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COST OPTIMIZATION OF POST-TENSIONED I- GIRDER

Devashree U. Sawant, N.G.Gore, P.J.Salunke, V.G.Sayagavi

devashreesawant81289@gmail.com

Abstract

Nowadays Post-tensioned simply supported pre-stressed concrete (PC) I-girder bridges are widely used bridge system for short to medium span (20m to40m) highway bridges due to its moderate self-weight, structural efficiency, ease of fabrication, low maintenance etc. In order to compete with steel bridge systems, the design of PC I-girder Bridge system must lead to the most economical use of materials.

In this present study, cost optimization approach of a post-tensioned PC I-girder is presented. The objective is to minimize the total cost in the design process of the bridge system considering the cost of materials. For a particular girder span and bridge width, the design variables considered for the cost minimization of the bridge system, are top flange width, girder depth, bottom flange thickness, number of cables (i. e. X1, X2, X3,X4 resp.) Design constraints for the optimization are considered according to AASHTO (American Association of State Highway and Transportation Officials) Standard Specifications and IS: 1343-1980. The optimization problem is characterized by having a combination of continuous, discrete and integer sets of design variables. For An optimization purpose Matlab Software with SUMT (Sequential Unconstrained Minimization Technique) is used that is capable of locating directly with high probability the minimum design variables.

1. INTRODUCTION

In conventional structure design process, the design method proposes a certain solution that is validated by mathematical analysis in order to verify that the problem requirements or specifications are satisfied. If such requirements are not satisfied, then a new solution is proposed by the designer based on his intuition experience .The process undergoes many manual iterations before the design can be finalized making it a slow and very costly process. There is no formal attempt to reach the best design in the strict mathematical sense of minimizing cost. The process of design is relied exclusively on the designer's experience, intuition and creativity resulting in high cost in terms of times and human efforts.

An alternative to the conventional design method is optimum design. An optimum design normally implies the most economic structure without harming the functional purposes of the structure. An optimization technique transforms the conventional design process of trial and error into a formal and systematic procedure.

Pre-stressed concrete (PC) I-girder bridge systems are ideal as short to medium span (20 to 40 m) highway bridges because of their moderate self-weight, structural efficiency, ease of fabrication, fast construction, low initial cost, long life expectancy, low maintenance, simple deck removal, and replacement. Large and important projects containing I-girder bridge structures have the potential for substantial cost reduction through application of optimum design methodology and thus, will be of great value to practicing engineers.

Rana et al. (2010) presented Cost optimization approach of a post-tensioned PC I-girder bridge system. A global optimization algorithm named EVOP (Evolutionary Operation) was used. The comparison was made between optimum design and a real life project named Teesta Bridge. This comparison leads up to 35% saving. Ahsan et al. (2012) presented an optimization approach to the design of simply supported, post-tensioned, pre-stressed concrete I-girder bridges. Sami et al(1996) presented a systematic procedure for selecting the most economic girder type and spacing for a given span. They conclude that it is more economical to space the girders at their maximum spacing. Macrae et al(1984) presented a computer approach to the optimal design of structural concrete beams. An optimal design program called OSCON was used for this purpose. The main objective of this study was Minimizing the amount of reinforcement for a given concrete-section, evaluating the effect of steel cost ratios on optimal solutions, Optimizing the section shape of partially pre-stressed concrete beams, Analysis of given designs with respect to all relevant criteria.

2. PROBLEM FORMULATION

A. Design variables

For a particular girder span and bridge width, a large number of parameters control the design of the bridge such as girder spacing, cross sectional dimensions of girder, deck slab thickness, number of strands per tendon, number of tendons, deck slab reinforcement, configuration of tendons, anchorage system, pre-stress losses, concrete strength etc. the design variables consider in this study are tabulated in Table 1. A typical cross-section of the PC I-girder is illustrated in Fig. 1 to highlight several of the design variables reflect in this study.

Figure 1: Girder composite section with design variables

Pre-stress is considered to be applied in two stages, a percentage of total pre-stress at initial stage to carry only the girder self-weight and stress produced during lifting and transportation and full pre-stress during casting of deck slab.

Table1. Design variables with constraints

Sr No.	Design Variables	Constraints
1	Top flange width (X1)	$300 \leq X1 \leq S$
2	Girder depth (X2)	$1000 \leq X2 \leq 3500$
3	Bottom flange thickness (X3)	$a \leq X3 \leq 600$
4	Number of cables (X4)	$1 \leq X4 \leq 20$

a= clear cover + duct diameter, S= Girder spacing

B. Objective function

The objective function in the present optimization problem is the cost of PSC slab bridge deck whose 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 pre-stressing steel, hence all these cost are included in the rate of pre-stressing steel.

Objective function can be expressed as:

$$\text{TOTALcost} = \text{Qconc}*\text{Ccost}+\text{Qsteel}*\text{Scost}$$

Rate of objective function can be expressed as,

Qconc = Quantity of concrete in m^3
Qsteel = Quantity of steel in Kg
Ccost = Cost of concrete/ m^3
Scost = Cost of steel/ Kg

C. Constraints

These are specified limitation (upper or lower limit) on design variables which are derived from geometric requirements (superstructure depth, clearances etc.), minimum practical dimension for construction, code restriction etc. The constraint is defined as

$$X_L \leq X \leq X_U \quad \text{..} \quad (1)$$

Where
X = Design variable.
X_L = Lower limit of the design variable.
X_U = Upper limit of the design variable.

The constraints imposed in the design of pre-stressed concrete flexural member are generally the following:

1. Stresses developed at top n bottom fibres of the critical section at the stage of transfer of pre-stressed and under service loads. These conditions yield four inequalities expressed as:

……..…………………………………….…(2)

…………………………………………... (3)

…………………………………... (4)

……………………………………….. (5)

2. Code requirements for the limit state of collapse to ensure desirable load factors against flexural failure which can be written as:

……………………………….. (6)

D. Deflection constraint at the limit state of serviceability which takes the form,

………………………………………………………… (7)

Where,
and are the actual and permissible deflection, which is usually a small fraction of the span.

E. Limitation on the minimum ratios of reinforcement in the section is expressed in the form,

Where, ▯▯is the ratio of reinforcement provided,

is the minimum ratio required to prevent failure by fracture of steel in tension, and is the maximum permissible ratio to ensure failure of the section by yielding of steel. The constraint equations used for this study are tabulated in Table 2.

Table 2 Constraint equation

Check for minimum section modulus	G1=(Zb2/Zb1)-1
Pre-stressing force	G2=((p/Psf)-1)
Permissible tendon zone at support section	G3=((es/J)-1)
Permissible tendon zone at support section	G4=((es/K)-1)
Stresses at transfer stage at top	G5=((Ftt/Sgtr)-1)
Stresses at transfer stage at bottom	G6=(Sgbt/Fct)-1
Stresses at working load stage at top	G7= (Sgtw/Fcw)-1
Stresses at working stage at bottom	G8=(Ftw/Sgbw)-1
Check for ultimate flexural strength	G9= (Mu1/Mu2)-1
Check for shear stress	G10=((Tv/Tc)-1)

3. OPTIMIZATION METHOD

Mathematical Programming Techniques

Stochastic Programming Techniques

Statistical Methods

Mathematical Programming Techniques

1. Calculus Method
2. Calculus Of Variations
3. Nonlinear Programming
4. Geometric Programming
5. Quadratic Programming
6. Linear Programming
7. Dynamic Programming
8. Integer Programming
9. Stochastic Programming
10. Separable Programming
11. Multi Objective Programming
12. Cpm & Pert
13. Game Theory

Stochastic Programming Techniques

1. Stastical Decision Theory
2. Markov Processes
3. Queing Theory
4. Renewal Theory

5. Simulation Methods
6. Reliability Theory

Statistical Method

1. Regression Analysis
2. Cluster Analysis
3. Design of Experiments
4. Discriminate Analysis

The optimum cost design of I-Girder formulated in is nonlinear programming problem (NLPP) in which the objective function as well as constraint equation is nonlinear function of design variables. The various methods available for the solution of NLPP are compared in brief and the advantages and limitation of the chosen method is discussed. The various subroutines used in the program are also discussed.

Methods for the Solution of the NLPP

1. Method of Feasible Directions
2. Sequential Unconstrained Minimization Technique (SUMT)
3. Sequential Linear Programming (SLP)
4. Dynamic Programming

A. The sequential unconstrained minimization technique (SUMT)

In SUMT the constraint minimization problem is converted into unconstraint one by introducing penalty function. In the present work is of the form, *f*(x, r) is the penalty function *f*(x) is 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 value of r is reduced sequent rained and the sequence of minima obtained converges to the constrained minimum of problems as r ✹ 0.

A. Computer program

The present optimization problem is solved by the interior penalty function method. The 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.

4. CONCLUSIONS

The objective of this study is to investigate the appropriate optimization method to the minimum cost of a PSC I Girder. In view of achieving this objective it is decided to develop a computer code in MATLAB. After validating this computer code by comparing the results with analytical results, it is planned to carry out the economical and safe design.

1. It is possible to formulate and obtain solution for the minimum cost design for PSC I-Girder.
2. It is possible to obtain the global minimum for the optimization problem by starting from different starting points with the interior penalty function method.
3. Significant savings in cost over the normal design can be achieved by the optimization. However the actual percentage of the saving obtained for optimum design for PSC I-Girder depend upon the span of slab and grade of material.
4. Maximum cost saving of 14.25% for conventional design is achieved in PSC I-Girder 30m span of M50 grade concrete. Maximum cost saving of 9.81% for conventional design is achieved in PSC I-Girder 30m span of M60 grade concrete.
5. The cost of PSC I-Girder decreases with the increase in the girder depth.
6. The cost of girder is directly proportional to grade of concrete.

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