**IOSR Journal of Engineering (IOSR JEN)** **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 92-101

# Comparative Study On I Girder And Box Girder For Design Of Psc Bridge

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***Abstract:*** *Prestressed concrete consists high strength concrete and high tensile steel which has greater advantages in bridge construction. PSC bridges are widely used in recent developments due to the reason that it leads to durable and economical sections with increased aesthetic appearance as compared with conventional bridges. The major advantage of PSC is for composite construction including precast prestressed girders with cast in-situ slab deck which is emerging popular in recent developments, involves construction of bridge with minimum disruption of traffic. In this project, comparison is made between prestressed I girder and box girder to find out the most suitable section for superstructure of the bridge. Since, both having distinct sections, comparison of quantity of materials resulting from design of sections for a particular span is carried out. For this purpose, a 4-lane major bridge having span of 40m is selected. The main objective of the present study is to analyze and design the I girder and box girder bridge. Also, substructure is designed for economical superstructure design resulting from the comparison of both the girders. Analysis and design results for I girder and Box girder have been tabulated and compared for concrete, reinforcing steel and prestressing steel. Comparative study shows that, for the particular span, I girder superstructure consumes less quantity of materials than box girder. Hence, substructure has been designed for I girder bridge with suitable sections as per IRC Standards.*

***Keywords:*** *Major bridge, Prestressed Concrete, Post tensioned girders, STAAD Pro, Substructure Design*

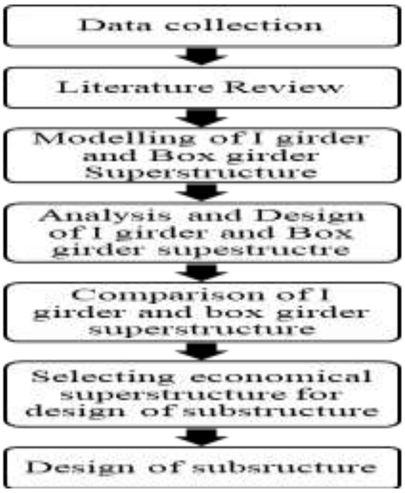
## I. Introduction

Choice of sections for the girder of a bridge depends upon the span, load acting on it and other site conditions. When the span increases, dead load of the structure also increases. I sections are open sections which reduces the dead weight and upon prestressing increases the load carrying capacity. Also, under high transverse bending due to large spans, girders will no longer be in their original position. To keep them in their original position the bulbs at bottom should be tied together which in-turn leads to evolution of box girder. Box girders are advantageous to accommodate prestressing cables at the bottom and hence reducing the efforts of proving additional provisions for prestressing. In other case, I girder require additional section at the bottom to provide prestressed cables which results in bulking of the bottom flange than the top flange. I girder sections has high stability for bending moments generating in the structure and bear high shearing stresses. However, box girder being a closed section, has high torsional stiffness. But the effects like distortion and warping of box girders can be minimized by appropriate internal stiffening.

For the present work, a comparative study is made between I girder and box girder in which both the girders are analyzed and designed and the resulting economic girder is chosen for further design of substructure. In practical conditions of bridge construction, there are many criteria in selecting suitable girder. For the present study, two commonly used girders are selected for a span of 40 m. In general, when the carriageway width of bridge is small, number of I girders for a span will be less and section being conservative than box section, I girders shall be used and vice versa. However, many other conditions shall be considered like, ease of construction, availability of materials, etc. for selecting economical and safe sections for a bridge. In this project I girders and box girders are designed for same carriageway width and substructure is designed for economical girder as mentioned earlier. Generally, PSC I girders are not used for long spans. But when multistage prestressing for different loading cases is introduced, Bgirder depth is reduced and it is proposed to be used as an economical alternative to other types of PSC girders for long-span bridges [5].

## II. Methodology

The below flow chart shows the steps followed for the present project.



## III. Analysis and design of superstructure

Analysis of superstructure for both girder systems are carried out for dead loads, superimposed loads and vehicle loads. Vehicle live loads for class A and 70R vehicles are assigned to the model and load combinations are used as per IRC 6:2016 standards. Results for maximum load cases were extracted and corresponding ultimate strength capacity checks are carried out.

Superstructure consists of cast in-situ deck slab with a width of 14m to cater 4 lane carriageway and precast PSC I girder having total depth of 2400mm and that of box girder is of 2200 mm. The superstructure is simply supported over the abutment cap with pedestal and bearing arrangement.

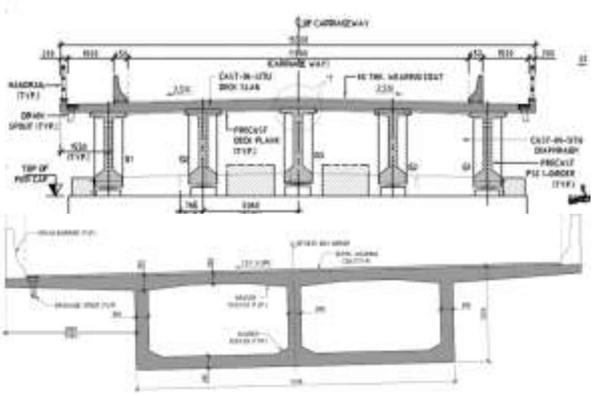


**Fig 1: General arrangement of PSC I Girder and**

**Box girder**

The grade of concrete M45 and Modulus of Elasticity of 34000 MPa are considered for deck slab and PSC girder. The grade of reinforcement considered is Fe 500. The unit weight of reinforcement is taken as 7.85kN/m3. The Modulus of elasticity considered is 2x$10^5$ Mpa. Prestressing steel will be conforming to IS: 14268, class II-7 ply strand of low relaxation with 12.7 mm diameter type.Superstructure is modelled for PSC I girder and box girder using STAAD pro.

I girder system consist of 5 girders for one span and hence grillage modelling is adopted as per guidelines provided by CIRIA [1]. Whereas, a line beam model is adopted for PSC Box girder and the respective section properties are assigned and analysed.

**Fig 2: Grillage Model and Line beam model of PSC I Girder and Box girder**

Section properties are calculated for both the girders and assigned to respected beams modelled in STAAD Pro. Properties are calculated for mid-section and support section. Properties for varying section is approximately taken as average of mid-section and support section.

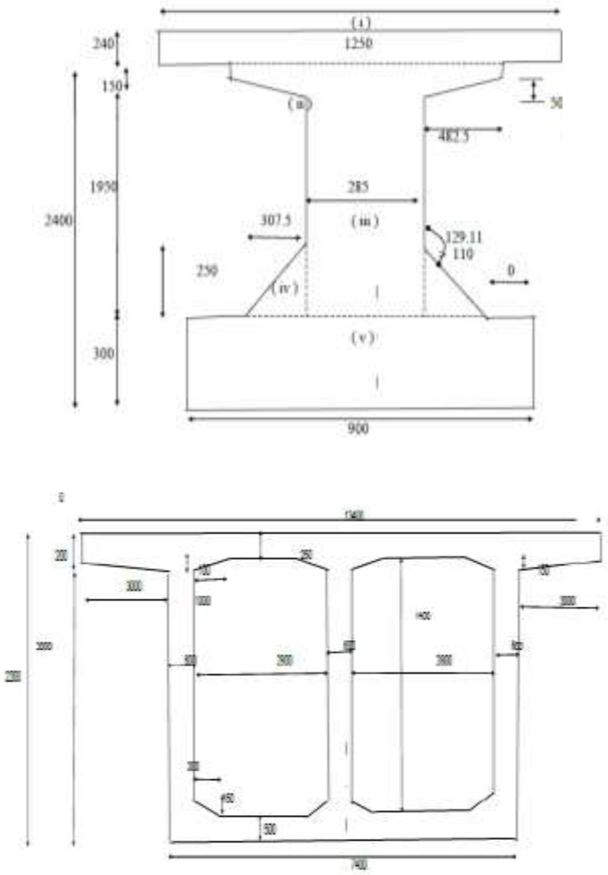
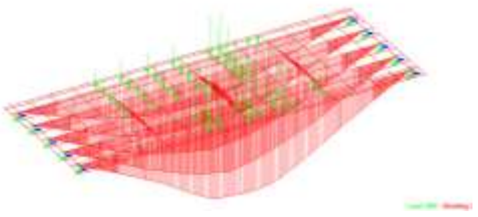


**Fig 3: Sections of PSC I and Box girder**

Results taken from analysis using STAAD Pro software for governing load case (CLA A+70R) of both the girders are shown below. Also, results for DL+SIDL and Live load (moving load) cases are compared for both the girders and economical superstructure is selected by further quantity comparison for substructure design.



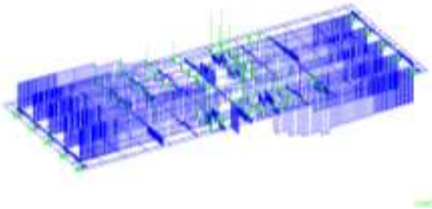


**Fig 4: Bending moment and Shear Force for PSC I girder**

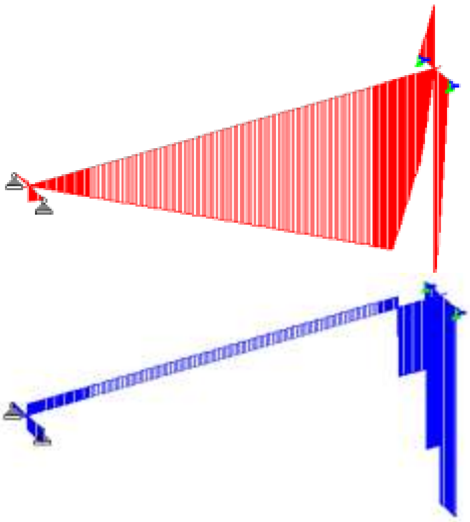


**Fig 5: Bending moment and Shear Force for PSC Box girder**

### 3.1 Prestress analysis

3.1.1 Cable layout

The cable profile adopted generally for these cables are combination of straight and parabolic curves. Cable duct outer diameter considered is 95mm and 110mm for 12T13 and 19T15 strands respectively and 110 mm for 19T13 strands. Prestressing system adopted are 12 strands of 13 mm diameter and 19 strands of 13 mm diameter for I girder and 19 strands of 13mm diameter for box girder.

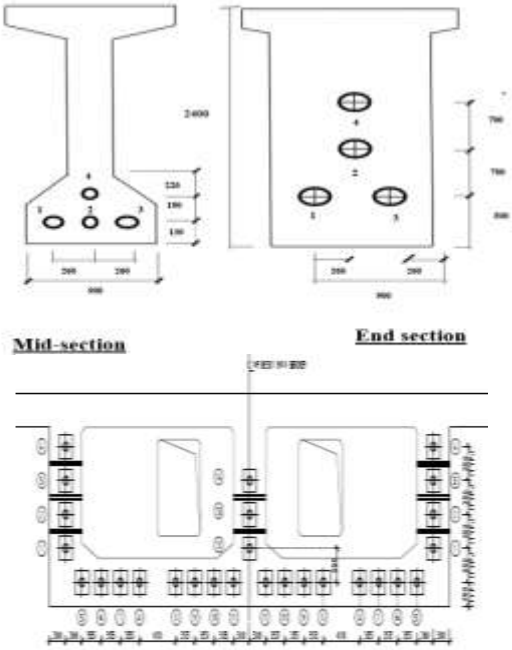


**Fig 6: Cable Layout for I girder and Box girder**

### 3.1.2 Prestress losses

Losses of prestress is calculated as per IRC 112 provisions. Properties of sections are calculated and respective losses are calculated. For I girder, permissible stresses for losses are estimated at 7 days, 21 days and end of life (total life of the structure is considered as 100 years as per IRC 5). For box girder, losses are estimated for 7 days, 14 days and end of life.

### 3.1.3 Stress check

Stress checks are carried out in two stages for PSC I girder. At 1st stage, stresses are calculated when cables 2&4 are prestressed, for which immediate losses and time dependent loses are calculated and checked for permissible stresses as per IRC:6-2016. Whereas, at stage 2, stresses are calculated when cables 1&3 are prestressed, and same procedure is followed. For Box girder, Single stage stressing is proposed for all the cables on 14th day after casting (or) concrete achieves a compressive strength of 45Mpa which is earlier.

Also, the resisting stresses generated in the cross section due to differential temperature are calculated as per clause 215.3 IRC-6-2016.The Equivalent force is calculated from the stresses.

The Equivalent moment due to stresses is found by taking moments due to each fiber about top of the slab. The Combined stresses are found by subtracting equivalent force stresses and equivalent moment stresses from resisting stresses.

Permissible concrete stress in compression for rare combination case and frequent. Combination case is 0.48fck (19.2 Mpa) (as per IRC -112 -cl.12.2.1). Permissible concrete stress in compression for quasi permanent case is 0.36fck (14.4 Mpa), as per IRC-112-cl.12.2.1. Stresses calculated for both the girders are within the permissible limits and also, it was observed that, all the stresses for PSC I girder is lesser as compared with PSC Box girder.

## 3.2 Design for secondary reinforcement

After estimating stresses in the girder and deck slab, the superstructure is designed for reinforcements as per the provisions provided in IRC 112. RC detailing for Girders, Anchor blocks, deck slab are tabulated below. Anchor blocks are designed for maximum bursting force and equilibrium reinforcements are provided as per CIRIA guide[2] and area of steel (HTS) for strands used in the girder are designed as per the same guidelines.

Transverse analysis is conducted using STADD pro for different moving load cases, which includes the calculation of effective width of deck slab and load intensity of wheel. Transverse analysis is generally conducted to check the behavior due to presence of lateral girder stiffness, diaphragms and tendon profile under vertical wheel loads [3]. Corresponding strength checks and deflection checks are carried out for the safe design of sections as tabulated below.

Diaphragms are designed for jacking case and service case for Precast prestressed girders to improve the stiffening of girders and reducing the girder deflections. Usually, diaphragms are provided to keep the girders together. And also improving the load distributions. It also, helps in reducing the accidental overturning of girders during construction. However, bearing pads are designed to carry the loads and transfer to the substructure and allows horizontal movement of the bridge superstructure. But the combine effect of diaphragms and bearing pads increase the total performance of the bridge for deformations and service load conditions.

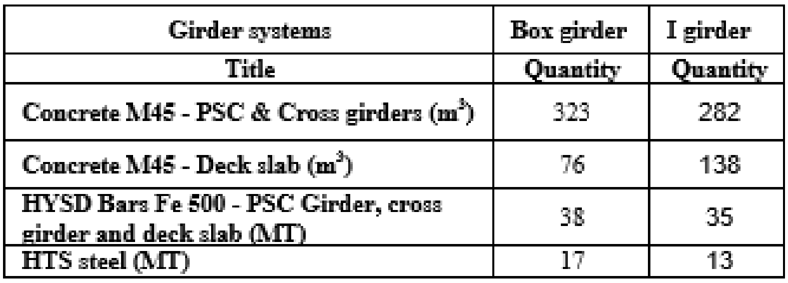
**Table 1: Reinforcement steel detailing for box girder and I girder**

| TITLE | PSC I Girder | | | | PSC Box Girder | | | |
|---|---|---|---|---|---|---|---|---|
| | Girde | Anchor block | Deck slab | Diaphragm | Girder | Anchor block | Deck slab | Diaphragm |
| Ast Required ($mm^2$) | 1214 | 6125 | 1022 | 1196 | 2337 | 3569 | 2157 | 7658 |
| Ast Provided ($mm^2$) | 1282 | 6283 | 1095 | 1257 | 2413 | 3619 | 2513 | 7771 |
| Dia of Bars (mm) | 16 | 20 (19T13)/16(12T13) | 12 | 20 | 16 | 16 | 20 | 32 |
| No.Of Bars | 3 | 10 (19T13)/8(12T13) | 6 | 4 | 12 | 9 | 8 | 6 |
| Spacing (mm) | 110 | 150 | 175 | 150 | 125 | 145 | 125 | 150 |

## IV. Comparison of I girder and Box girder

Estimation of stresses for PSC girders resulting in lesser stresses for I girder as compared with box girder. Also, deflection for I girder resulted less than box girder for transverse analysis of superstructure where girders are considered as supports. Economy of the structure is generally measured in amount of quantities and cost criteria. Hence, quantities of concrete and steel for both the girder systems were also calculated and summary of the same is tabulated as below.

**Table 2: Quantities of Box girder and I girder**



| Girder systems | Box girder | I girder |
|---|---|---|
| Title | Quantity | Quantity |
| Concrete M45 - PSC & Cross girders ($m^3$) | 323 | 282 |
| Concrete M45 - Deck slab ($m^3$) | 76 | 138 |
| HYSD Bars Fe 500 - PSC Girder, cross girder and deck slab (MT) | 38 | 35 |
| HTS steel (MT) | 17 | 13 |

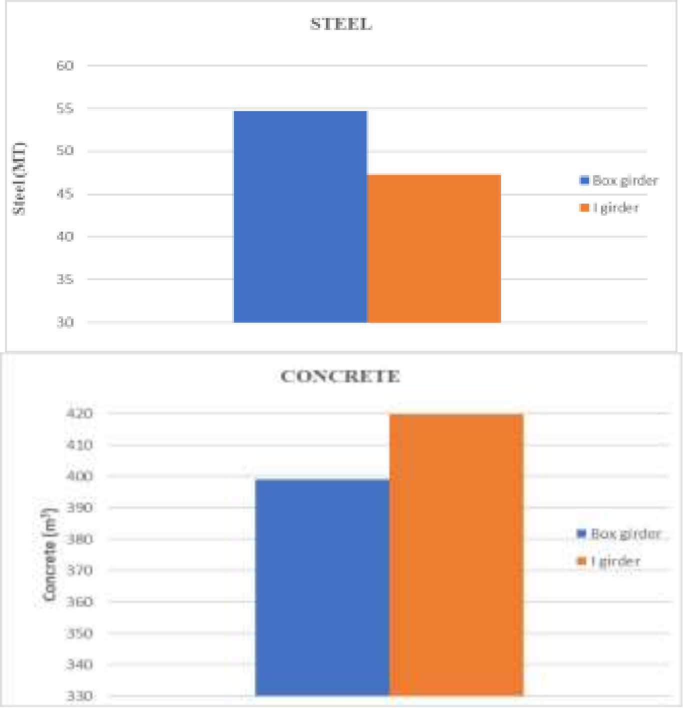


**Fig 7: Graphs showing comparison of quantities of Box girder and I girder**

From the above comparison it is clear that, quantity of concrete for I girder is more than box girder. But, quantity of steel consumed by I girder is less than box girder. So, comparatively, I girder being economical section than box girder for a straight span irrespective of various site constraints, it is selected for design of substructure. Also, from the analysis and design results, I girder resulted in safe section. Flexural stresses were found to be within permissible limits and serviceability cases were also within safe limits for the particular span as per IRC standards.

## V. Design of substructure

In a bridge, loads from superstructure are transferred to substructure by bearings. Type of substructure depends on the soil conditions, construction methodology of bridge and type of bridge. For the present work, substructure is designed for I girder superstructure as explained above. Design of substructure shall be carried out as per IRC 78-2014.

### 5.1 General arrangement

For pier, the distance between the bearings along traffic over the pier is 0.825 m and 3.06 m across the traffic direction. Accordingly, the plan dimension of the pier cap is derived as 14.8 m x 2.9 m. At the bottom of pier cap an offset of 150 mm is provided across traffic direction. The outer dimension of the Solid Pier is 5.5 m x 1.8 m. The pier is oriented such a way that 5.5 m is across the traffic and 1.8 m along the traffic direction. Based on the pier design, the dimension of Pile cap is arrived as 5.1 m along traffic direction & 8.7 m across traffic direction.

For abutment, consists of Abutment/Pile cap with dirt wall & Pile. Bored cast-in situ piles of 1200 mm diameter is used for pile foundation. The distance between the bearings across traffic is 3060mm. Accordingly, the plan dimension of the Abutment/pile cap is derived as 15300 mm x 5100 mm x 1800 mm. The dimension of Dirt Wall is provided as 15300 mm x 3040 mm with 300 mm thickness. Based on the design, the spacing between the piles were arrived as 4.6 m in transverse and 3.6m in longitudinal direction.

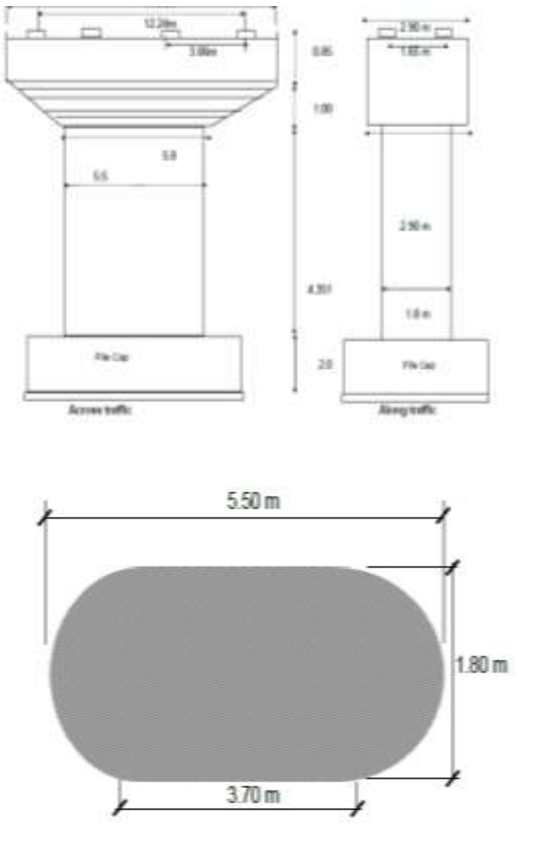


**Fig 8: Section of Pier**

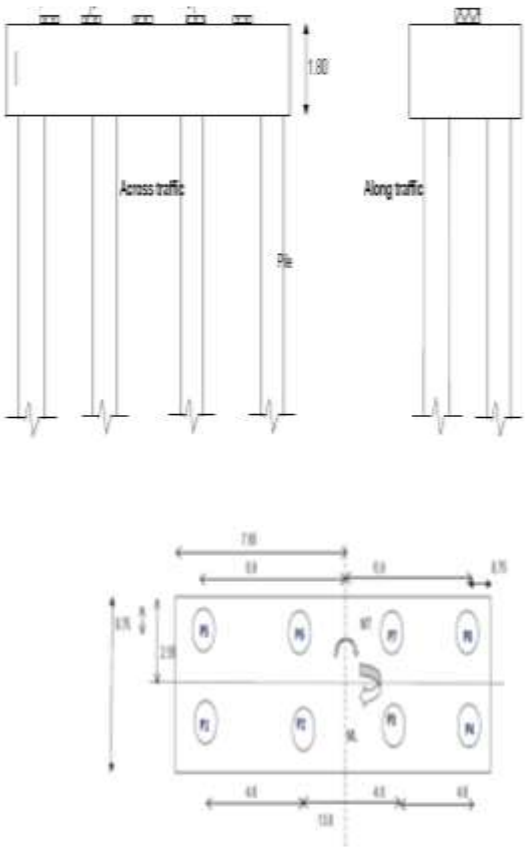


**Fig 9: Section of Abutment**

Bridge having 12 spans and hence total length is 480 m. There are total of 11 number of piers having support reactions for fixed ($F_x$) and free ($F_R$) conditions with the same level. Whereas, abutments on left and right side free and fixed support conditions respectively. Each abutment was designed to have 8 number of piers in the direction across the traffic and two piers in the direction along the traffic.

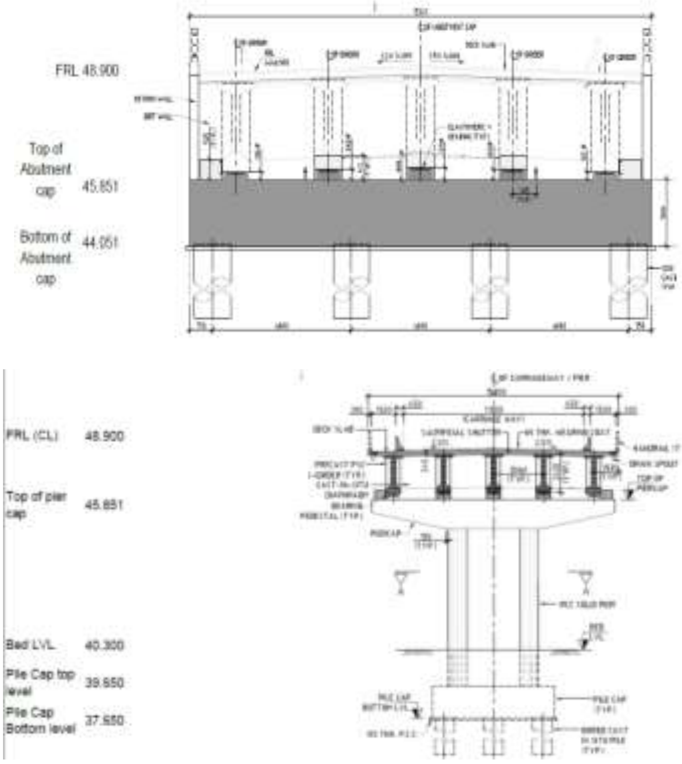


**Fig 10: Different levels of substructure**

## 5.2 Analysis and Design

For analysis of substructure, superstructure was analysed for various dead loads, permanent loads and vehicle load conditions. Load combinations are adopted as per IRC 6-2017. The model below shows the typical analysis of two span superstructure for governing live load case. For pier, loads due to dead weight, permanent loads, bearing resistance, water current, seismic forces, buoyancy, wind loads are considered for HFL and LWL conditions for SLS and ULS conditions. Whereas for abutments, earth pressure is calculated in addition to the above mentioned loads.

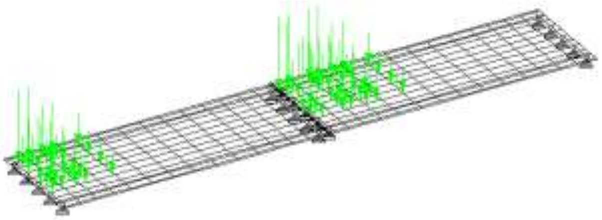


**Fig 11: Analysis of superstructure of two spans**

The reactions from analysis is taken for further design of substructure using developed excel sheets and corresponding stresses, ULS and SLS criteria are checked. From which maximum axial force, transverse moment and longitudinal moments are calculated for different load conditions and load combinations.

**Table 3: Summary of analysis results for typical pier**

| Load Combination | P (kN) | ML (kN-m) | MT (kN-m) | Load Condition (Governing) |
|---|---|---|---|---|
| **Max axial load** | **26259** | 7339 | 5822 | LWL Condition1 |
| **Max longitudinal moment** | 22908 | **19612** | 6007 | HFL Condition14 |
| **Max transverse moment** | 22858 | 6288 | **20315** | HFL Condition15 |
| **Max Longitudinal Shear** | 23009 | 19532 | 6119 | HFL Condition13 |
| **Max Transverse Shear** | 23009 | 6446 | 19766 | HFL Condition13 |

Loads were calculated at pier top level and bottom level, the reactions are then taken to design the suitable foundation. Stresses for pier were calculated for pier and abutments and were found to be within the permissible limits. Requirement for shear reinforcement was checked and suitable reinforcement was provided as per the standard provisions. Typical RC detailing for pier and abutments are shown below.

For pier,
Diameter of bar along Width of Pier (Bc) = 16 mm
No of bars along Width of Pier (one side) = 21 Nos.
Diameter of bar along Depth of Pier (Dc) = 20 mm
No of bars along Depth of Pier (one side) = 21 Nos.
Effective cover = 69 mm
Percentage of Steel provided = 0.24%
For Abutments,
Dia of bars = 20 mm
C/C spacing = 140mm
No of bars = 108
Area of reinforcement provided, As, prov = 33929 mm$^2$
Also, Detailing for surface reinforcement, shear reinforcement and ductile detailing were done as per IRC Standard provisions.

## VI. Conclusion

In this paper, detailed design for I girder and box girder were explained. Comparative analysis was done and economical section was selected for substructure design. Also, a brief detail about analysis and design of substructure was presented. It can be concluded from the following points:

- For the particular span, different criteria are adopted to select a suitable girder for a superstructure like, site conditions, ease of materials, etc. The most important criteria is the economy and safety of the section. I girder and box girder are the most commonly used section for medium to large span PSC bridges.
- From the analytical study, I girders are mostly used sections due to higher stability than the box girder due to the closed section. Box girders are generally useful where spans having curves to avoid distortion and warping.
- However, sections are chosen depending upon the quantity of materials used for the particular span which is again based upon the number of girders per span. This is due to the simple reason that, when the width of slab increases more number of longitudinal girders are required resulting in reduction of stiffness of beams in transverse direction.
- From the comapritive analysis, I girder resulted in economic section than the box girder, by less quantity of steel than the box section. Quantity of concrete being comparatively equal for both the girders, I girder is chosen as economical section for the design of substructure.
- Substructure design was carried out using developed excel sheets whose reactions were obtained from the analytical results of superstructure. Subsequently, suitable design for foundation shall be carried out.

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## IRC STANDARDS

1. IRC: 5-2015, General Features of design (Eight revision)
2. IRC: 6-2017, Loads and Stresses (revised edition) with latest amendments
3. IRC: 78-2014, Foundations and substructures with latest amendments
4. IRC:112-2011, Code of practice for concrete road bridges with latest amendments
5. IRC: 83-2002 (PART 3-SEC IX), Pot, Pot cum PTFE, Pin and metallic guide bearings
6. IRC: 83-2015 (PART 2), Elastomeric bearings
7. IRC: SP 69-2011, Guidelines to design and construction of expansion joints.
8. IRC: SP 87-2013, Manual of specifications and standards or six laning of highways through public private partnership
9. IRC: SP 109-2015, Explanatory hand book to IRC 112 code of practice for concrete road bridges
10. IS: 2911-2011 (PART 1-SEC2), Bored cast in-situ piles
11. IRC:38-1988, Guidelines for design of horizontal curves
12. IRC: SP 23-1993, Vertical curves for highways
13. IRC: SP 41`-1994, Design of at grade junctions
14. IRC: 67-2012, code of practice for road signs
15. IRC: 35-2015, Code of practice for road markings
16. IRC: SP 42-2014, Guidelines on road drainage
17. IRC: SP-50-2013, Guidelines on urban drainage
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