APPLICATIONS OF MATLAB IN OPTIMIZATION OF BRIDGE SUPERSTRUCTURES

Rajesh F. Kale[1], N.G.Gore[2], P.J.Salunke[3]

[1]*M.E Student, Civil Engineering Dept., M.G.M.'s College of Engineering & Tech. Kamothe, Navi Mumbai*
[2]*Professor, Civil Engineering Dept., M.G.M.'s College of Engineering & Tech. Kamothe, Navi Mumbai*
[3]*Professor, Civil Engineering Dept., M.G.M.'s College of Engineering & Tech. Kamothe, Navi Mumbai*

Abstract

Optimization is an act of obtaining the best results under given circumstances. In design, construction and maintenance of any engineering system engineers have to take many technological and managerial decisions at several stages. The ultimate aim of all such decisions is either to minimize the efforts required or to maximize the desired benefit. Optimization is a process of finding the conditions that give the maximum or minimum value of any function. Any engineering system or problem is defined by set of quantities and these quantities can be classified as design variables, constraints, and objective function. All these quantities collectively form a optimization problem and this problem can be solved with the help of MATLAB programming language. The optimization problem is characterized by having a combination of continuous, discrete and integer sets of design variables. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB we can analyse data, develop algorithms, and create models and applications. The language contains tools, and built-in math functions which enable us to explore multiple approaches and reach a solution faster than with spread sheets or traditional programming languages such as C, C++, java, Fortran etc. In this present study, cost optimization approach for various bridge superstructures is presented. The main objective function is to minimize the total cost in the design process of the bridge system considering the cost of materials. The cost of structural element covers cost of material and labor for reinforcement, concrete and formwork. Design constraints for the optimization are considered according to Standard Specifications for road bridges. The optimization process is done for different grades of concrete and steel. The comparative results for different grades of concrete and steel are presented in tabulated form.

Keywords: *Bridge superstructure, MATLAB, Structural optimization*

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1. INTRODUCTION

Transportation needs commensurate with infrastructural development which demands shortest routes to cover longer distances. Such short routes require crossing of number of obstacles such as rivers, railway lines and existing roads etc. Bridge structures are the only solutions for such problems. Bridges are essential and vital elements of any road network. The lack of bridge or failure of bridge can cause serious bottlenecks and dislocation of traffic resulting in unacceptably large economic losses to the country. A bridge may be defined as a structure providing passage over an obstacle without closing the way beneath. Various types of bridges are present today and different types of methods of construction of bridges are also available such as R.C.C., prestress, steel, composite bridges etc. The ultimate aim of any engineer is to select proper type of bridge and proper methodology so as to construct bridge with economy and with fewer efforts.

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. Bridge superstructure generally consists of girder, deck slab, parapet wall, kerbs and footpaths. In this study cost optimization approach for girder and deck slab is presented for various bridge superstructures. The structure is modelled and analyzed using the direct design method. Optimization problem is formulated is in nonlinear programming problem (NLPP) by SUMT. The evolution of bridges from the ancient times to present age is a continues process and is a result of human desire to use more and more improved methods and materials in order to build cheaper, finer and stronger bridges of any spans and of lasting quality. The search for further improvement is not over and experimentations for building cheaper, stronger and aesthetically better bridges for all times to come.

The method of cost optimization of bridge superstructures can be applied to any type of bridge superstructures such as I-girder, T-beam girder and box girder along with deck slab. The methodology for optimization is similar in all problems of optimization thus in this paper a single problem of cost optimization of R.C.C T-beam girder is presented. Referring to this solution any bridge superstructure can be successfully optimized.

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. Andres Guerra and Panos D. Kiousis (2006) demonstrated Design optimization of reinforced concrete structures. A novel formulation aiming to achieve optimal design of reinforced concrete (RC) structures is presented. Successful implementation demonstrates the abilities and performance of MATLAB's Sequential quadratic programming algorithm for the design optimization of RC structures.

2. OPTIMIZATION

Optimization is the act of obtaining the best results under given circumstances. In design, construction and maintenance of any engineering system engineers have to take many technological and managerial decisions at several stages. The ultimate aim of all such decisions is either to minimize the effort required or to maximize the desired benefit, since the effort required or the benefit desired in any practical situation can be expressed as a function certain decision variables. Optimization can also be defined as process of finding the conditions that give the maximum or minimum value of a function. The ever increasing demand on engineers to lower production costs to withstand competition has promoted engineers to look for rigorous methods of decision making, such as optimization methods, to design and produce products both economically and efficiency.

3. DESIGN VARIABLES

Any engineering system or component is defined by a set of quantities some of which are usually fixed at the outset and these are called as preassigned parameters. Some of which are variables during design processes and are called as design variables or decision variables. The various design variables considered in process of optimization of R.C.C. T-beam girder are

3.1) X1 = Depth of deck slab
3.2) X2 = Width of web
3.3) X3 = Overall depth of girder

4. DESIGN CONSTRAINTS

In many practical problems design variables cannot be chosen arbitrarily sometimes they have to satisfy certain specified functional and other requirements, the restrictions that must be followed to produce an acceptable design are collectively called as design constraints. These constraints depend on physical limitations. If the design meets the entire requirement placed on it, it is called a feasible design.The various design constraints considered in process of optimization of R.C.C. T-beam girder are

Constraint equations are:
4.1) Depth of deck slab constraint G1 = (dsmax/X1)-1< 1

4.2) Shear stress constraint for deck slab G2 = (Tv/Tc)-1< 1

4.3) Steel constraint for deck slab G3 = (AstminSLAB/Ast)-1 <1

4.4) Shear stress constraint for longitudinal girder G4 = (TvmaxIG/Tvlimit)-1 < 1

4.5) Shear stress constraint for cross girder G5 = (TvmaxCG/Tvlimit)-1 < 1

4.6) Steel constraint for longitudinal girder G6 = (AstminGIRDER/AstproLG)-1 < 1

4.7)Steel constraint for cross girder G7 = (AstminGIRDER/AstproCG)-1 < 1

4.8) Compressive stress constraint for girder G8 = (O1/Ocbc)-1 < 1

4.9) Tensile stress constraint for girder G9 = (O2/Ost)-1 < 1

4.10) Overall depth constraint for girder G10 = (Dmax/X3)-1 < 1

Where, dsmax= minimum depth of slab from bending moment calculations, Tv = nominal shear stress in slab, Tc = Permissible shear stress in slab, AstminSLAB = minimum steel required in slab, Ast = steel provided in slab from calculations, TvmaxIG = nominal shear stress in longitudinal girder, deff = effective depth of girder, Tvlimit = limiting shear stress in girder, TvmaxCG = nominal shear stress in cross girder, Tvlimit = limiting shear stress in girderAstminGIRDER = minimum area of steel required in girder, AstproLG = Area of steel provided in longitudinal girder from calculations, AstminGIRDER = minimum area of steel required in girder, AstproCG = Area of steel provided in cross girder, O1 = compressive stress in girder, Ocbc = permissible compressive stress in girder, O2 = Tensile stress in girder, Ost = permissible Tensile stress in girder, Dmax = maximum depth of girder.

5. FORMULATION OF OPTIMIZATION PROBLEM

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, deck slab reinforcement, concrete strength, materials of construction, reinforcement in cross girder and intermediate girders etc. By studying proper design procedures of R.C.C. T-beam girder we will get preassigned parameters, design variables or decision variables, design constraints, design vectors and objective functions. By using these all parameters we can convert normal design problem of R.C.C. T-beam girderinto optimization problem and this optimization problem can be solved with the help of various optimization techniques or software's which are available so as to achieve desired objective function, so as to optimize box girder. Optimization problem is formulated is in nonlinear programming problem (NLPP) by 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 $r \rightarrow 0$.The present optimization problem is solved by the interior penalty function method. Themethod is used for solving successive unconstrained minimization problems coupled with cubic interpolation methods of on dimensional search. The program developed S. S. RAO for SUMT is used for the solution of the problem. The program is written in MATLAB language.The various design variables and constraint equations used in analysis are explained as earlier.

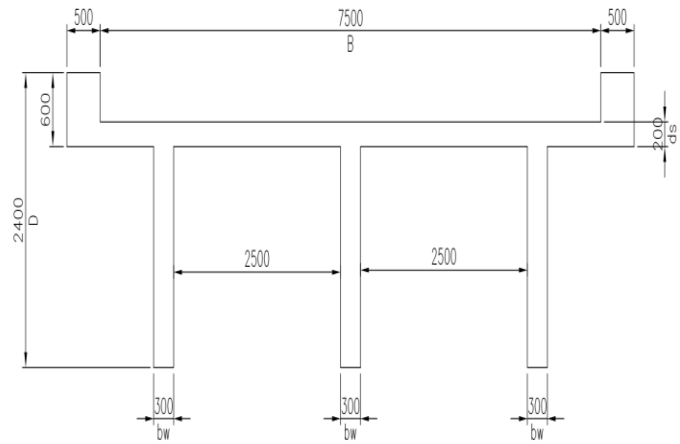


Fig 1 Cross section of R.C.C. T-beam girder

As shown in above figure X_1 = ds, X_2 = bw, X_3 = D

6. OBJECTIVE FUNCTION

The main objective inthe present optimization problem is to optimize R.C.C T-beam girder with deck slab system and also to formulate the problem properly in terms of optimization problem and so as to solve this optimization problem with the help of optimization techniques.Objective function to be satisfied is the cost of R.C.C. T-beam bridge deck whose main components are cost of concrete and steel. It is assumed that cost of steel, launching and casting formwork etc. are directly proportional to volume of concrete, hence all these costs are included in the rate of concrete.

Objective function can be expressed as:

CONCCOST = QC*RATECONC
STEELCOST = QS*RATESTEEL
TOTAL COST = CONCCOST+STEELCOST
Rate of objective function can be expressed as,
QC= Quantity of concrete in m^3
QS= Quantity of steel in Kg
RATECONC= Cost of concrete/ m^3
RATESTEEL= Cost of steel/ Kg

7. 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 $r \rightarrow 0$.
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.

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

8. VARIOUS METHODS OF OPTIMIZATION

Mathematical Programming Techniques **Stochastic Programming Techniques** **Statistical Methods**

8.1 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

8.2 Stochastic Programming Techniques

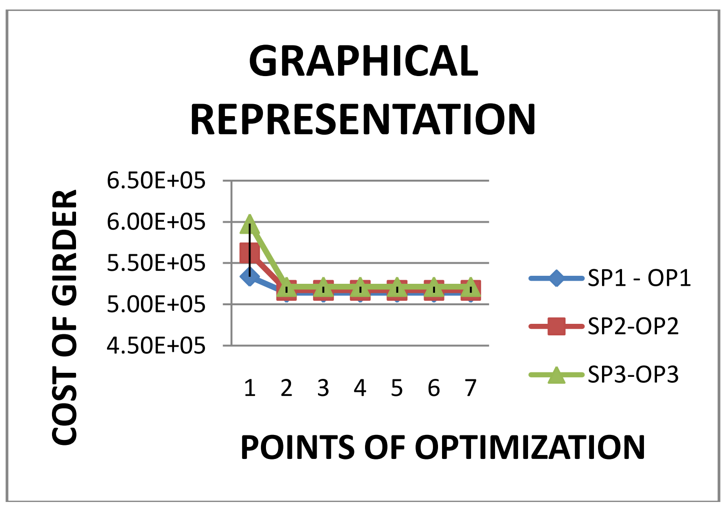
1. Stastical Decision Theory
2. Markov Processes
3. Queuing Theory
4. Renewal Theory
5. Simulation Methods
6. Reliability Theory

8.3 Statistical Method

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

9. ILLUSTRATIVE EXAMPLE

For different conditions and start from starting point and end with optimized point the result shown in graphical form as below, Typical format of graph



10. SUMMARY

The objective of this study is to investigate an appropriate optimization method for minimum cost of bridge superstructures. Parametric study with respect to different types of spans and grades of concrete and steel for combinations of girder superstructures has been carried out. The results of optimum design for girder has been compared and conclusions drawn. 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.

11. CONCLUSIONS

1. It is possible to formulate and to obtain solution for the minimum cost design for bridge superstructures with help of MATLAB and it can be suitable to any type of bridge superstructure.
2. In present study optimization technique for R.C.C. T-beam girder is presented and explained, similar technique can be applied to any bridge superstructure in order to optimize it.
3. It is possible to obtain the global minimum for the optimization problem by starting from different starting points with the interior penalty function method.
4. Interior penalty function method can be used for solving resulting non-linear optimization problems. Exterior penalty function method can be used for solving resulting non-linear optimization problems.
5. The minimum cost design of girder 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.
6. Actual percentage of the saving obtained for optimum design for girder depend upon the deck slab thickness, depth of girder, grade of steel and grade of concrete.
7. The cost of bridge superstructures increased rapidly with respect grade of concrete increases and grade of steel increases whereas cost decreases as the span of bridge reduces, also the cost of girder decreases with the increase in the girder depth.
8. 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 bridge superstructures depend upon the span of slab and grade of material.

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