DESIGN ANALYSIS AND COST ESTIMATION OF A PRE-STRESSED POST-TENSIONED RAIL-CUM-ROAD BRIDGE STRUCTURE

Project Report submitted in partial fulfillment of the degree of

Bachelor of Technology

In

Civil Engineering

Under the Supervision of

Mr. Chandra Pal Gautam

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CERTIFICATE

This is to certify that project report entitled "Design Analysis and Cost Estimation Of a Pre-Stressed Post-Tensioned Rail-cum-Road Bridge Structure", submitted by Pranav Agrawal (101613), Aviral Vikram (101669) and Palak Sabharwal (101408) on partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date:

Supervisor's Name: Mr. Chandra Pal Gautam
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ABSTRACT

In a slow growing economy like India, the need to check for economy in its projects becomes vital. Bridges play the backbone of a country's infrastructure. We see that various places there are two separate bridges for railways and highway to cross a river or in cities there are separate bridges for metro rail and highway.

It has been observed that it is not possible to make separate bridges in some situations, especially in cities for metro rail and highway where availability of space is problem. The decision whether to choose separate rail and road bridges or rail-cum-road bridge is a major issue. This decision depends upon a number of factors.

In this project we tried to design a rail-cum-road bridge. The project deals with the design and analysis of Pre-Stressed Post-Tensioned Concrete Bridge. The analysis of superstructure is done manually as well as on the software (SAP 2000). The analysis of substructure and foundation is done manually. Finally the design values for superstructure for both the methods are compared. We have also done the cost estimation of the designed bridge.

DEDICATION

This Project is dedicated to our project guide & mentor Mr. Chandra Pal Gautam for teaching us a lot more than just Structural Engineering. We are also thankful to Mr. Lav Singh for his continuous support and motivation.

LIST OF TABLES

LIST OF FIGURES

CONTENTS

Chapter 1 – SCOPE AND OBJECTIVE

Man has always pursued to cross the obstacles in his path by building bridges. His constant effort to innovate, invent and improvise has always created revolutionary materials and construction techniques to build bridges. One of the most influencing factors in any bridge design is its cost. The economics plays a very important role in choosing the best possible design as the amount of money that is required to build and rehabilitate a bridge is quite large as compared to other infrastructure projects. Hence, the need to find the cost-effective bridge arises.

Now-a-days, we see bridges that are constructed using either Pre-stressed Concrete or Steel. Pre-stressed Concrete is basically concrete in which internal stresses of a suitable magnitude and distribution are introduced so that the stresses resulting from external loads are counteracted to a desired degree. Pre-stressed concrete members are slender; therefore, weigh less than reinforced concrete members. They are durable as they don't have any cracks during service and are much cheaper than steel.

In this project we have made efforts to design and analyze a rail-cum -Road Bridge (having Railways and Roadways on same deck). The analysis and design is presented in MS- Excel spreadsheets that can also be used for different loading and geometric conditions. We have also presented the design using SAP2000 software that uses IRC loading and IRS loading (user defined). In the end we estimate the cost of the bridge.

Chapter 2 – LITERATURE

2.1 Bridge – Definition

According to IRC: 5-1998[2], a bridge is defined as a structure having a total length of above 6 metres between the inner faces of the dirt walls for carrying traffic or other moving loads over a depression or an obstruction such as a channel, road or railway. These bridges are classified as given below:

a) Minor Bridge: A minor bridge is a bridge having a total length of upto 60m.

b) Major Bridge: A major bridge is a bridge having a total length of above 60m.

2.2 Components of a Bridge

The main parts of a bridge structure are:

1) Deck, consisting of deck slab, girders, trusses etc.

2) Bearings for the decking.

3) Abutments and Piers.

4) Foundation for the abutments and piers.

5) River training works like revetment of slopes for embankment at abutments and aprons at river bed levels.

6) Approaches to the bridge to connect the bridge proper to the roads on either side.

7) Handrails, parapets.

The figure on the next page shows the components of a bridge structure. The components above the level of bearings are grouped together as ***super-structure,*** while the parts below the level are classed as ***substructure.***

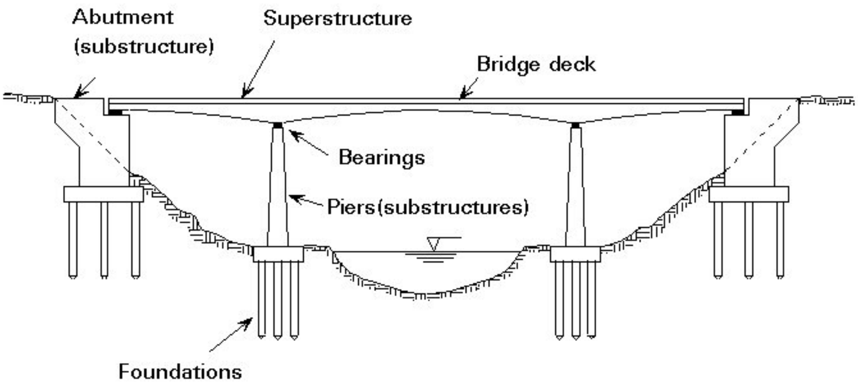

Figure 1 - Components of Bridge

2.3 Flow of Forces:

The loads that are acting on a bridge structure are first imposed on the deck slab. There are various types of decks:

1) Pre-stressed Concrete Bridge Deck.

2) Reinforced Concrete Bridge Deck.

3) Orthotropic Steel Bridge Deck.

The Deck is the part of the superstructure which carries the moving load. This load is then transferred to the substructure by the following:

1. Longitudinal and Cross Girders (as in Beam Bridge).
2. Trusses/ Frames.
3. Cables (as in cable stayed and suspension bridge).
4. Arch Rib (as in arch bridge).
5. Box Girders.
6. Balanced Cantilevers.

The load is taken up by the above structural system and then transferred to the substructure in the form of shear forces and bending moments acting at the supports. The above system of force transfer decides the type of bridge. The loads are then transferred to the ground by piers/ bents and abutments.

2.4 Bridge Loading Standards

Highway bridge decks have to be designed to withstand the live loads specified by the Indian Road Congress (IRC). The standard IRC loads specified in IRC: 6-20003 are grouped under four categories as detailed below:

- **IRC Class AA Loading:** Two different types of vehicles are specified under this category grouped as tracked and wheeled vehicles. All the bridges located on National and State Highways have to be designed for this heavy loading. The IRC Class AA tracked vehicle (simulating an army tank) of 700 kN and a wheeled vehicle (heavy duty army truck) of 400 kN are shown:

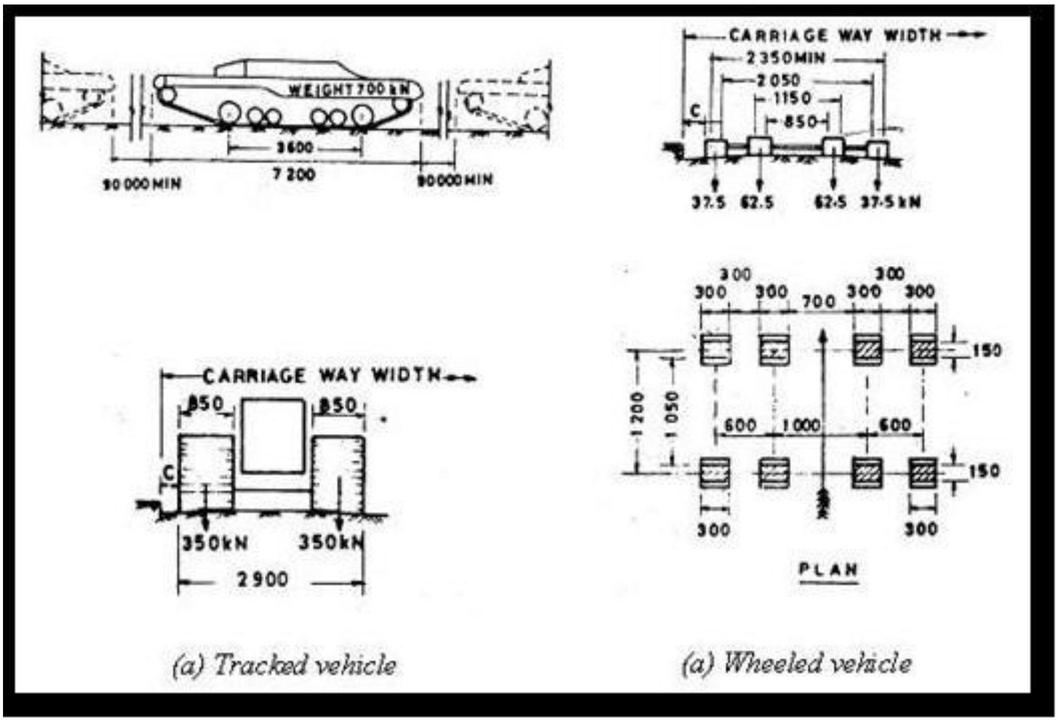

Figure 2 - IRC AA Tracked & Wheeled Vehicle

2. **IRC Class 70 R Loading:** This loading consists of three types of vehicles:

a) Tracked vehicle of total load 700kN with two tracks each weighing 350kN.

b) Wheeled vehicle comprising 4 wheels, each with a load of 100kN totaling 400 kN.

c) Wheeled vehicle with a train of vehicles on seven axles with a total load of 1000 kN.

3. **IRC Class A Loading:** This type of loading consists of a wheel load train comprising a truck with a trailer of specified axle spacing and loads.

4. **IRC Class B Loading:** Class B loading is similar to Class A loading except that the axle loads are comparatively of lesser magnitude. This type of loading is adopted for temporary structures and timber bridges.

2.4.1 Impact Factors

Impact factors are generally applied to the moving wheel or distributed loads to enhance their magnitude; to include their dynamic effects on the bridge deck. The impact factor is always inversely proportional to the length of the span and is different for reinforced concrete and steel bridges.

For IRC Class AA Tracked Loading, span of 9 m or more, the impact factors for the following bridges is given below.

a) RC Bridges- 10% up to a span of 40 m.

b) Steel Bridges- 25% up to a span of 23 m.

2.5 Materials for Prestressed Concrete Bridges

2.5.1 Grades of Concrete

According to IRC: 18-2000[4], the minimum prescribed characteristic compressive strength of concrete should not be less than 35 N/mm^2. The code also stipulates that for Pre-stressed concrete construction, only “Design Mix Concrete” should be used. The concrete mix should be designed as per the Indian Standard Code IS: 10262-19825 which sets out the guidelines for concrete mix design.

2.5.2 High Tensile Steel

Concrete is precompressed using high tensile steel available in the form of wires, bars and strands. The mechanical properties of strands are covered in the Indian Standard, IS: 600[6]-1983[6].

2.5.3 Untensioned Steel or Supplementary Reinforcement

Supplementary reinforcements are required in Pre-stressed concrete beams and slabs to safeguard against cracks and for resisting shear forces.

2.5.4 Permissible Stresses in Concrete

The maximum permissible stress in high strength concrete at the stages of transfer and service loads are compiled in Table 1. However, concrete should have attained a minimum compressive strength of 20 N/mm^2 before any Pre-stress is applied.

Loading Stage	**Compressive Stresses**	**Tensile Stresses**
At Transfer	Not to exceed 0.5*fck* which shall not be more than 20 N/mm^2.	Not to exceed one-tenth of the permissible compressive stress
At Service Loads	Not to exceed $0.33f_{ck}$	No tensile stresses permitted

Table 1 - Permissible Stresses in Concrete (IRC: 18-2000)

The maximum permissible stress immediately behind the anchorages in adequately reinforced end blocks according to IS: 1343-19807 code may be computed by the equation:

$$f_b = 0.48\, f_{ci} \sqrt{Abr/Apun}$$

Or $0.8fci$ whichever is smaller.

Where,

f_b = the permissible unit bearing stress
A_{br} = the bearing area
A_{pun} = punching area

Properties/Permissible Stresses	**M25**	**M40**	**M60**
Modulus of Elasticity (GPa)	29	32.5	37
Permissible Direct Compressive Stress (σ_{co}) (N/mm2)	6.25	10.0	15
Permissible Flexural Compressive Stress (σ_{cb}) (N/mm2)	8.33	13.33	20

Table 2 - Properties and Basic Permissible Stresses in Concrete (IRC: 21-2000[8])

2.5.5 Permissible Stresses in Steel

The IRC: 18-2000[4] code prescribes that the maximum jack pressure should not exceed 90% of the 0.1 % proof stress of the Pre-stressing steel. In addition it stipulates that 0.1 % proof stress should be taken as equal to 85% of the minimum ultimate tensile strength. The permissible stress in untensioned reinforcement comprising mild steel and HYSD bars are prescribed in IRC: 21-2000[8].

2.5.6 Anchorages

In the case of post-tensioned Pre-stressed concrete members, proprietary anchorages are used to stress the tendons and anchor them against concrete using anchoring devices

2.5.7 Sheathing Ducts

In post-tensioned members, tendons are threaded in sheathing ducts or cables which are positioned to conform to the predesigned profile before concreting the member. The sheathing ducts are generally made of mild steel or high density polyethylene (HDPE). The ducts should be corrugated on both sides and transmit the full tendon force to the surrounding concrete over a length not greater than 40 times the duct diameter. The sheathing ducts should conform to the requirements specified in the Appendix IA and IB of IRC: 18-2000[4].

2.6 Limit State Design of Reinforced Concrete Bridge Deck Sections

2.6.1 Design Philosophy

The Limit State Design is a method of designing structures based on statistical concept of safety and the associated statistical probability of failure. The limit state design philosophy recognizes the need to provide the structures which are serviceable at working loads and have the desired load factor against collapse.

2.6.2 Elastic Design Coefficients for RC sections

Based on the permissible stresses, the design constants are used for the computation of effective depth'd' of the structural element and the area of the steel 'A_{st}' in the tension zone along with the neutral axis depth factor 'n', lever arm factor 'j', and the moment factor 'Q' expressed as a function of the permissible compressive stress 'σ_{cb}' in concrete are given by the following expressions and are compiled in Table 3.

$$n = \frac{1}{1+\left(\frac{\sigma_{st}}{m\sigma_{cb}}\right)}$$

$$j = 1 - \frac{n}{3}$$

$$Q = 0.5\ \sigma_{cb}\ n\ j$$

2.6.3 Flexure and Shear Strength of Reinforced Concrete Sections

The basis of design specified in Clause 304.2.1 of IRC: 21-2000[8] regarding reinforced concrete road bridges confines to the principles of the elastic theory and no recommendations are specified for computation of the ultimate strength of the reinforced concrete section in flexure and shear. However, the design equations recommended for shear stress computation in this code are same as that specified in IS: 456-2000[9].

The design shear stress 't_v' at any cross section of the beam or slab of uniform depth is calculated by the equation:

$$\tau_v = \left(\frac{V}{bd}\right)$$

Where:

V = the design shear force across the section

b = breadth of the member which for flanged sections should be taken as the breadth of the web, and

d = effective depth of the section.

The code also specifies that for obtaining maximum shear stress, the section at a distance equal to the effective depth from the face of the support should be considered in the computations.

When the shear stress 't_v' exceeds the permissible shear stress 't_c' in the beams compiled in the Table 4, shear reinforcements in the form of vertical links, inclined stirrups or bent up bars should be designed.

When the shear reinforcements are provided, the shear stress in beams should not exceed the value of shear stress '$t_{c,max}$' shown in Table 5. In the case of solid slabs, the permissible design shear stress in concrete is computed as '*Ktc*' where '*K*' is a factor having values shown in the Table 6. In the case of slabs, the value of the shear stress should not exceed half the value of '$t_{c,max}$' shown in Table 5. 9

Grade of Concrete & Steel	M	σ_{cb} (N/mm2)	σ_{st} (N/mm2)	n	j	Q
M-25 Fe-415	10	8.3	200	0.29	0.90	1.100

Table 3 - Elastic Design Coefficients

100As/ bd	M-25
0.15	0.19
0.25	0.23
0.50	0.31
0.75	0.36

Table 4 - Permissible Shear Stress in Concrete

Concrete Grade	M-20	M-25	M-30	M-35	M-40 & above
tc,max	1.8	1.9	2.2	2.3	2.5

Table 5 - Maximum Shear Stress in Concrete (tc,max)

Overall Depth of Slab (mm)	300 or more	275	250	225	200	175	150 or less
K	1.00	1.05	1.10	1.15	1.20	1.25	1.30

Table 6 - Values for K for Solid Slabs

2.7 Design of Prestressed Concrete Sections for Service Loads

Pre-stressed concrete sections subjected to flexural moments should satisfy the limits specified for permissible stressed at the age of transfer of Pre-stress at service loads. Expressions for the minimum section modulus required, Pre-stressing and the corresponding eccentricity as recommended in the Indian Standard Code IS: 1343.

Minimum section modulus is expressed as:

$$Zb \geq ((\mathrm{Mg} + \mathrm{Mq}) - \frac{\eta \mathrm{Mg}}{fbr})$$

Where,

M_g = Dead load bending moment

M_q = Live load bending moment

Z_b = Section modulus of bottom fibre of structural element

f_{br} = Range of stress at bottom fibre = $(\eta f_{ct} - f_{tw})$

f_{ct} = Permissible compressive stress in concrete at transfer of Pre-stress

f_{tw}= Permissible tensile stress in concrete under service loads

The equation for minimum Pre-stressing force is expressed as,

$$\mathrm{P} = (\frac{\mathrm{A}(Ztft + Zbfb)}{Zb + Zt})$$

Where,

P = Minimum Pre-stressing force

A = Cross sectional area of concrete section

Z_b & Z_t = Section Modulus of top & bottom fibres of concrete sec tion

Also,

$$f_{\mathrm{t}} = (f_{tt} - \frac{\mathrm{Mg}}{\mathrm{Zt}})$$

$$f_b = (\frac{\mathrm{ftw}}{\eta} + \frac{(\mathrm{Mg} + \mathrm{Mq})}{\eta\ \mathrm{Zb}})$$

The eccentricity corresponds to the minimum Pre-stressing force is expressed as

$$e = \frac{Zb\ Zt\ (fb - ft)}{A(ft\ Zt + fb\ Zb)}$$

Where,

f_t = Pre-stress in concrete at the top of the section

f_b = Pre-stress in concrete at the bottom of section

e = Corresponding eccentricity of Pre-stressing force

In the case of long span bridge girders, the self-weight moment is very large and the minimum stress at transfer developed at the top fibre will be compressive in nature due to the limitation of position of Pre-stressing force within the cross-section. The required Pre-stressing force P acting at known eccentricity *e*, which can develop the required Pre-stress f_b at the bottom fibre is computed using the equation,

$$P = \left(\frac{\text{A fb Zb}}{\text{Zt} + \text{A e}}\right)$$

Where *A* and *Zb* are the cross-sectional area and the section modulus of the cross-section actually provided.

2.7.1 Flexure and Shear Strength of Prestressed Concrete Sections

The critical sections of a bridge deck designed for service loads should satisfy the limit state of collapse both in flexure and shear. According to IRC 18-2000[4], Pre-stressed concrete bridge sections should be checked for failure conditions. The Ultimate load of the section under different exposure conditions should satisfy the following criteria:

U = (1.25 G + 2.5 SG + 2.5 Q) under moderate exposure conditions

U = (1.5 G + 2 SG + 2.5 Q) under service exposure conditions

Where U = ultimate load

G = Permanent dead load

SG = super imposed dead load

Q = live load including impact

The super imposed dead load includes the dead load of foot path, hand rails, wearing course, utility services, kerbs, etc.

a) Flexural Strength: The code recommends separate equations for the computation of the ultimate flexural strength of sections failing by:

1) Yielding of steel (under reinforced sections)

2) Crushing of concrete (over reinforced sections)

The ultimate moment of resistance of sections failing by yielding of steel is expressed as,

$$M_{us} = (0.9\ d\ A_p\ f_p)$$

Where,

d = effective depth

A_p = area of high tensile steel

f_p = ultimate tensile strength for steel without definite yield point or yield stress or stress at 4% elongation whichever is higher for steel with a definite yield point.

Any supplementary untensioned reinforcement used is considered as contributing to the steel section and the effective area is calculated as $(\frac{As\ fy}{fp})$

Where,

A_s = area of untensioned reinforcement

f_y = yield stress

The ultimate moment of resistance of sections failing by crushing of concrete is calculated by the equation, for rectangular sections:

$$M_{uc} = (0.176\ b\ d^2\ f_{ck})$$

And for flanged sections:

$$M_{uc} = (0.176\ b\ d^2\ f_{ck} + 23\ 0.8\ (B_f - b)(d - 0.5t)t\ f_{ck})$$

Where,

b = width of rectangular section or web of a flanged section

B_f = effective width of flange

T = thickness of flange

b) Shear Strength: The IRC: 18-2000[4] specifies separate equations for computing the shear strength of sections uncracked in flexure (support sections) and sections cracked in flexure (span section). The empirical equation recommended for sections uncracked in flexure is the same as that specified in IS: 1343-1980[7] code.

i) Sections Uncracked in Flexure: The ultimate shear strength of sections uncracked in flexure (normally support sections) is governed by the occurrence of maximum principal tensile stress at the centroidal axis of the section leading to diagonal tension cracks and is expressed as a function of the characteristic compressive strength of concrete by the relation:

$$f_1 = 0.24\sqrt{f_{ck}}$$

The ultimate shear strength V_{co} is given by the relation:

$$V_{co} = (0.67\, bh\sqrt{f_t^2 + 0.8\, f_{cp}}) + (\eta P \sin\theta)$$

Where,

b = width of rectangular section or width of rib in flanged section

H = overall depth of the section

f_t = tensile stress of concrete corresponding to maximum principal tensile stress

f_{ck} = characteristic compressive strength of concrete

f_{cp} = compressive stress at centroidal axis due to Pre-stress

η = loss ratio

P = Pre-stressing force

θ = inclination of the cable from the horizontal axis

The support sections free from flexure are generally checked for shear strength using this expression and suitably designed to resist the shear forces.

ii) Sections Cracked in Flexure: The ultimate shear strength of sections cracked in flexure (V_{cf}) is calculated using the empirical relation:

$$V_{cf} = 0.037\, b\, d\sqrt{f_{ck}} + \left(\frac{\text{Mo}}{\text{M}}\right) V$$

Where,

d = distance from the extreme compression face to the centroid of the tendons

Mo = cracking moment at the section considered and is calculated as

$$(0.37\sqrt{f_{ck}} + 0.8\, f_{pt})\frac{I}{y}$$

Where,

f_{pt} = stress in concrete due to Pre-stress only at the extreme tensile fibre

I= second moment of area of the section

y = distance from the extreme tensile fibre from the centroid of the concrete section.

2.7.2 Forces in End Blocks

In the case of post tensioned Pre-stressed concrete members, larger forces from the cables are transmitted to concrete concentrated over a small area through the anchorages. The concentrated force at the end of the member develops bursting tension in the concrete over a length equal to the depth of the structural member which constitutes the end block. To prevent spilling of concrete in these zones, suitable reinforcements are to be designed in the end blocks.

According to Clause 17.2 of IRC: 18-2000[4], the bursting tensile force in the end block depends upon the anchorage force, size of the end block and the type of anchoring device. The ratio of the bursting tension to the force in the tendon is computed from the Table 7 for the values of ratio (y_{po}/y_o) varying from 0.3 to 0.7.

(y_{po}/yo)	0.3	0.4	0.5	0.6	0.7
F_{bst}/P_k	0.23	0.20	0.17	0.14	0.11

Table 7 - Design Bursting Tensile Force in End Blocks (IRC: 18-2000[4])

Where,

P_k = force in the tendons or cables

F_{bst} = bursting tensile force

y_o = side of the end block

y_{po} = side of the loaded area

The busting tensile force is distributed over a region extending from *0.2yo* to *2yo* from the loaded area of the end block and suitable reinforcements are designed to resist the tensile force and distributed in the end block zone generally in the form of a mesh with reinforcements in the longitudinal and transverse directions.

2.8 Analysis of Deck Slab

a) Dispersion of Loads along the Span

The effective length of slab in the direction of the span is computed as the sum of the tyre contact area over the wearing surface of the slab in the direction of the span and twice the overall depth of the slab inclusive of the thickness of the wearing surface.

If:

D = depth of the wearing coat

H = depth of the slab

x = wheel load contact area along the span

v = effective length of dispersion along the span

We have the relation,

$$v = x + 2(D+H)$$

b) Dispersion of Loads in Slabs Spanning in two Directions

In bridge decks comprising slab integrally cast with longitudinal and cross girders as in the case of Tee Beams and Slab Decks, the moments develop due to wheel loads on the slab both in the longitudinal and transverse directions. These moments are computed by using the design curves developed by M. Pigeaud. Pigeaud's method is applicable to rectangular slabs supported freely on all the four sides and the slab should be symmetrically loaded.

The following notations are used in calculating the dispersion width and moments due to concentrated wheel loads on slabs.

L = Long span length

B = Short span length

u & v = Dimensions of the load spread after allowing for dispersion through the wearing coat and structural slab

K = Ratio of short to long span of slab (B/L)

M_1 = Moment in the short span direction

M_2 = Moment in the long span direction

m_1 & m_2 = Coefficients for moments along the short and long spans respectively

μ = Poisson's ratio for concrete generally assumed as 0.15 as per IRC: 21-2000[8]

W = Wheel load under consideration

The dispersion of the wheel or track load may be assumed to be at 45 degrees through the wearing coat and structural slab according to Clause 305.16.3 of IRC: 21-2000[8] specifications.

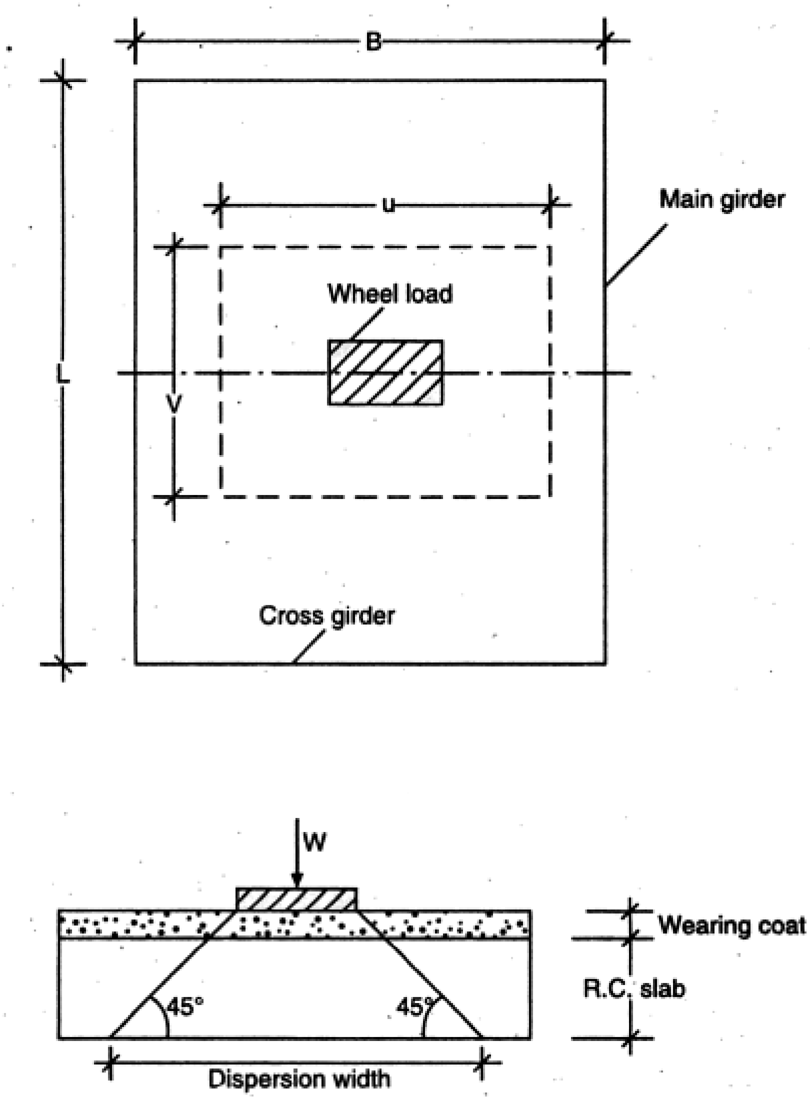

Figure 3 - Dispersion of Wheel Load through Wearing Coat and Deck at 45 Degrees

The bending moments in the short and long span directions are expressed as:

$$M_1 = (m_1 + \mu m_2)$$

$$M_2 = (m_2 + \mu\, m_1)$$

The values of the moment coefficients m1 and m2 depend upon the parameters (*u/B*) and (*v/L*) and the value of *K* = (*B/L*). Pigeaud's curves are used for the estimation of moment coefficients m_1 and m_2 for various values of *K*. Moment coefficients m_1 and m_2 corresponding to *K* and (*1/K*) for slabs supporting uniformly distributed load (dead load of the slab) are also obtained from these curves.

2.8.1 Load Distribution Method for Beam and Slab Bridge Decks:

The beam and slab bridge decks comprising longitudinal and cross girders with the deck slab may be considered as rigid grid structure for purposes of analysis under concentrated live loads. Concentrated wheel load on the deck is shared between longitudinal girders depending upon the position of the load, the number of girders and their spacing.

Courbon's Method is used to find out the reaction factors for interior and exterior girder. This method is applicable when the following conditions are satisfied.

a) The ratio of span to width of deck is greater than 2 but less than 4.

b) The longitudinal girders are interconnected by at least 5 symmetrically spaced cross girders.

c) The cross girders extends to a depth of at least 0.75 times the depth of the longitudinal girders.

In this method wheel loads are placed in such a way that the centroid of loads has the maximum eccentricity from the centerline of the roadway. The load shared by any girder is computed in terms of reaction factor expressed by empirical relation as,

$$R_x = \left(\sum \frac{\mathrm{W}}{\mathrm{n}}\right)\left[1 + \left(\frac{\Sigma \mathrm{I}}{\sigma \mathrm{Dx2I}}\right) d_x\, e\right]$$

Where,

R_x = Reaction factor for the girder under consideration.

I = Second Moment of area of each longitudinal girder.

d_x = Distance of the girder under consideration from the centre line of the road.

W = Total concentrated live load.

n = No. of longitudinal Girders.

e = Eccentricity of live load with respect to the axis of the bridge deck.

2.9 Components of Substructure

2.9.1 Bearing

Bearings are structural devices positioned between the bridge superstructure and the substructure.

Their principal functions are as follows:

1. To transmit loads from the superstructure to the substructure, and
2. To accommodate relative movements between the superstructure and the substructure.

The forces applied to a bridge bearing mainly include superstructure self-weight, traffic loads, wind loads, and earthquake loads. Movements in bearings include translations and rotations. Creep, shrinkage, and temperature effects are the most common causes of the translational movements, which can occur in both transverse and longitudinal directions. Traffic loading, construction tolerances, and uneven settlement of the foundation are the common causes of the rotations.

Usually a bearing is connected to the superstructure through the use of a steel sole plate and rests on the substructure through a steel masonry plate. The sole plate distributes the concentrated bearing reactions to the superstructure. The masonry plate distributes the reactions to the substructure.

The connections between the sole plate and the superstructure, for steel girders, are by bolting or welding. For concrete girders, the sole plate is embedded into the concrete with anchor studs. The masonry plate is typically connected to the substructure with anchor bolts.

2.9.2 Types of Bearings

Bearings may be classified as fixed bearings and expansion bearings. Fixed bearings allow rotations but restrict translational movements. Expansion bearings allow both rotational and translational movements. There are numerous types of bearings available.

2.9.3 Selection of Bearings

Generally the objective of bearing selection is to choose a bearing system that suits the needs with a minimum overall cost. The following procedures may be used for the selection of the bearings.

2.9.4 Elastomeric Bearings

An elastomeric bearing is made of elastomer (either natural or synthetic rubber). It accommodates both translational and rotational movements through the deformation of the elastomer. Elastomer is flexible in shear but very stiff against volumetric change. Under compressive load, the elastomer expands laterally. To sustain large load without excessive deflection, reinforcement is used to restrain lateral bulging of the elastomer. This leads to the development of several types of elastomeric bearing pads — plain, fiberglass-reinforced, cotton duck-reinforced, and steel-reinforced elastomeric pads.

Plain elastomeric pads are the weakest and most flexible because they are only restrained from bulging by friction forces alone. They are typically used in short- to medium-span bridges, where bearing stress is low. Fiberglass-reinforced elastomeric pads consist of alternate layers of elastomer and fiber glass reinforcement. Fiberglass inhibits the lateral deformation of the pads under compressive loads so that larger load capacity can be achieved.

Cotton-reinforced pads are elastomeric pads reinforced with closely spaced layers of cotton duck. They display high compressive stiffness and strength but have very limited rotational capacities. The thin layers also lead to high shear stiffness, which results in large forces in the bridge. So sometimes they are combined with a PTFE slider onto of the pad to accommodate translations. Steel-reinforced elastomeric pads are constructed by vulcanizing elastomer to thin steel plates. They have the highest load capacity among the different types of elastomeric pads, which is only limited by the manufacturer’s ability to vulcanize a large volume of elastomer uniformly.

All above-mentioned pads except steel-reinforced pads can be produced in a large sheet and cut to size for any particular application. Steel-reinforced pads, however, have to be custom-made for each application due to the edge cover requirement for the protection of the steel from corrosion.

The steel-reinforced pads are the most expensive while the cost of the plain elastomeric pads is the lowest. Elastomeric bearings are generally considered the preferred type of bearings because they are low cost and almost maintenance free. In addition, elastomeric bearings are extremely forgiving of loads and movements exceeding the design values.

2.9.5 Piers and Columns

Piers provide vertical supports for spans at intermediate points and perform two main functions: transferring superstructure vertical loads to the foundations and resisting horizontal forces acting on the bridge. Although piers are traditionally designed to resist vertical loads, it is becoming more and more common to design piers to resist high lateral loads caused by seismic events. Even in some low seismic areas, designers are paying more attention to the ductility aspect of the design.

Piers are predominantly constructed using reinforced concrete. Steel, to a lesser degree, is also used for piers. Steel tubes filled with concrete (composite) columns have gained more attention recently.

2.9.5.1 General

Pier is usually used as a general term for any type of substructure located between horizontal spans and foundations. However, from time to time, it is also used particularly for a solid wall in order to distinguish it from columns or bents. From a structural point of view, a column is a member that resists the lateral force mainly by flexure action whereas a pier is a member that resists the lateral force mainly by a shear mechanism. A pier that consists of multiple columns is often called a *bent*.

There are several ways of defining pier types. One is by its structural connectivity to the superstructure: monolithic or cantilevered. Another is by its sectional shape: solid or hollow; round, octagonal, hexagonal, or rectangular. It can also be distinguished by its framing configuration: single or multiple columns bent; hammer head or pier wall.

2.9.5.2 Selection Criteria

Selection of the type of piers for a bridge should be based on functional, structural, and geometric requirements. Aesthetics is also a very important factor of selection since modern highway bridges are part of a city's landscape. Figure 2.1 shows a collection of typical cross section shapes for over crossings and viaducts on land and Figure 2.2 shows some typical cross section shapes for piers of river and waterway crossings. Often, pier types are mandated by government agencies.

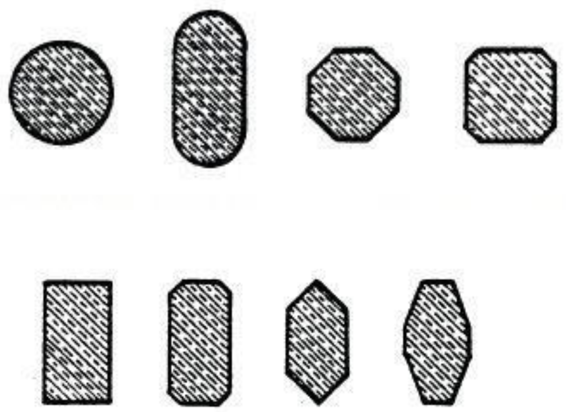

Figure 4 - Typical cross-section shapes of piers for overcrossings or viaducts on land

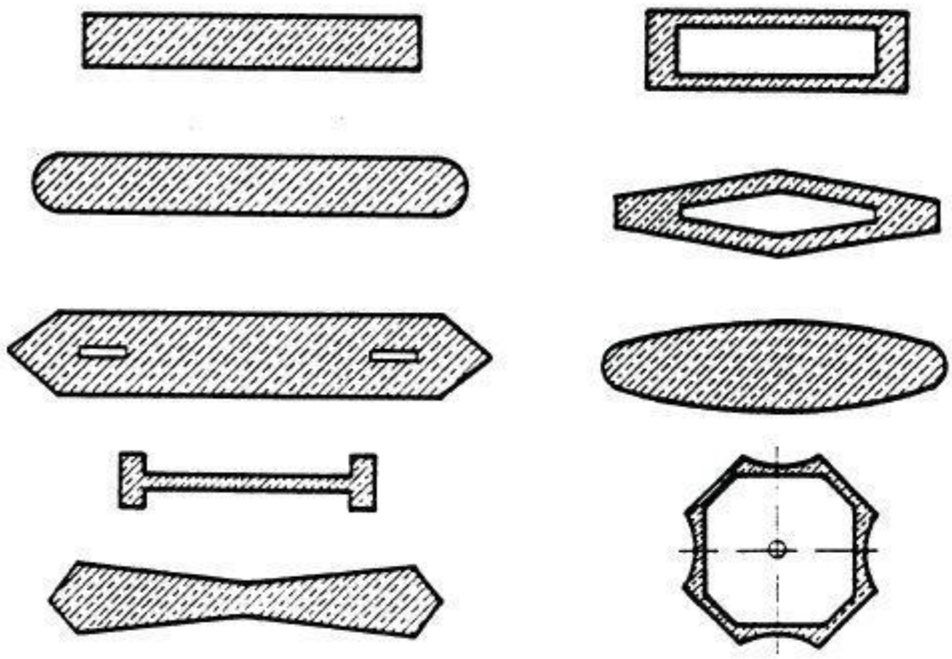

Figure 5 - Typical cross-section shapes of piers for river and waterway crossings.

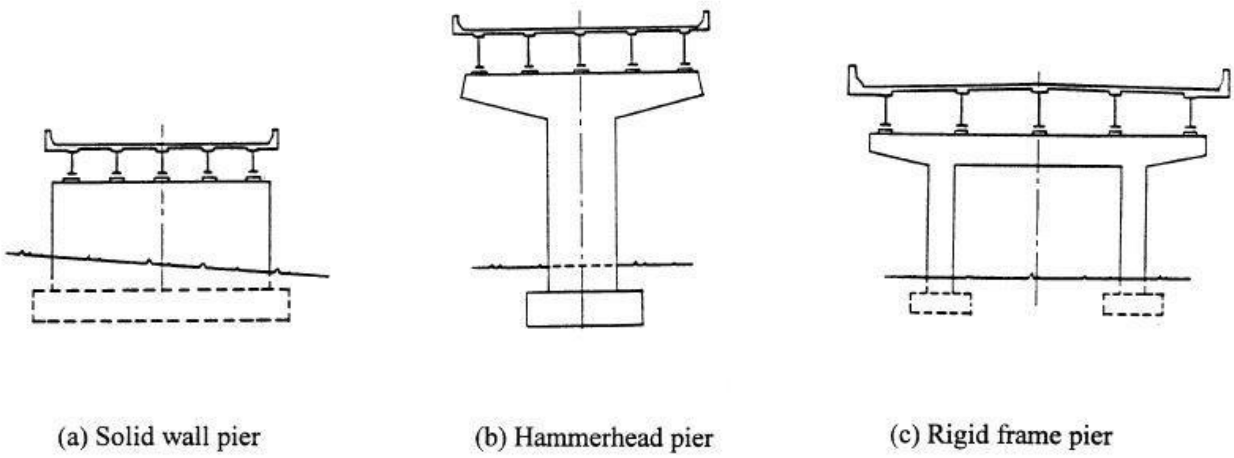

Figure 6 - Typical pier types for steel bridges

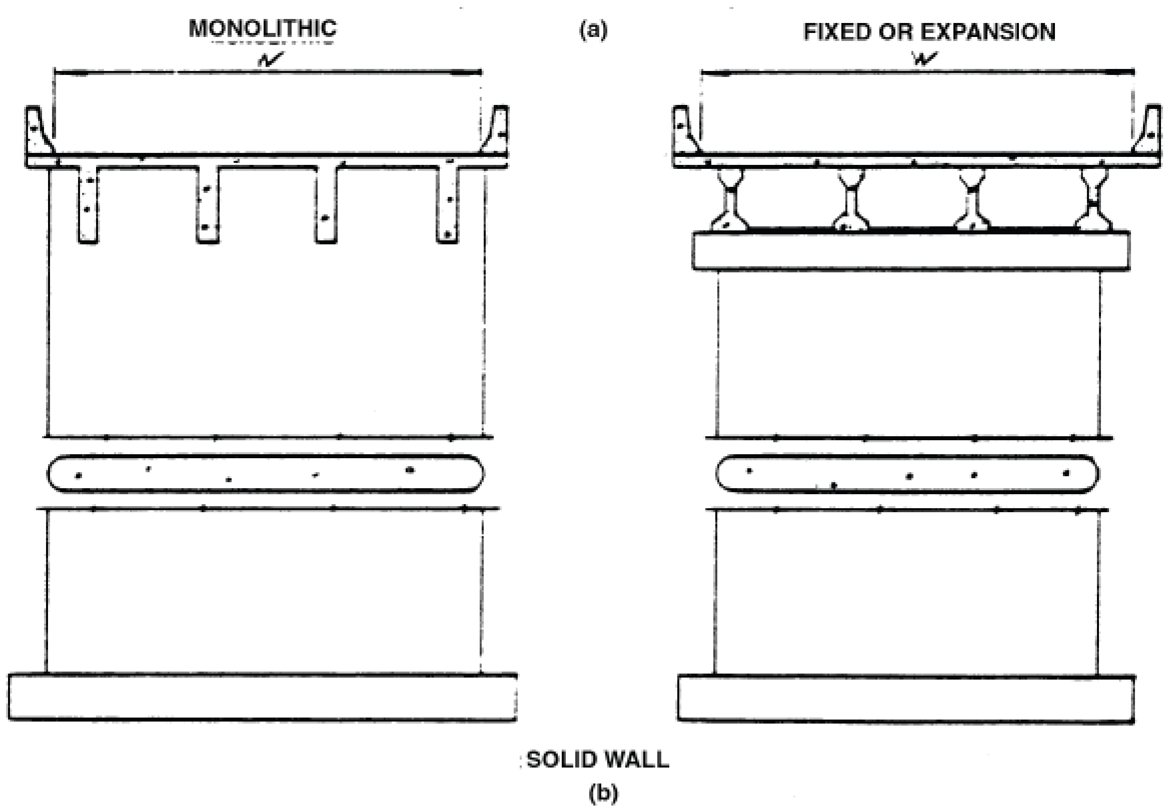

Figure 7 - Typical pier types and configurations for river and waterway crossings.

2.9.6 Foundation

2.9.6.1 Shallow Foundations

A shallow foundation may be defined as one in which the foundation depth (*D*) is less than or on the order of its least width (*B*), Commonly used types of shallow foundations include spread footings, strap footings, combined footings, and mat or raft footings.

Shallow foundations or footings provide their support entirely from their bases, whereas deep foundations derive the capacity from two parts, skin friction and base support, or one of these two.

2.9.6.2 Deep Foundations

A bridge foundation is part of the bridge substructure connecting the bridge to the ground. A foundation consists of man-made structural elements that are constructed either on top of or within existing geologic materials. The function of a foundation is to provide support for the bridge and to transfer loads or energy between the bridge structure and the ground.

A deep foundation is a type of foundation where the embedment is larger than its maximum plane dimension. The foundation is designed to be supported on deeper geologic materials because either the soil or rock near the ground surface is not competent enough to take the design loads or it is more economical to do so.

2.9.6.3 Pile foundation

A pile is a relatively small diameter shaft, which is driven into the ground with suitable means. The piles are usually driven in groups to provide foundation for structures. The pile group may be subjected to vertical load horizontal load or a combination of both. Pile transfers the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity.

Types of piles

Piles are classified using different criteria. Some of these criteria are:

1. Material of construction: e.g. timber, steel concrete etc.

2. Cross section: e.g. cylindrical, tapered, under-reamed etc.

3. Shape: e.g. circular, square, hexagonal, I-section, H-section.

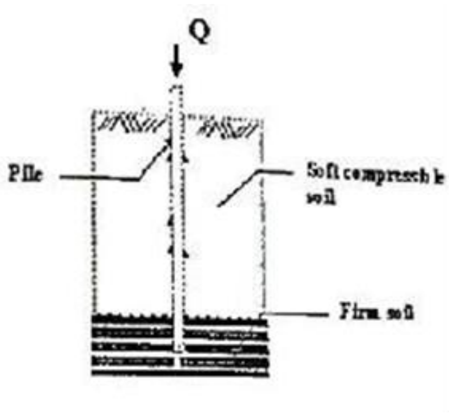

Figure 8 - End Bearing Pile

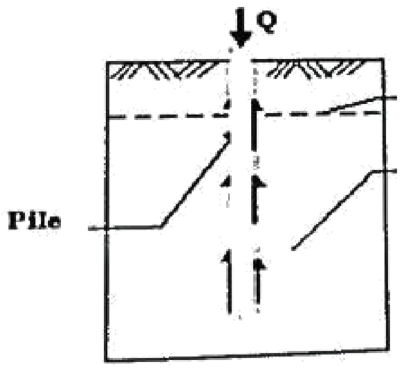

Figure 9 - Friction Pile

CHAPTER 3 – PROJECT SPECIFICATIONS

3.1 Objective

Design Analysis and Cost Estimation Of a Pre-Stressed Post-Tensioned Rail-cum-Road Bridge Structure.

3.2 Specifications

The project specifications are as follows:

1. To design a Reinforced Concrete Bridge Deck with the following specifications.

- Width of deck slab = 15m.
  - Clear width of railway = 5m.
  - Clear width of roadway = 7.5 m (two lanes of 3.75 m each).
  - Allowance for footpath and railing = 2.5m (1.25m on each side).
- Span = 30m.
- No. of Traffic Lanes = 2.
- Loading:
  - IRS modified B.G. loading (1987)
  - IRC Class AA Wheeled Live Load.
- Wearing Coat thickness = 80 mm.
- M-60 grade of concrete and Fe-415 grade of steel.
- Loss ratio = 0.8
- HTS cable diameter = 100mm.
- Simply Supported.

2. To design the Piers & Foundation for the maximum superstructure load with the following specifications.

- Dry bed condition.
- M-60 Grade of Concrete and Fe-415 grade of steel.

3. To compare the design values from manual analysis and software analysis.

- Ms-Excel for manual calculation
- SAP2000 for software analysis

3.3 Project Plan

The project work was divided into three parts. The first part was responsible for design of Prestressed Concrete Bridge Superstructure. The second part was responsible for the design Prestressed Concrete Bridge Sub-structure. And the third part was responsible for the design of foundation. The groups were divided among the three students.

The project work was divided into two semesters. In the first semester we completed the manual designs of the bridges using MS-Excel. In the second semester we modelled our bridges in SAP2000 and analyzed it. We also calculated the cost of designed bridge. In the end, we got results that are compiled at the end of this report.

Chapter 4– PRESTRESSED BOX GIRDER BRIDGE

4.1 Analysis and Design – Manual (Microsoft Excel)

The analysis and design of the proposed 30m bridge was done using manual calculations and excel sheets were prepared using Microsoft Excel 2013. The spreadsheets are presented below:

Specifications of Bridge				
Details	**Value**	**Units**	**Symbols**	**Comments and Formulas**
Span of bridge	30	m	L	
Overall depth of box girder	2	m		
Width of roadway	7.5	m		As per IRC for two lane roadway
Total width of footpaths	2.5	m		
Total width of box girder at road level	15	m		
Spacing between webs	1.676	m	L_w	
Thickness of web	0.45	m	t_w	At least 200+dia of cable duct
Thickness of top and bottom of slab	0.4	m	t	
Density of concrete	24	kN/m^3	γ	
Density of WC	22	kN/m^3		
Thickness of WC	0.08	m		
Loss ratio	0.8		η	

Specifications of Bridge				
Details	**Value**	**Units**	**Symbols**	**Comments and Formulas**
Length of each rail on a BG track	12.8	m	M	
Weight of rail	0.5886	kN/m		
Density of sleeper	18.8			no. of sleepers under each rail: (M+6)
No. of sleepers per metre	1.46			
Weight of one sleeper	2.44	kN/m		
Weight of sleeper per metre length	3.58	kN/m		
Width of ballast	3.35	m		
Depth of ballast	0.25	m		ranges between 0.2 - 0.25
Quantity of stone ballast per metre length	1.036	m^3/m		
Unit weight of stone	1.65	kN/m^3		
Weight of ballast per metre length	1.70	kN/m		

Dead Load Moment and Shear Force

Details	Value	Units	Symbols	Comments and Formulas
Cross sectional area	13.24	m^2	A	
Density of concrete	24	kN/m^3	γ	
Density of WC	22	kN/m^3		
Thickness of WC	0.08	m		
Dead weight of Box Girder	317.76	kN/m	$A \times \gamma$	
Dead weight of WC	26.4	kN/m		
Dead Load of sleeper and rail	5.88	kN/m		
Total UDL Dead load	350.04	kN/m		
Total dead load Bending Moment	39379.70	kN.m	Mg	
Total dead load Shear Force	5250.63	kN	Sg	

Live Load Bending Moment and Shear Force

Details	Value	Units	Symbols	Comments and Formulas
Coeff. of dynamic augment	0.293			(0.15+8/(6+L))
Live load for bending moment for railway	26.62	kN/m		As per IRS Bridge Rule Appendix II
Live load for Shear Force for railway	29.26	kN/m		As per IRS Bridge Rule Appendix II
Allowance for roadway and footpath	1.9	kN/m^2		As per IRS Bridge Rule Clause2.3.3.1(b)
Total uniformly distributed allowance	19	kN/m		
Total live load for bending moment	45.6	kN/m		
Live load for Shear Force	48.3	kN/m		
Max. Live Load Bending moment	5132.3	kN.m		
Max. Live Load shear force	723.8	kN		

Check for Minimum Section Modulus

Details	Value	Units	Symbols	Comments and Formulas
PERMISSIBLE STRESSES				
M60 AND Fe415				
Permissible stress in concrete in compression	11500	kN/m^2	σ_{cb}	
Permissible stress in steel in tension	200000	kN/m^2	σ_{st}	
Characteristic cube compressive strength of concrete	60000	kN/m^2	f_{ck}	
Characteristic compressive strength of concrete in Prestress	45000	kN/m^2	f_{ci}	
Permissible compressive stress in concrete at transfer of Prestress	20250	kN/m^2	f_{ct}	
Permissible tensile stress in concrete under service load	19800	kN/m^2	f_{cw}	
Modulus of Elasticity of concrete	38729833	kN/m^2	E_c	
Dead load moments at mid support section B	39379.70	kNm	M_g	
Live load load moments at mid support section B	5132.33	kNm	M_q	
Total moment due to dead and live loads	44512.03	kNm	M_d	
Range of stress in bottom fiber	16200	kN/m^2	f_{br}	((η*fct)-(ftw))
Prestress in concrete at top section	11528.01	kN/m^2	f_b	(ftw/η)+(Mg/(η*Zb))
Section Modulus for section provided	2.75	m^3	Z_b	(Mq+((1-η)xMg))/fbr
Maximum Section Modulus	4.27	m^3	$Z_{b(actual)}$	

Prestressing Force

Details	Value	Units	Symbols	Comments and Formulas
Cable Type:Parallel Wire Strand(TATA STEEL)				
Cross section Area of Top Slab	6	m^2	A'	
No. of strands	15	mm		
Diameter of Cable	100	mm		
Clear Cover	75	mm		
Diameter of Cable Duct	100	mm		
Clear Spacing b/w cables (min.)	100	mm		not less than dia. of cable
Max. possible eccentricity	775	mm	e	y_b-cover-dia. of cable duct-0.5*spacing
Prestressing force	25690.58	kN		$(A' \times f_b \times Z_b)/(Z_b + (A' \times e))$
Characteristic Strength of Strand	177	kN		
Loss Ratio	0.8		η	
Force in each cable	2124	kN		no. of strands*loss ratio*strength
No. of cables to be provided	12			Prestressing force/ force in each cable
Initial Prestressing Force	25690.58	kN		
Area of each cable	0.00785	m^2		no. of strands * nominal area of each strand
Total area of high tensile steel	0.09495	m^2		no. of cables provided*area of each cable

4.2 Analysis and Design - Software (SAP2000)

Using this software we modeled our superstructure in such a way that the deck slab rests on the PSC girders as shown below. The software uses IS 456:2000 to design the bridge. We analyzed our PSC Bridge Superstructure in this software and checked its design.

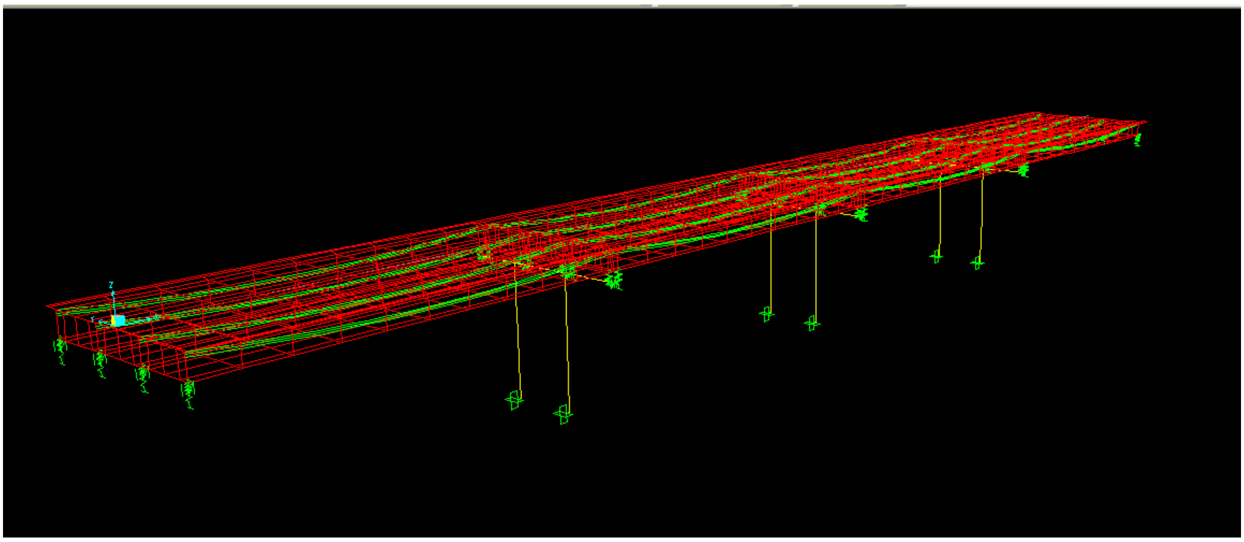

Figure 10 – Bridge Model (in SAP2000)

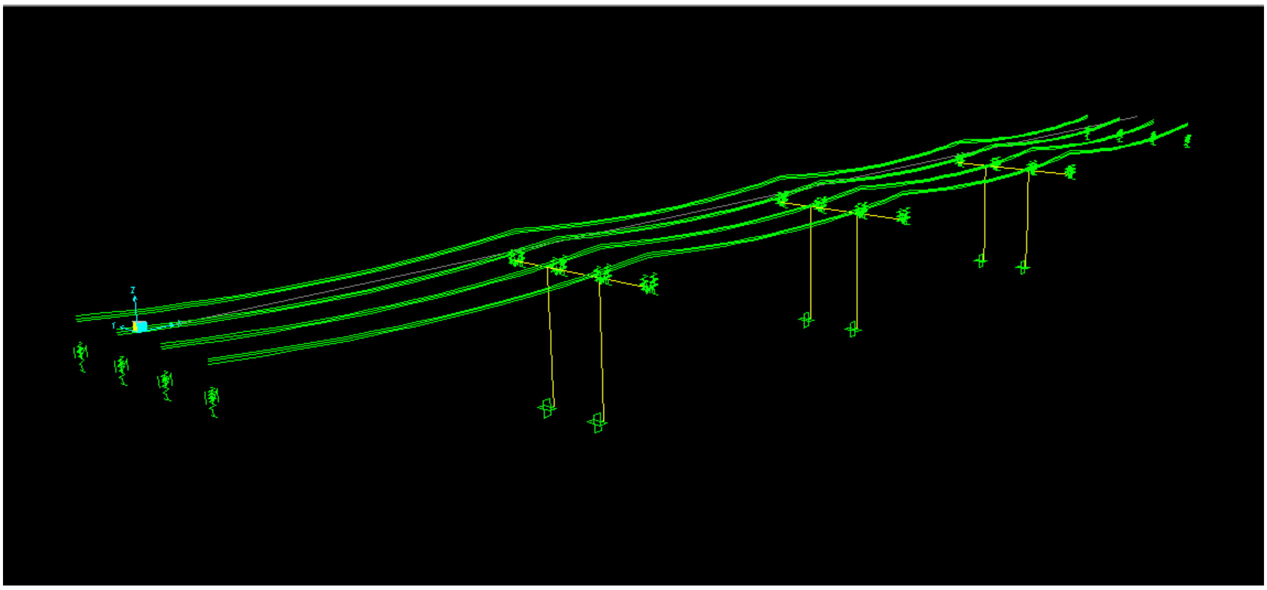

Figure 11 – Cable Profile

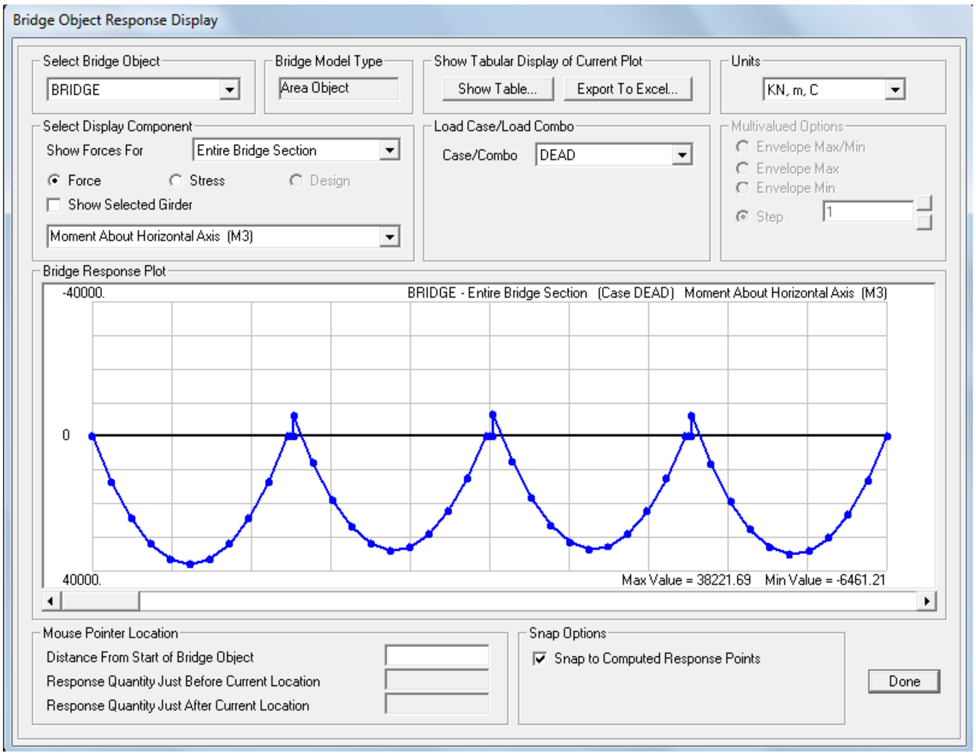

Figure 12 – Dead Load Bending Moment for Entire Bridge

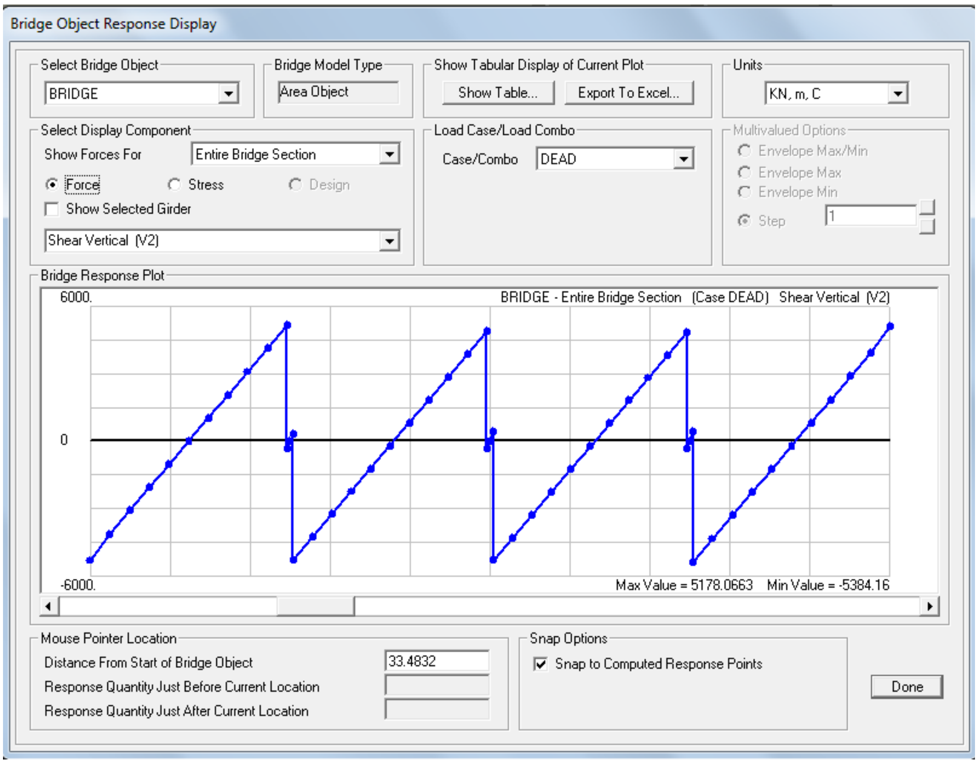

Figure 13 - Dead Load Shear Force for Entire Bridge

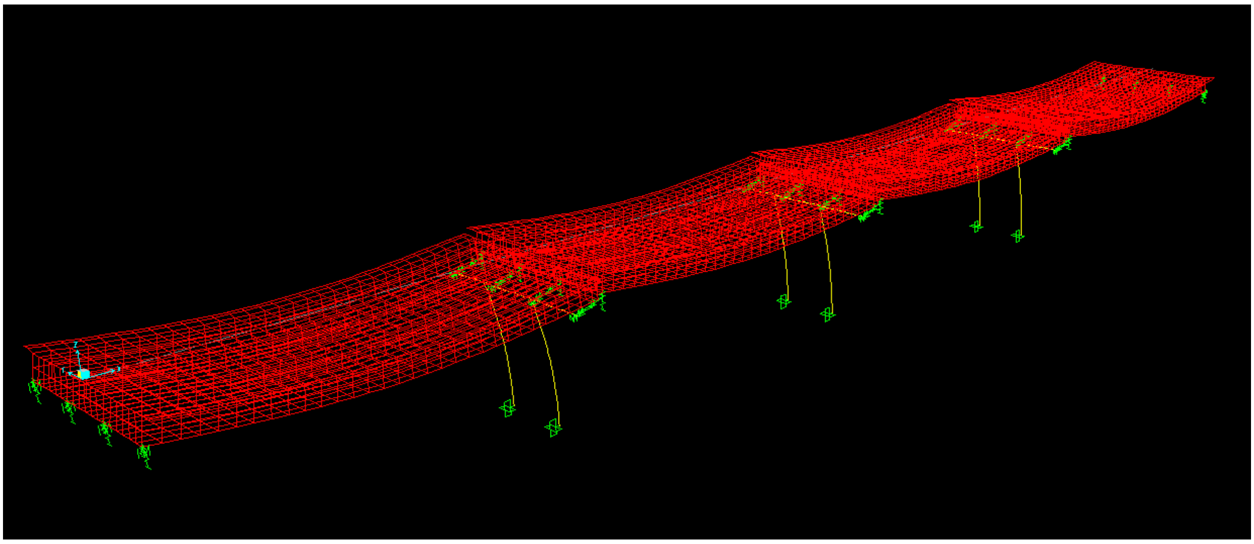

Figure 14 – Deflected Shape due to Dead Load

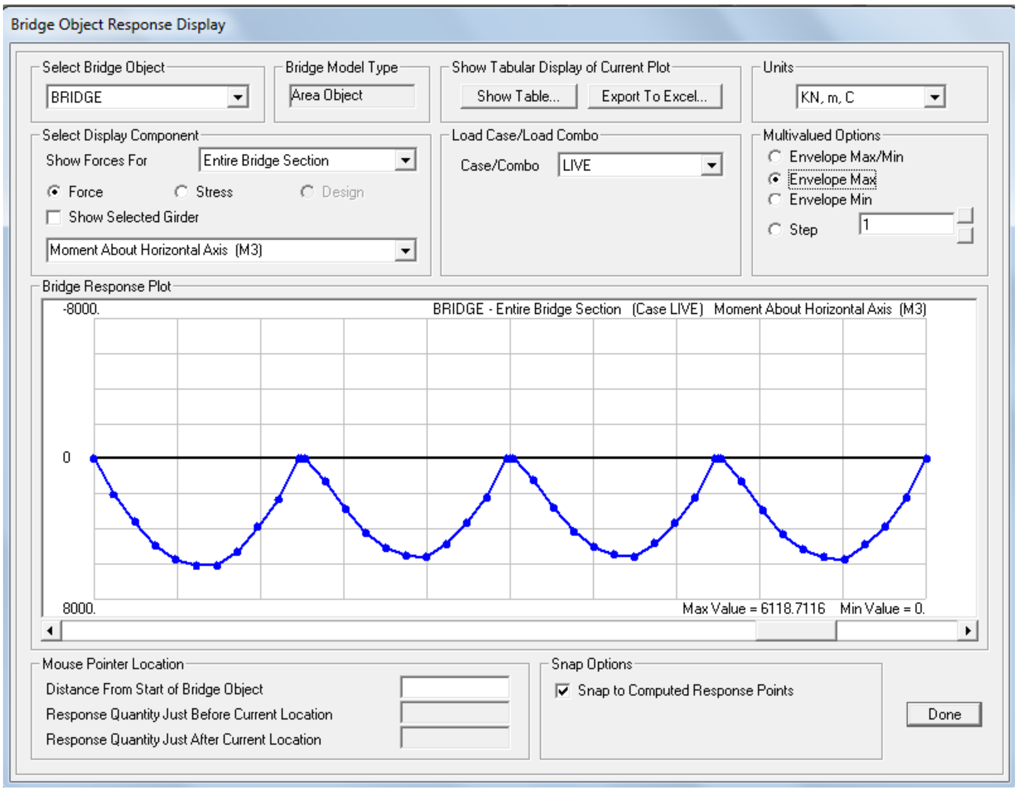

Figure 15 - Live Load Bending Moment for Entire Bridge

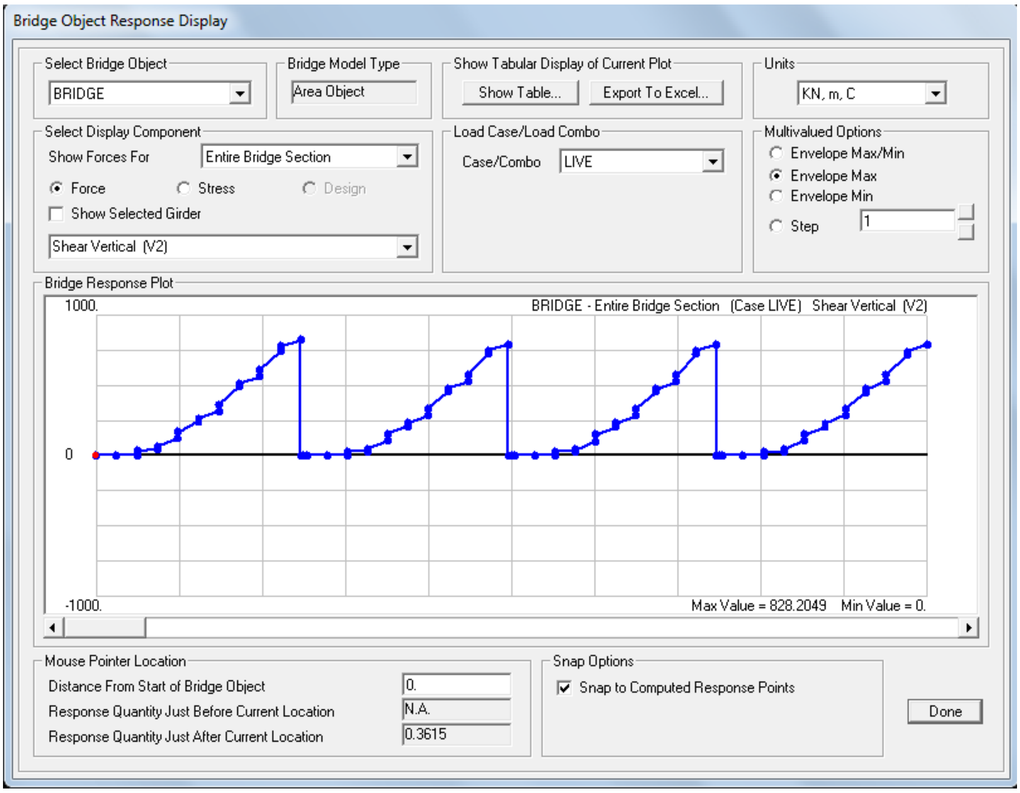

Figure 16 - Live Load Shear Force for Entire Bridge

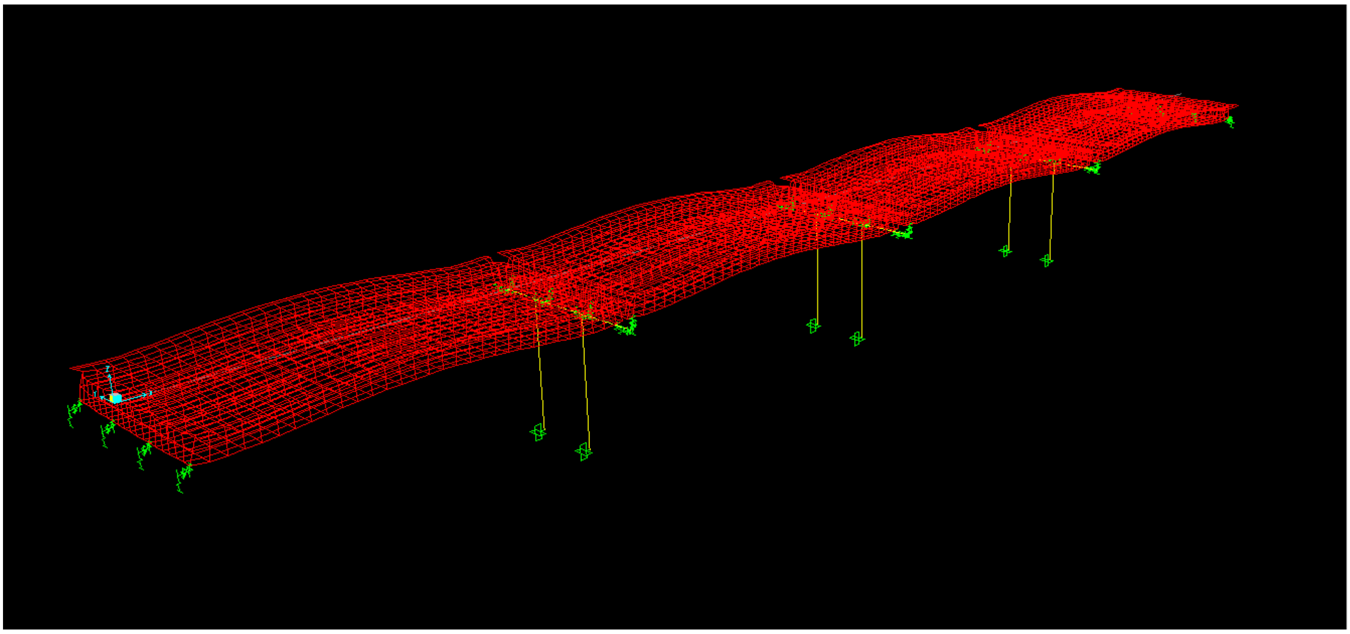

Figure 17 – Deflected Shape due to Prestress force

Comparison – Manual Calculations and SAP2000

Analysis Result	Manual Calculation	SAP2000	%Difference (with respect to manual calculation)	Units
Dead Load				
Bending Moment	39379.7	38221.7	-2.94	kN.m
Shear Force	5250.6	5178	-1.38	kN
Live Load				
Bending Moment	5132.3	6118.7	19.22	kN.m
Shear Force	723.8	828.2	14.24	kN

Table 8 – Manual Calculation and SAP200 for the Superstructure

Chapter 5 – BRIDGE SUBSTRUCTURE

5.1 Analysis and Design – Manual (Microsoft Excel)

The analysis and design of the substructure for the proposed 30m bridge was done using manual calculations and excel sheets were prepared using Microsoft Excel 2013. The spreadsheets are presented below.

Figure 16 – Design Model of Pier and Pier Cap (in STAADPro)

Design of Bridge Pier

Details	Value	Units	Symbols	Comments and Formulas
Length of Pier cap	12	m	l	
Width of Pier cap	2	m	w	
Depth of Pier cap	0.7	m	d	
Volume of each Pier cap	16.8	m^3	Vol.	(l)x(w)x(d)
Dia. of Pier	1.5	m	d'	
No. of Pier at each support	2			
Height of Pier	10	m	H	
Spacing between two Pier	5	m	s'	
Area of each Pier	1.766	m^2	a'	πx(d^2)/4
Density of Concrete	24	kN/m^3	ρ	
Stresses due to Dead Load and Self-Weight of Pier				
Dead Load	5250.63	kN	DL	
Self-weight of Pier	1251	kN	SW	(ρxVol.)+(2x(H)x(a')x(ρ))
Total Direct Load	6501.63	kN	TL	
Reaction due to Live Load	723.8464	kN	LL	
Braking Force	0	kN		
Load on Each pier	2987.24	kN		(DL+LL)/2
Compressive Stress at base of Pier, C.S.B	2045.43	kN/m^2		(TL+LL)/(2X(a'))

Soil Profile

Details	Value	Units	Symbols	Comments and Formulas
Loose sand				
Depth	3	m		
Unit weight	16	kN/m^3		
Angle of shearing resistance	30	degrees		
Clay				
Depth	6	m		
Unconfined compressive strength	15	kN/m^2	Cu	
Saturated Unit Weight	18	kN/m^3		
Dense sand				
Saturated Unit Weight	20	kN/m^3		
Angle of shearing resistance	40	degrees		

Design of Pile Foundation

Details	Value	Units	Symbols	Comments and Formulas
Length of Pile	35	m		L
Dai. of Pile	600	mm		d
Spacing between Piles	1.8	m		s=2.5xd
Dimension of Pile cap	4.2	m		(2xs)+d
Ultimate pile Load capacity	8080	kN		
Factor of Safety	2.5			
Allowable Pile Load capacity	3232	kN		
Total load from Superstructure and Pier	7225.47	kN		
Load carring capacity of each Pile	3232	kN		
Number of Piles	2.6			Total load from Superstructure and Pier/Load carring capacity of each Pile
Number of Piles Provided	4			square arrangement

Chapter 6 – Cost estimation

6.1 Material Cost Calculation for the Bridge:

Details of cost of 1m3 of cement concrete (M60); 1: 1.35 :2.19 :0.29 :0.8$^{\theta}$				
Material	**Quantity#**	**Units**	**Rate per Unit* (in Rs.)**	**Cost per m^3 (in Rs.)**
Stone Aggregate	782.946	kg	0.75	587.21
Sand	350.378	kg	0.32	112.12
Cement	570	kg	5.20	2964.00
Water	131.1	kg	0.10	13.11
Super Plasticizer	6.024	kg	50.00	301.20
Silica Fumes	30.025	kg	30.00	900.75
			Total	4878.39

Table 9 – Cost Details

Cost of Bridge per span (including a deck, a piercap, two pier and foundation)			
Item	**Vol^{m} of concrete**	**Cost per m^3**	**Total Cost (in Rs.)**
PSC Box Girder	397.2	4878.39	19,37,696.69
Pier	35.32	4878.39	1,72,304.75
Piercap	16.8	4878.39	81,956.96
Foundation	54.3	4878.39	2,64,896.60
		Total	24,56,855.00

Table 10 – Final Cost

Notes:

* Rates have been taken from article on **Effect of Fineness of Sand on the Cost and Properties of Concrete** by Prashant Agrawal, QC Manager, HCC Ltd. Dr. Y.P. Gupta, Materials Consultant, BCEOM-LASA JV, Suryakanta Bal, QC Engineer, HCC Ltd. Allahabad Bypass Project, Allahabad, UP. From NBM Media (www.nbmcw.com)
# Quantity has been picked up from B.Tech Project Thesis: **Study of Cost Effectiveness in Design of Structures with High Performance Concrete** by Indubhusan Jena & Sunil Kumar Sahoo Under the guidance of Prof. A.K.Sahoo Department of Civil Engineering National Institute of Technology Rourkela 2008
θ Cement : Fine agg. (kg/m3) : Coarse agg. (kg/m3) : Water (kg/m3): Super plasticizer (kg/m3)

Conclusion

Form this project we have learned the design of bridge in accordance with the Indian Standard Code of Practice (IRS for railway loading and IRC for highway loading). At the end of this project and from the results we conclude that:

1) We designed a Pre-Stressed Post-Tensioned Rail-cum-Road Bridge manually with the help of MS-EXCEL and by design and analysis software SAP2000.
2) As calculated and shown above we can say that the results from both the methods are comparable.
3) The final details of the structure are listed below.

FINAL DETAILS	COMMENTS AND VALUES	RESULTS
Section provided	checked for shear force and bending moment	Section Provided is Adequate
Shear reinforcement	τ does not exceed $k\tau_c$	Minimum Shear R/F provided
Section modulus	provided is less than maximum section modulus	Checked O.K.
Cables	Cable Type: Parallel Wire Strand: 12 cables provided throughout the section	Cables provided are sufficient to withstand load
Pier design	2 piers provided at 5m c/c	Compressive Stress at base of Pier<11500kN/m^2
Pile	Allowable Pile Load capacity with F.O.S. 2.5: 3232kN Number of piles provided : 4 (square arrangement, 2x2)	Pile Design is Adequate

RESEARCH SCOPE

In this project we have determined the cost-effectiveness of bridges. What we have done is just a drop in the ocean. There is a wide scope for research and to learn more about bridges. Following are just a few.

- Cost Variation in bridges with increase in span.
- Cost Variation in bridges with increase in no. of lanes.
- Simply Supported span bridges vs. Continuous span bridges.
- Economizing the section with changing the number of box girders.
- Rehabilitation Cost comparison.
- Maintenance Cost comparison.
- Comparison in Cost of Construction.
- Designing the bridges for other types of loading and comparing them.

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