20	2.00 1.20	2.00 1.20	2.00 1.20	- 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	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	- -	- -	- -
Tempe rature	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	2.00 1.10	1.75 1.00	1.75 1.00	- -	- -
Derailment loads		SLS	(As specified by bridge rules for combination 5 only)				

NOTE 1-ULS : Ultimate limit state SLS : serviceability limit state

NOTE 2-Wind and earth quake loads shall not be assumed to be acting simultaneously.

NOTE 3- Live load shall also include dynamic effect, forces due to curvature exerted on track, longitudinal forces, braking forces and forces on parapets.

3. STRUCTURAL SYSTEM OF VIADUCT

Simply supported precast segmental box girder is chosen for viaduct structures. A standard span of 30 m is assumed for analysis and design purpose. The proposed viaduct structure is to be analyzed for 4-car train configuration which comprises of D.T.C._M.C._M.C._D.T.C.

Where, D.T.C. : Driving Trailer Car, M.C. : Motor Car and T.C. : Trailer Car

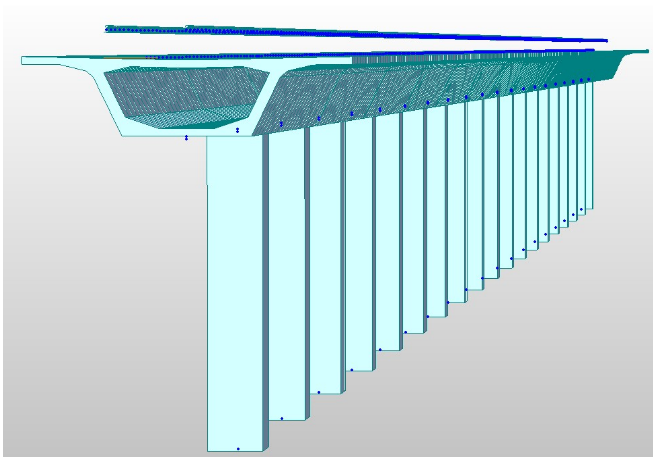

Fig 1: 3-D model of viaduct structure in Midas Civil

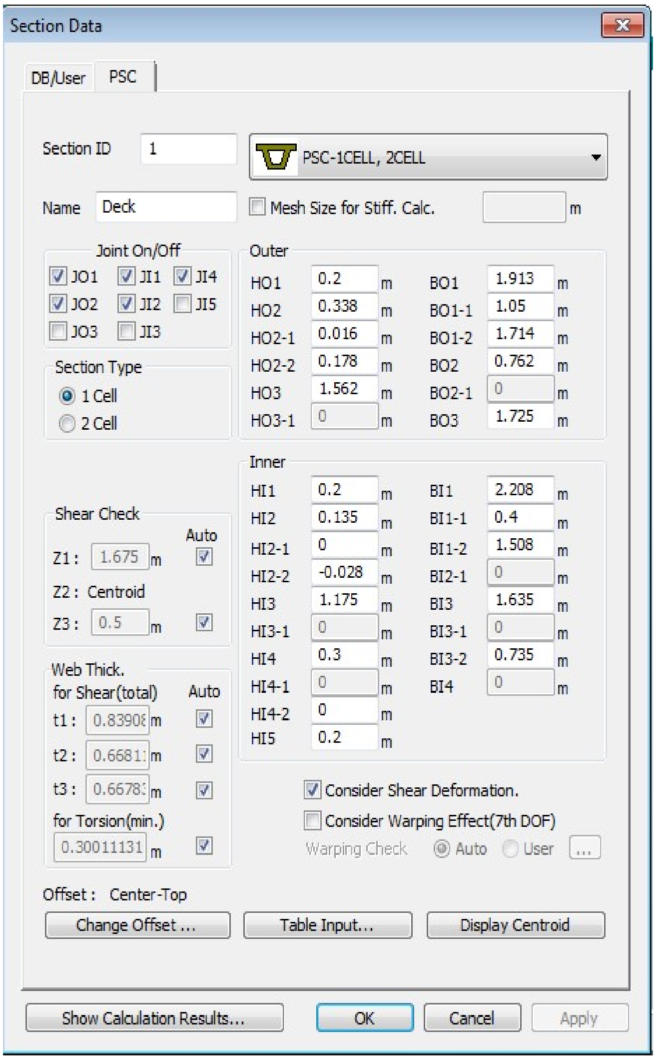

Fig 2: Cross sectional properties of deck slab

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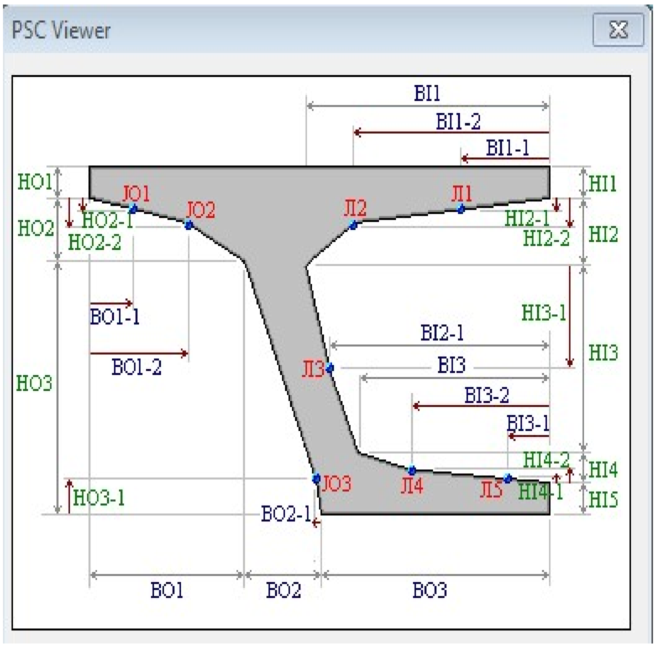

Fig 3: Cross sectional view of deck slab in MIDAS

Paragraph A solid rectangular section is considered having dimension 2 m X 1.6 m for pier section.

- **Cement:** in general 53 grade cement is to be used as per the clause given in IRS Concrete Bridge Code (Refer Clause 4.1)
- **Concrete:** Minimum grade of concrete to be used for structural element is M-40 as per clause 5.4.4 of IRS CBC. Hence while assigning material properties in midas civil, M-40 grade of concrete is assigned to the deck as well as to the pier section.
- **Reinforcement Steel:** TMT bars of Fe 500 grade as per clause 4.5 of IRS CBC is adopted.
- **Pre-stressing Steel:** The pre-stressing steel used shall be any of the following (IRS CBC, clause 4.6.1):-

  i) Plain, hard-drawn steel wire conforming to Indian standard IS 1785 (part-I)

  ii) Uncoated, stress-relieved strand conforming to Indian standard IS 6006.

  iii) High tensile steel bars conforming to IS 2090.

  iv) Uncoated stress relieved low relaxation strands conforming to Indian standard IS 14268.

4. LOADING SPECIFICATIONS

Loading specification as per the various codes for all the static and dynamic (wind and seismic) loads are described below. IRS Bridge Rules for calculation of impact factor, longitudinal force, nosing force, force on parapet and footpath live load.

4.1 Super Imposed Dead Load (SIDL)

SIDL is separated into two parts i.e. SIDL variable and SIDL fixed. Only parapet load comes under the fixed. SIDL load in kN/m is as shown below:

Table 2: Super Imposed Dead Load

Item	Load kN/m	Item	Load kN/m
Rail + Pad	3	Miscellaneous	4
Cable + trays	0.8	Cable trays	0.1
Plinth	28	Hand rails	0.8
Light wt. drainage conc.	2.4	Cable duct cover	2
Cables through cell	7.4	Parapet (SIDL Fix)	32.6

4.2 Live Load

The live load considered as per consecutive coaches or cars which is 6 in numbers for a single train having the length of each car 2180 mm. Each coach consists of four number of axles and each axle is assumed to transmit a load of 160 kN as shown in Figure shown below. To calculate maximum response moving load analysis were performed in MIDAS Civil for both single track and double track loadings. Impact factor for I and Box girder metro bridge was calculated as per IRS: Bridge rule, EN 1991-2 and California high speed rail authority which is given in Table 2.

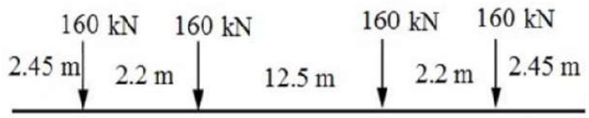

Fig 3: Standard axle distance for proposed project

Table 3: Impact factor for the viaduct

Code	Formula	CDA I-Girder	CDA Box-Girder
IRS Bridge Rules	$1+(0.15+\frac{8}{6+L})\geq 1.2$	1.4	1.32
EN1991-2	$\frac{2.16}{\sqrt{L}-0.2}+0.73\geq 1$	1.18	1.08
California high speed rail authority	$I=\frac{225}{\sqrt{L}}\%$ (12 to 38.7 m) I= 20% > 39m	1.24	1.2

4.3 Longitudinal Forces

Traction and braking forces were calculated for various codes which are given in Table as shown below, in which L' is live load on the deck

Table 4: Longitudinal forces for the viaduct analysis

Code	Traction load	Braking load
IRS: Bridge Rules	0.2L'	0.18L'
EN1991-2	0.25L'	0.25L'
California high speed rail authority	0.25L	0.25L

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4.4 Nosing Force

Force on parapet and footpath live load are compared between various codes.

Table 5: comparison of Nosing forces with various codes

Code	Nosing Force (kN)	Force on parapet (kN/m)	Footpath live load (kN/m2)
IRS: Bridge Rules	100	1.5	4.9
EN1991-2	100	1.5	4
California high speed rail authority	98	1.5	4.8

4.5 Wind Load and Seismic Force

The wind and seismic forces were calculated as per the codal provisions of various codes which are given in following Table. Design basis report suggests, for calculation of the wind and seismic forces IRS Bridge rules and RDSO guidelines for seismic design of railway bridges [7] shall be used. As per DBR both the dynamic forces to be calculated using IRC: 6 [8].

Table 6: Wind & seismic forces according to various codes

Load	Seismic Force	Wind Force
IRS guidelines	IRS-Bridge rules clause 2.12	IRS-Bridge Rules , clause 2.11
IRC: 6	IRC: 6 clause 209	IRC: 6, clause 218
Euro-code	EN 1998-1 [9] EN 1998-2 [10]	EN 1991-1-4 [11]
California high speed rail authority	AASHTO LRFD [12] Clause 3.10	AASHTO LRFD With Caltrans Amendment Clause 3.8

4.6 Temperature Load (TL)

The temperature load need to be taken in to account while analyzing the structure 25° C is considered in case of deck and 32° C is considered for rails.

4.7 Stiffness (According to UIC code and RDSO Specifications)

4.7.1 Ballast Bed

Lateral limited displacement $U_d = 0.002$ m
Unloaded condition stiffness = 20 kN/m when only temperature loading is active.
Loaded condition stiffness = 60 kN/m when only vertical loading is active.

4.7.2 Concrete Bed

Lateral limited displacement $U_d = 0.002$ m
Unloaded condition stiffness = 20 kN/m when only temperature loading is active.
Loaded condition stiffness = 60 kN/m when only vertical loading is active.

5. CONCLUSION

The purpose of this paper was to spread knowledge of the analysis and design of Prestressed Segmental concrete Box girder type super structure by provisions of Indian codes and to show how to automize the same using MIDAS civil software.

Important features of this paper are as follows:
1) Most economical and safe section can be achieved by taking numbers of trials with minimum of time. This type of atomization is most useful in all design offices.
2) It could be easily concluded that this option of segmental box girder is more economical compared to conventional precast girders
3) The dimension of a bridge plays a governing role for the involvement of various loads and there cases for the designing purpose.
4) For designing any metro railway bridge relevant IRS codes, design basis reports are to be very meticulously followed.

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BIOGRAPHIES

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