Optimization of PSC Slab Bridges

Brij Kishor Kushwaha, N. G. Gore, P.J. Salunke

***Abstract:** The objective of this study is to investigate the appropriate optimization method to find minimum weight and the minimum cost of a Railway PSC slabs. In view of achieving this objective it is decided to develop a computer code in MATLAB7. After validating this computer code by comparing the results with analytical results, it is planned to carry out the economical and safe design of PSC slab. For the minimum weight and cost design of the PSC slab unit the following design variables are chosen: 1-Depth of PSC slab unit at center, 2-Depth of PSC slab unit at end, 3-Eccentricity of prestressing cable at center, & 4-Total prestressing force.*

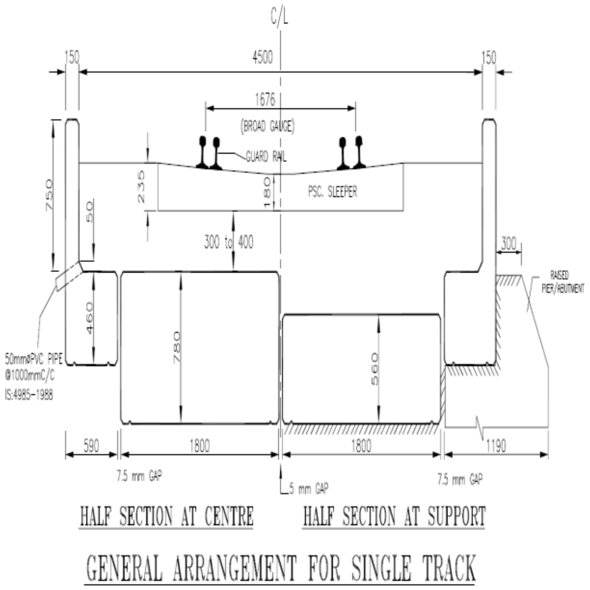
***Index terms:** Prestressed concrete slab, Railway bridges, Structural optimization, prestressing force, cost and weight optimisation.*

I. INTRODUCTION

The PSC slab is very important structure for small span Railway Bridges. Indian Railway replacing steel girders by PSC/RCC slabs on programme basis due to low maintenance and economical cost. PSC slabs are most suited for Railway Bridges of span 3m to 12m. The main drawback of PSC slab is that PSC slabs are three times heavier than steel plate girders. The launching of PSC slab is more expensive due to its heavy weight. Hence, it is necessary to optimise the design of PSC slab to get the light design and minimum launching cost for such important structure. The design of prestressed concrete slab for Railway bridges is done based on Concrete Bridge code (CBC) of Indian Railway Standards. The code requirement is generally concerned with the safety of the structure in its lifetime. RDSO issued standard drawings for simply supported pre cast slabs for 6.1m, 9.15m, 12.2m, span Bridges for pre tensioned and post tensioned both methods. These precast slabs are replaced in short duration traffic blocks. The lightness of precast slabs is economical not only by material cost but also more economical for launching cost and cost of traffic block. Apart from satisfying the code requirement, the slab may be designed economically from RDSO Drawings. For a given condition, there might be a large number of alternatives that satisfy the requirements imposed by codes. But the designer must be in position to choose the one, which is optimal against certain measure of optimality.

Therefore, the designers have to do some optimization to arrive at such design. The objective of this Project is to achieve the optimal design of a prestressed concrete Slab for Railway Bridge. It will establish a general relationship among different design variables at optimum and will recommend a simple procedure to identify the optimum design.

Fig. 1



II. STRUCTURAL OPTIMIZATION

Optimization is the act of obtaining the best result under given circumstances. It can be also stated mathematically as "the process of finding the conditions that gives the maximum or minimum value of the function". The optimum cost design of PSC slab formulated in is nonlinear programming problem (NLPP) in which the objective function as well as Constraint equation is nonlinear function of design variables. The Sequential Unconstrained Minimization Technique (SUMT) is one of the methods for the solution of the NLPP. In SUMT the constraint minimization problem is converted into unconstraint one by introducing penalty function. In the present paper the function f (X, r) is the penalty function f (X) and the objective function r is the non negative penalty parameter, and m is the total number of constraints. The penalty function (X, r) is minimized as an unconstrained function of X and r, for a fixed value of r. The present optimization problem is solved by the interior penalty function method. DFP method is used for solving successive unconstrained minimization problems coupled with cubic interpolation methods of on dimensional search. The program developed by S.S. Rao for SUMT is used for the solution of the problem. The program is written in MATLAB language.

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III. FORMULATION

3.1 Design Variable

The design variable in optimal design problem of restressed concrete elements includes concrete dimensions, restressing force and the tendon eccentricity

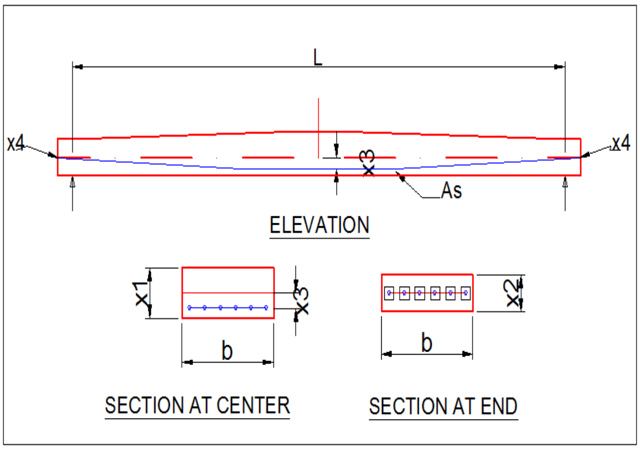

Fig: 2

X1 = depth at center
X2 = depth at end
X3 = eccentricity of prestressing cable at center
X4 = Total prestressing force.

Span L, slab width b and nos. of voids are taken as pre-assigned parameters.

3.2 Constraints

The restrictions that must be satisfied in order to produce an acceptable design are collectively called design constraints and formulated as below.

Normal Stress Constraint

G1= Stress in top fiber at transfer

$$= \frac{\left(\frac{P}{A} - \frac{Pe}{Zt} + \frac{Mg}{Zt}\right)}{ftt} - 1 \geq 0$$

G2= Stress in bottom fiber at transfer

$$= \frac{\left(\frac{P}{A} + \frac{Pe}{Zt} - \frac{Mg}{Zt}\right)}{fct} - 1 \leq 0$$

G3= Stress in top fiber at service

$$= \frac{\left[\eta\left(\frac{P}{A} - \frac{Pe}{Zt}\right) + \frac{Mg}{Zt} + \frac{Mq}{Zt}\right]}{fcw} - 1 \leq 0$$

G4= Stress in bottom fiber at service

$$= \frac{\left[\eta\left(\frac{P}{A} + \frac{Pe}{Zt}\right) - \frac{Mg}{Zt} - \frac{Mq}{Zt}\right]}{ftw} - 1 \leq 0$$

Ultimate Strength, Shear Constraints

G5= Ultimate Strength $= \frac{\mathrm{Mu}}{\mathrm{Mult}} - 1 \leq 0$

G6= Ultimate shear $= \frac{Vu}{Vco} - 1 \leq 0$

G7= Maximum shear capacity =Vu/Vm-1 ≤ 0

Deflection Constraints

G8= Deflection check $= \frac{\mathrm{D}}{\mathrm{Du}} - 1 \leq 0$

Design Constraints

G9= Minimum depth at center $= \frac{h}{2(e+c)} - 1 \leq 0$

G10= Minimum depth at end $= \frac{h1}{2F} - 1 \leq 0$

G11= Maximum eccentricity $= \frac{X3}{(.5X1-c)} - 1 \leq 0$

G12= Max. prestressing force $= \frac{X4}{(0.8cable*no*str)} - 1 \leq 0$

G13= Minimum section modulus $= \frac{Zc\ min}{Zc} - 1 \leq 0$

3.3 Objective Function

The objective function in the present optimization problem is the cost of PSC slab which main components are cost of concrete, and pre stressing steel. It is assumed that cost of steel, launching and casting formwork etc are directly proportional to volume of concrete, hence all these cost are included in the rate of concrete. It is also assumed that cost of anchor, sheathing etc are directly proportional to volume of prestressing steel, hence all these cost are included in the rate of prestressing steel. Objective function can be expressed as:

COST = (wt. of Pre stressing steel x Rate) + (Vol of Concrete x Rate) or

Z = Vp x Rp + Vc x Rc

Sr. No.	Span (in mm)	Fck	Weight of slab unit (KN)				Cost of slab unit (Rs.)			
			As per RDSO DRG	Opt. wt	RDSO vs opt. wt	variation from opt. M60	As per RDSO DRG	Opt. cost	RDSO vs opt. cost	variation from opt. M60
1	3050	M40	57.74	51.69	11.7%	7.98%	78670	73508	7.0%	1.86%
2	3050	M50	57.74	51.57	12.0%	7.73%	79593	74235	7.2%	2.87%
3	3050	M60	57.74	**47.87**	20.6%	0.00%	80979	**72167**	12.2%	0.00%
4	6100	M40	178.61	146.04	22.3%	9.58%	243868	216093	12.9%	2.64%
5	6100	M50	166.79	134.21	24.3%	0.71%	236460	**208140**	13.6%	-1.13%
6	6100	M60	166.79	**133.27**	25.2%	0.00%	240463	210526	14.2%	0.00%
7	9150	M40	315.88	279.91	12.9%	7.12%	401028	370341	8.3%	1.48%
8	9150	M50	315.88	265.44	19.0%	1.58%	406080	**362250**	12.1%	-0.73%
9	9150	M60	315.88	**261.31**	20.9%	0.00%	413663	364930	13.4%	0.00%
10	12200	M40	593.8	414.92	43.1%	9.43%	732476	579896	**26.3%**	2.72%
11	12200	M50	593.8	387.37	53.3%	2.16%	741977	**562588**	31.9%	-0.35%
12	12200	M60	593.8	**379.17**	**56.6%**	0.00%	756228	564561	33.9%	0.00%
13	15300	M40		610.31		10.85%		915859		3.26%
14	15300	M50		569.69		3.47%		890324		0.38%
15	15300	M60		**550.58**		0.00%		**886926**		0.00%

Table 1: Variation of Slab Cost and Weight for Different Span and Grade of Concrete

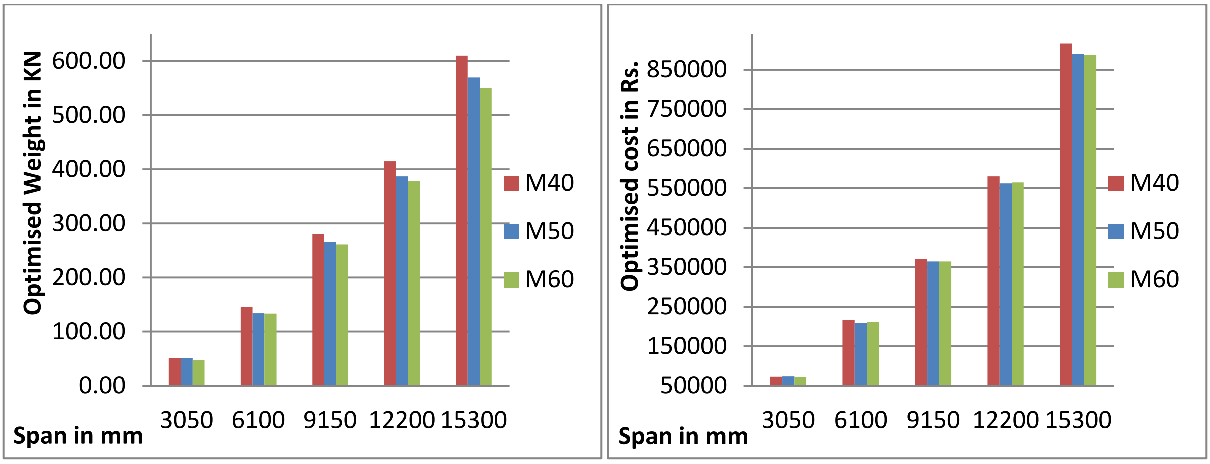

Fig.:3: Optimized Weight and Cost for Various Span and Concrete Grade

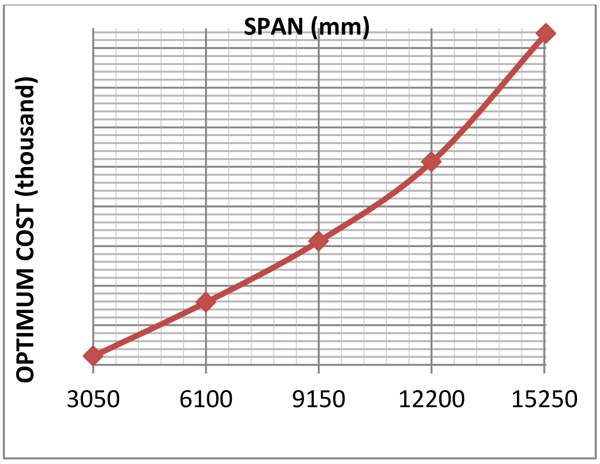

Fig 4: Optimum Cost v/s Span

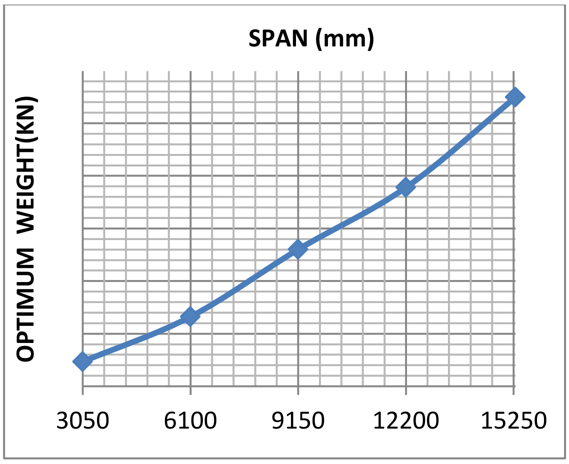

Fig 5: Optimum Weight v/v Span

IV. RESULT ANALYSIS

A computer code developed in MATLAB7 based on above design variables, constraints and objective functions to find minimum weight and the minimum cost of a Railway PSC slabs. After validating this computer code by comparing the results with analytical results, it is planned to carry out the economical and safe design. The active constraints calculated by this computer code for the various grade of concrete and various spans.

- The results of various illustrative examples are presented as per Table 1 and graphically analysed in fig.3.The conclusion drawn from the results of the illustrative examples are presented as below. It is possible to formulate and obtain solution for the minimum weight and cost design for PSC slab.
- Interior penalty function method can be used for solving resulting non-linear optimization problems. The chosen values of initial penalty parameter r0 and reduction factor C worked satisfactorily.
- It is possible to obtain the global minimum for the optimization problem by starting from different starting points with the interior penalty function method.
- The minimum weight and cost design of PSC slab is fully constrained design which is defined as the design bounded by at least as many constraints as there are the design variables in the problems.
- Significant savings in weight and cost over the normal design can be achieved by the optimization. However the actual percentage of the saving obtained for optimum design for PSC slab depend upon the span of slab, prestressing tendons and grade of concrete (refer Table1).
- Maximum cost savings of 26.30% over the RDSO standard design is achieved in PSC slab unit of 12200mm of M40 grade concrete. Maximum weight reduction of 56.6% over the RDSO standard design of PSC slab unit of 12200mm span of M60 grade concrete(refer Table1).
- The optimum cost for a PSC slab is achieved in M50 grade of concrete which is the average of M40 and M60 grade of concrete, but optimum weight for a PSC slab unit reduced with increase in grade of concrete (refer fig. 3).
- The cost of PSC slab unit increased exponentially (refer fig.4) with respect to span where as weight of PSC slab unit increased linearly (refer fig.5) with respect to span.

V. CONCLUSION

The constrained optimization problem resulting from the mathematical programming problems of optimum design of prestress slab has been solved by SUMT. The constrained optimisation has been converted into unconstrained, one by interior penalty function method. DFP method was used for solving the resulting unconstrained problems the one dimensional minimization problem arising in DFP methods is solved by cubic interpolation method. The computer program is written in MATLAB. The optimized weight and cost of PSC slab unit compared with conventional and RDSO standard design. A significant cost savings and weight reduction over the RDSO standard design and conventional design is achieved by optimization.

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