Optimization of Pre Cast Post Tensioned Concrete Deck Type Box Girder Bridge

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Abstract: ***Bridge is a structure which provides passage over an obstacle without obstructing the way beneath. PSC bridges are adopted for span greater than 20 m. In present study a two lane simply supported Box Girder Bridge is designed for moving loads as per Indian Road Congress loadings (IRC:6-2014) prestressed concrete code (IS: 1343-2012) and IRC: 18-2000 specifications. The cable is prestressed with parabolic tendons.Deck slab is designed by working stress method and girder is designed by limit state method. A computer program is developed in C- programming language to design the deck slab and PSC Box-girder. Optimization is carried out by using sequential linear programming with improved move limit method.***

Keywords: Pre Stressed Concrete, Deck slab, Box Girder, C-Program, Optimization

1. Introduction

Bridge is a kind of structure which provides the passage over an obstacle without obstructing the way beneath. Bridges can be used as the passage of railway, road way and even transfer of fluids. Prestressed concrete bridges will be used in the longer and moderate span bridge construction.For the 30m to 70m span single or multi cell box-girder bridge is recommended.Pre-cast Post-tensioned concrete deck type box girder bridges are widely used inthe highway bridges. In these bridges top flange act as cross girder.

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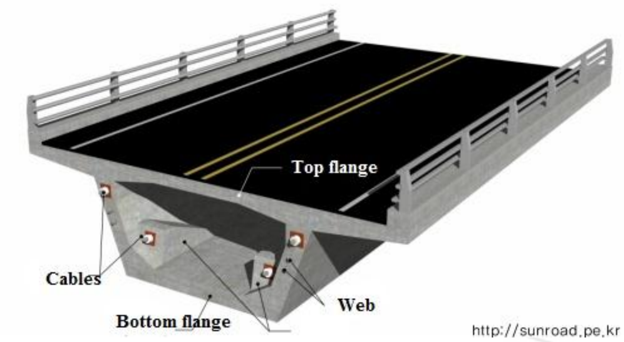

Figure 1: Typical box girder

1.1 Advantages of prestressed concrete bridges

Prestressed concrete offers great technical advantages in comparison with other construction, such as reinforced concrete and steel. Some of them are listed below,

- The structure will be slender since steel and concrete of high strength are used.
- In prestressed concrete bridges even higher cracks can be avoided by designing it as class I type in which tensile stress is negligibly small.
- Maintenance cost of prestressed concrete bridge is negligible as compare to steel bridges.

1.2 IRC Tracked Vehicle For Live Loads

The live load to be considered for bridge design, particularly for roadways are specified in IRC:6-2014. The various differentiating parameters between different IRC vehicles are, loading, ground contact area and side clearance.
The various IRC vehicles are specified in IRC: 6 - 2014,
(a) IRC class AA

- Tracked, with loading of 70 tonnes.
- Wheeled, with loading of 20 tonnes for single axles & 40 tonnes for two axles

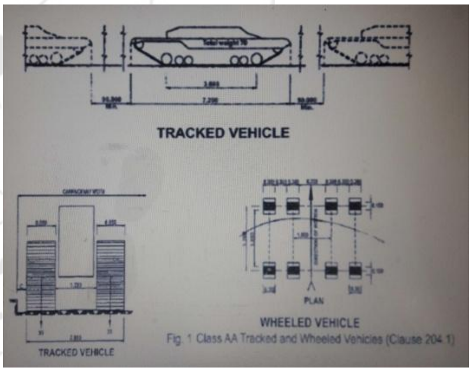

Figure 2: Tracked vehicle of IRC class AA

1.3 Need for optimization

There are many acceptable designs for a single design problem but among all the acceptable designs, one which is most economical will satisfy both structural engineering standards as well as economical need.The act of obtaining the best results under given circumstances is called optimization. Optimization has got huge scope in structural engineering. In this project the cost optimization of pre-cast post tensioned concrete deck type box-girder bridge is carried out.

1.4 Objectives

The various objectives to be achieved are,

- To employ the sequential linear programming optimization technique for optimum design of pre-cast post-tensioned concrete box girder.
- To provide the bases for selection of economical dimension in designing of pre-cast post-tensioned concrete deck type box -girder to the structural engineer.
- To study the effect of change in grade of concrete and steel on economy of the pre-cast post-tensioned concrete deck type box -girder
- To carry out the parametric study on effect of cost ratio on optimum design

2. Design Requirements

Prestressed concrete is a type of concrete in which appropriate quantity of internal stress is provided in such way that stresses due to external loads will be reduced to required quantity Prestress is generally introduced by the method of tensioning of the steel reinforcement.

2.1 Check for ultimate moment and shear

Ultimate moment check

The strength of prestressed concrete structure will be checked against the failure conditions.The ultimate moment is calculated as follows:

Ultimate moment with reference to clause 12 P No 20 IRC: 18 – 2000

Ultimate moment under normal condition = 1.25 DLBM + 2 SDLBM + 2.5LLBM

Ultimate moment under severe condition = 1.5 DLBM + 2 SDLBM + 2.5LLBM

where,

DLBM=Dead Load Bending Moment

SDLBM=Superimposed Dead Load Bending Moment

LLBM=Live Load Bending Moment

Failure by yielding of steel with reference clause 13(i) P No 20 IRC : 18 -2000

Mulim=0.9xdbxApxfup

where,

Mulim=Ultimate moment due to yielding of steel

db = Depth of the box girder from the extreme compression edge to the center of gravity of the tendons.

Ap = Total area for high tensile steel tendon.

fup = The ultimate tensile strength for steel.

Failure by crushing of concrete with reference clause 13(ii) P No 21 IRC 18 - 2000

$$Muc = 0.176 * bw * d^2 * fck1 + \left(\frac{67}{100}\right) * 0.8x(bf - bw) * \left(dg - \frac{df}{2}\right) x * df * fck1$$

where,

Muc=Ultimate moment due to crushing strength of concrete

bw = the width of web of a box girder

d = Depth of the box girder from the edge of maximum compression to the center of gravity of the tendons.

fck1= 15 cm cubes characteristic compressive strength at 28 days.

bf = The width of top flange of box girder

t = Thickness of flange of a box girder.

df = Depth of top flange

Check for ultimate shear

Ultimate shear resistance of concrete is considered in flexure for the cracked and un cracked and lesser value will be taken. If required shear reinforcement is provided.

Ultimate shear with reference to clause 12 P No 20 IRC : 18 – 2000

Ultimate shear under normal condition = 1.25 DLSF + 2 SDLSF + 2.5 LLSF

Ultimate shear under severe condition = 1.5 DLSF + 2 SDLSF + 2.5 LLSF

where,

DLSF=Dead Load Shear Force

SDLSF=Superimposed Dead Load Shear Force

LLSF=Live Load Shear Force

Ultimate shear resistance of a section un-cracked in flexure clause 14.1.2.1 P No 22

$$Vcw = 0.67 * bw * h * \sqrt{ft^2 + 0.8 * fcp * ft} + nl * Psf * sin\theta$$

Where,

bw = Width of the rib of box girder

d = Overall depth of the box girder.

ft = Maximum principal tensile stress which is given by$0.24\sqrt{fck}$

fcp = Positive prestress produces compressive stress at centroid axis.

Shear reinforcement

With reference to clause 14.1.4 P No 24 IRC : 18 – 2000

- If V <Vc/2

  No shear reinforcement is required.
- If V >Vc/2

  Minimum shear reinforcement is required.
- If V >Vc

  Shear reinforcement shall be provided.

Sv/Asv = (0.87fyvdt)/(V - Vc)

where,

Vc = Concrete carrying shear force in kN.

fyv = Yield strength given by shear reinforcement or proof stress of 0.2 per cent which should be taken within 415 MPa.

Asv = Cross-sectional area of link with two legs in N/mm2.

Sv = The link spacing with the length of member

dt = Depth from the top of compression fiber to thelongitudinal bars of diameter not less than the link bar over whichthe link will pass or to the centroid of the tendons, whichever is greater

3. Design Problem

To facilitate development of computer program and checking the program developed the following design is considered.

Preliminary data:

Clear span Lc = 40 m

Width of road way (cw) = 7.50 m

Depth of wearing coat (dwc) = 80 mm

Length of overhang from face of girder (lo) =1.25 m

Diameter for the short span in slab dia2 = 12mm

Diameter for the long span in slab dial=10 mm

Density of concrete ρc
$= 25\ kN/m3$Density of wearing coat $\rho wc = 22kN/m3$

The profile of the tendon parabolic in nature is considered for design.
Permissible stress in Prestressing concrete Fck1= 60 MPa
Permissible stress in concrete Fck2=20 MPa
Permissible stress in steel Fy= 415 MPa
Allowable stress in P S Concrete:
fci = 0.8fck = 48 MPa, As per IRC:18-2000
fct = 0.45fci = 21.6 MPa
fcw = 0.33fck = 19.8 MPa
ft = 1/10 th of fct = 0 MPa, ftw = 0 As referenced by IS:1343-2012
Ec = 5000$\sqrt{fck}$ = 38.72 kN/m2
Duct diameter dd= 100 mm
Clear cover dc= 50 mm
Allowable stresses in prestressing steel:
Ultimate tensile stress in steel Fp = 1862 MPa,
Loss ration in P.S concrete nl= 0.85
Modulus of elasticity in steel E = 2×105 MPa
Live load IRC Class AA tracked as Per IRC 6-2014
W1=W2=one wheel of tracked vehicle load= 350 kN

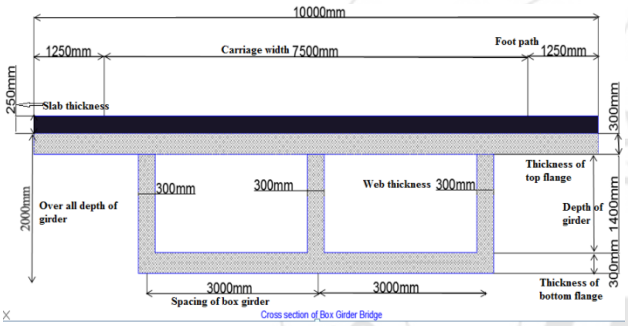

Figure 3: cross section of box girder

Final values of design forces obtained are tabulated as below.

Table 1: For design forces

Sl.No	Bending Moment(kN-m)	Shear Force(kN)
1.	DLBM=15536	DLSF=1553
2.	LLBM=3785.06	LLSF=484
	Total=2.5*LLBM+1.5*DLBM	Total=2.5*LLSF+1.5*DLSF
3.	TDLBM=32802.0	TDLSF=3539.5

where,
DLBM=Dead load bending moment in kN-m
LLBM=Live load bending moment in kN-m
DLSF=Dead load shear force in kN
LLSF=Live load shear force in kN
TDLBM=Total design load bending moment in kN-m
TDLSF= Total design load shear force in kN

3.1 Design Program

The problem is automated by writing a program in "C" language which is user friendly and edible for design of deck slab and PSC box-girder. But the program scope is limited to design for particular class of loading. The reinforcement details are clearly specified.

3.2 Mathematical formulation of optimization problem

Mathematical form of general optimization problem involves in finding the variable vector,
$x = (x1, x2, x3 \ldots \ldots xn)^T$
tominimize the objective function Z=f(x) subjected to constraints:
gj(x)≤0, where i=1,2 ...m
where,
x = Design vector with n-dimensions.
Z = Objective function.
gj(x)= Inequality constraints of m number.

There are three basic elements required to formulate the optimization problem mathematically they are design variables, objective functions and constraints.

3.3 Design variables

The design variables are,
- Over all depth of girder
- Depth of top flange
- Depth of bottom flange
- Thickness of web girder

3.4 Objective Function

The objective function considered is the minimization of material cost and is assembled as shown below,
Fcost=Qconc * Cconc + Qsteel * Csteel + Qcable *Ccable
where,
Fcost=Optimum cost of girder in lakhs
Qconc=Quantity of concrete in m3
Cconc=Cost of concrete in Rs/m3
Qsteel=Quantity of steel in m3
Csteel=Cost of steel in Rs/m3
Qcable=Quantity of cable (prestressing steel) in m3
Ccable=Cost of cable (prestressing steel)inRs/m3

3.5 Cost Consideration

The various cost to be considered are from Schedule of Rates (SR) of latest version and the region in which the site belongs to, for example if a site is in Hubballi then we need to refer schedule of rates 2016-2017 publicworks, ports & inlandwater transport department, north zone, Dharwad.

The various cost considered are, For M40 grade of concrete cost is 6,000 Rs/m3, Cost of steel (Fe415 TMT) is 40,000 per Tonne, Cost of prestressing steel is 1,25,000 per Tonne

Note: The above cost include cost of material, transportation and labor cost.

The objective function can be written as, For M40 grade of concrete and Fe 415 steel

Fcost=Qconc *6000 + Qsteel *40000 + Qcable *125000

3.6 Constraints

The various condition that need to be satisfied are related to section properties, stress at transfer, stress at working load stage, check for ultimate flexural strength and various side constraints that need to be satisfied as per IRC codes, and the condition to find the reaction factor (Courbon's theory).

Behavior constraints

- $Zb = \left[\frac{Mq+(1-n)*Mg}{fbr}\right] \leq Zprovided$

i.e $Zb = \left[\frac{\text{Required section modulus}}{\text{Section modulus of provided section}} - 1\right] \leq 0$

- $\frac{Etransfer}{0.45*fci} - 1 < 0$
- $\frac{Eworking}{0.33*fck} - 1 < 0$
- $\frac{Mu}{Mulim} - 1 < 0$
- $\frac{Total\ deflection}{Permissible\ deflection} - 1 < 0$
- $\frac{\tau c}{\tau cmax} - 1 < 0$

where,
Zb=Section modulus of girder
Mq=Bending moment due to live load
Mg=Bending moment due to dead loads
fbr = (fctxnl- ftw)
fct=Allowable compressive stress in concrete at initial transfer of prestress
ftw=Allowable tensile stress in concrete under service loads
nl= Reduction factor for loss of prestress or loss ratio
Zprovided=Section modulus of provided section
Etrans=Stress at transfer
fck=Characteristic cube strength of concrete
Mu=Ultimate moment required
Mulim=Ultimate moment carrying capacity of provided section
Tc = Critical shear stress of the section
Tcmax= Maximum permissible critical shear stress of the section

4. Optimization Technique

4.1 Introduction

Sequential linear programming is used to solve non-linear optimization problems. In this method originally non-linear programming problem is linearized by using first order Taylors expansion about present design vector. The new design vector is obtained by solving the linear programming problem, which was originally non-linear programming problem. The same procedure continuous till optimum is reached

Procedure for improved move limit method of sequential linear programming

Step by step procedure for improved move limit method of SLP is as explained bellow:

i) Select the initial feasible design point X and initial move limit M. Set K=1.
ii) Linearise the constraints and objective function with respect to design point.
iii) Impose initial move limit as additional constraints |X – Xk| ≤|Mk|.
iv) After reducing the non linear programming to linear programming problem. Next step is to solve the linear programming problem to get new design point Xk*
v) Check whether new design point Xk* is in feasible region. If not go to step (viii).
vi) Check is there improvement in objective function? if no go to step ix).
vii) Check whether termination criteria are satisfied. Termination criteria are.
a) $\frac{f(X^*) - f(Xk)}{f(X1)} \leq \varepsilon 1$ b) $\frac{x^*1 - xik}{xi1} \leq \varepsilon 2$ for i = 1, 2… n
where $\varepsilon 1$ *and* $\varepsilon 2$ are predefined small quantities.
If all the above conditions are satisfied, optimum is reached. Terminate thesearch and print the results.
viii) Steer the design vector to feasible region in the direction S=∇gj(X). where j is the most violated constraint by step length.b= $\frac{-gj(X^*k)}{(\nabla gj(Xk))^T \nabla gj(Xk)}$

Check whether the steered point is in feasible region. If not repeat the same procedure to steer it to feasible region.Incase the feasible region is not reached even after considerable attempts calculate afresh derivatives and use them to steer tofeasible region. After getting design vector to feasible region take it as Xk+1 and go to step (iv).

ix) If there is no improvement in objective function the direction S =Xk-Xk is correct but step length is large. Hence step length is resorted by quadratic interpolation. Instead of directly going for quadratic interpolation, check Xnew = Xk+1 after steering to feasible region, check if direction S = X_k -Xkis not usable. first carry out the quadratic interpolation between Xk and Xk then steer the point to feasible region. Take new point as Xk+1 and go to step vi). For quadratic interpolation

$$\hat{a} = \frac{f^T(X)S}{f(Xnew)) - f(Xk) - Df^T(XI)S}$$

and take Mk+1 = a*Mk

Flow chart of improved move limit with SLP is shown in the figure-4

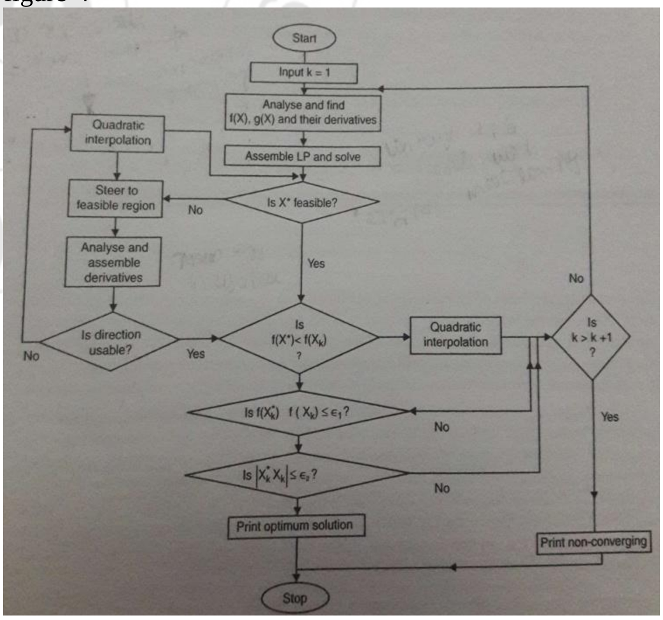

Figure 4: Flow chart of improved move limit method with SLP

5. Introduction to optimizer

Optimizer is built on bases of sequential linear programming with improved move limit method consist of five subroutines, namely FUNCT, DERIV, SIMPLX, QUADIN and STEER with a analyzer subroutine called `PROBLM'. All the subroutines perform a unique and specific purpose.

1) FUNCT

FUNCT subroutine calls the analyzer directly or through subroutine DERIV for function evaluation alone or for both function and derivative evaluation. This subroutine even checks the termination criteria for both maximum number of function and derivative evaluation.

2) DERIV

DERIV subroutine is called when derivatives of objective function and constraints with respect to design point is to be evaluated. DERIV subroutine is called by FUNCT wherever necessary.

3) SIMPLX

After linearizing of objective function and constraints through DERIV subroutine, SIMPLX subroutine is called through main program to assemble and solve the linear programming problem by simplex method.

4) QUADIN

If objective function obtained is higher than present value after solving linear programming problem, QUADIN subroutine will be called through main program to get improved design points which lead to objective function less than or equal to present value.

5) STEER

When starting point or any other design point after linear programming is in infeasible region then STEER subroutine is called by main program to steer the design point to feasible region.

6) PROBLM

PROBLM subroutine act as a connector between optimizer and design program or problem to be optimized.

Following are the inputs required for the optimizer:

1) No of variables.
2) No of constraints.
3) Initial move limits.
4) Lower limits on variables.
5) Upper limits on variables.
6) Step length for calculating derivatives.
7) Maximum number of function evaluation.
8) Maximum No of derivative evaluation.
9) Negligible values on variables, objective functions, constraint violation.
10) Initial design points.

5.1 Optimization of Pre-Cast Post-Tensioned Concrete Deck Type Box Girder Bridge

After the mathematical formulation of optimization problem, design program is developed and tested. Next step is to test the optimizer and connect the design program to optimizer. In this problem detailed study on process of Optimization of Pre-Cast Post-Tensioned Concrete Deck Type Box Girder Bridge is carried for span 40m with carriage way width of 7.5m, and M40 grade of concrete and Fe415 grade of steel.

- No of variables - 4
- No of constraints -6
- Initial move limits -0.06,0.06,0.06,0.06
- Lower limits on variables:1.50,0.26,0.26,0.3
- Step length for calculating derivatives - 0.001
- Maximum number of function evaluation - 1000
- Maximum No of derivative evaluation - 1000
- All the negligible values - 0.001 (Negligible value for difference in objective function, variables, constraints from subsequent iterations)

Design program developed is connected to sequential linear programming based optimizer with the inputs as mentioned. Optimizer proceeded for number of function and derivative evaluation till the optimum point is reached. Using M40 gradeconcrete and Fe415 steel optimization is carried out for 40 m span.

Table 2: progress of optimization

Iteration No.	X1	X2	X3	X4	Objective function (Rupees in Lakhs)
Initial points	2.000	0.30	0.30	0.30	13.699
1	1.750	0.27	0.27	0.30	13.058
2	1.745	0.26	0.26	0.30	12.943
3	1.743	0.26	0.26	0.30	12.930
Optim.	1.743	0.26	0.26	0.30	12.930

where:
X1=Over all depth of box girder in m
X2=Thickness of top flange in m
X3=Thickness of bottom flange in m
X4=Thickness of web girder in m

Table 3: Comparison of Optimum variables from various starting points

Starting Points				Cost Rupees in Lakhs	Optimum Points				Cost Rupees in Lakhs
X1	X1	X3	X4		X1	X2	X3	X4	
1.85	0.28	0.28	0.30	13.278	1.736	0.26	0.269	0.30	13.01
1.90	0.28	0.26	0.30	13.185	1.80	0.27	0.27	0.30	13.17
2.00	0.30	0.30	0.30	13.69	1.743	0.26	0.26	0.30	12.93
2.00	0.31	0.30	0.30	13.764	2.50	0.26	0.26	0.30	13.14
2.10	0.27	0.26	0.30	13.265	2.35	0.26	0.26	0.30	11.88
2.20	**0.26**	**0.27**	**0.30**	**11.82**	**2.09**	**0.26**	**0.265**	**0.30**	**11.74**
2.30	0.30	0.32	0.30	12.546	2.05	0.26	0.28	0.30	11.92
2.40	0.26	0.27	0.30	11.983	2.40	0.26	0.26	0.33	11.85
2.50	0.27	0.27	0.30	12.139	2.20	0.27	0.27	0.30	11.80

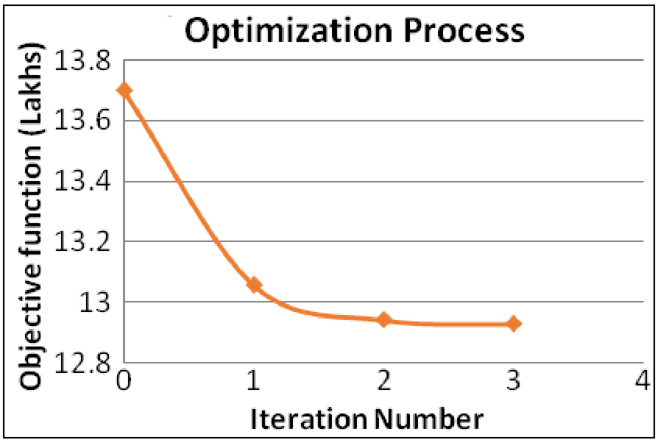

Figure 5: Variation of objective function with Corresponding iterations.

From the Table- No 3 the problem was started with different starting points it resulting in different optimum points. Hence we can say that there a number of local optimumpoints.

6. Results and Discussion

6.1 Effect of change in grade of concrete and steel.

Cost of the structure will be affected by grade of the concrete as well as steel. In this section effect of change in grade of the concrete and steel on optimum variables and cost of the structure is discussed

Table 5: Rates for different grade of concrete

Grade of concrete in N/mm2	M40	M45	M50	M60
Rate in rupees per cubic meter	6000	6500	7000	8000

Table 6: Rates for different grade of steel

Grade of steel in N/mm2	Fe415	Fe500
Rate in rupees per ton	40000	45000

Table 7: Variation of optimum cost with change in grade of concrete:

[For Fe415Steel] Grade of concrete	Total optimum cost(Rupees in Lakhs) M40	M45	M50	M60
Span in meter				
20.0	4.18	4.36	4.60	4.98
25.0	5.50	5.76	6.02	6.54
30.0	7.50	8.04	8.23	8.96
35.0	9.98	10.32	10.65	11.35
40.0	11.74	12.12	12.54	13.35

Table 8: Optimum cost for different grade of concrete and span.

[For Fe500 Steel] Grade of concrete	Total optimum cost(Rupees in Lakhs) M40	M45	M50	M60
Span in meter				
20.0	4.20	4.39	4.67	5.06
25.0	5.56	5.81	6.07	6.590
30.0	7.56	8.18	8.27	9.05
35.0	10.05	10.38	10.72	11.42
40.0	11.83	12.22	12.58	13.45

By referring to Table-No 7 & 8

- Total cost of the structure increases with increase in grade of concrete

By referring to Table-No 7 & 8Total cost of the structure slightly increases with increase in grade of steel.

6.1 Cost ratio

Cost ratio is defined as ratio of cost of unit volume of steel to the cost of unit volume of concrete. Cost of steel and concrete vary with time, hence parametric study is carried out for different cost ratios.

Study is carried out for carriage way width of 7.5m. Following are the inputs for each cost ratio.

- Characteristics strength of concrete- 40 N/mm2
- Characteristics strength of steel- 415 N/mm2
- Span- 40m

Parametric study is conducted for different cost ratios, various span and grade of concrete and steel as follows.

Table 9: Optimum points for different cost ratios

Sl.No	Cost Ratio	Optimum Points X1	X2	X3	X4
1.	50	2.09	0.26	0.265	0.30
2.	60	2.09	0.26	0.265	0.30
3.	70	2.09	0.26	0.265	0.30
4.	80	2.09	0.26	0.265	0.30
5.	90	2.09	0.26	0.265	0.30
6.	100	2.09	0.26	0.265	0.30
7.	**59.05**	2.09	0.26	0.265	0.30

From table No9it is clear that for cost ratio between 50 to 100 there is no change in the design variables

Table 10: Optimum cost and optimum points for M40 grade of concrete and Fe 415 steel for different spans

Span in Meter	Starting Points X1	X1	X3	X4	Cost (Rupees in Lakhs)	Optimum Points X1	X2	X3	X4	Cost Rupees in Lakhs
20	2.20	0.26	0.26	0.30	5.25	1.54	0.267	0.26	0.3	4.98
25	1.80	0.26	0.26	0.30	7.23	2.05	0.26	0.26	0.33	6.59
30	2.20	0.28	0.28	0.30	9.230	1.86	0.28	0.28	0.3	8.96
35	2.00	0.29	0.29	0.30	10.548	1.734	0.26	0.26	0.3	9.98
40	2.20	0.26	0.27	0.30	11.82	2.09	0.26	0.26	0.3	11.74

Table 11: Optimum variables with different span

Sl.No	Span in meter	Optimum design Variables			
		X1	X2	X3	X4
1.	20.0	1.54	0.267	0.26	0.3
2.	25.0	2.05	0.26	0.26	0.33
3.	30.0	1.86	0.28	0.28	0.3
4.	35.0	1.734	0.26	0.26	0.3
5.	40.0	2.09	0.26	0.265	0.3

Referring to the Table-11following observations can be made:

- It can be seen that variation of optimum dimensions for thickness of top and bottom flange and thickness of web girder for different span of are almost linear.

Table 12: L/D ratio for various span of PSC Box Girder Bridge

Sl.No	Span in meter	X1(D)	L/D ratio
1.	20.0	1.54	12.987
2.	25.0	2.05	12.195
3.	30.0	1.86	16.129
4.	35.0	1.734	20.185
5.	40.0	2.09	19.139

Following observations can be made from the Table-No 12

- For a span up to 25m optimum depth is $\left(\frac{1}{12}\right)^{th}$ of span. For a span of 35m onwards it is $\left(\frac{1}{20}\right)^{th}$ of span

Table 13: Various ratios for optimum variables with different span

Span in meter	Optimum design Variables				Ratios				
	X1	X2	X3	X4	x1/x2	x1/x3	x1/x4	x2/x4	x3/x4
20	1.454	0.26	0.26	0.3	5.768	5.923	5.133	0.890	0.867
25	1.98	0.26	0.26	0.3	7.885	7.885	6.212	0.788	0.788
30	1.734	0.26	0.26	0.3	6.643	6.643	6.200	0.933	0.933
35	2.26	0.26	0.26	0.3	6.669	6.669	5.780	0.867	0.867
40	2.09	0.26	0.265	0.30	8.038	7.887	6.967	0.867	0.883

7 Conclusion

1) Optimization of Pre-Cast Post-Tensioned Concrete Deck Type Box Girder Bridge can be carried satisfactorily by using sequential linear programming with improved move limit method..
2) For the design of the span of 20 m to 40 m M40 grade of concrete and Fe 415 steel(For untensioned reinforcement) is recommended.
3) For the cost ratio for the concrete in the range of 50 to 100 the optimum variables remains same.
4) For the cost ratio for the steel in the range of 150 to 200 the optimum variables remains same.

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