Cost Optimization of R.C.C. T-Beam Girder

Rajesh F. Kale, N. G. Gore, P. J. Salunke

Abstract— In this present study, cost optimization approach of R.C.C. T-beam girder 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 each structural element covers that of material and labor cost for reinforcement, concrete and formwork. For a particular girder span and bridge width, the design variables considered for the cost minimization of the bridge system, are deck slab depth, width of web of girder and, girder depth, (i.e. X1, X2, X3 resp.) Design constraints for the optimization are considered according to IRC-21:2000 (Indian road congress) Standard Specifications. The optimization process is done for different grade of concrete and steel. The comparative results for different grade of concrete and steel is presented in tabulated form. The optimization problem is characterized by having a combination of continuous, discrete and integer sets of design variables. The structure is modeled and analyzed using the direct design method. Optimization problem is formulated is in nonlinear programming problem (NLPP) by SUMT. The model is analyzed and designed for an optimization purpose by using Matlab Software with SUMT (Sequential Unconstrained Minimization Technique), and it is capable of locating directly with high probability the minimum design variables. Optimization for reinforced concrete R.C.C. T-beam girder system is illustrated and the results of the optimum and conventional design procedures are compared.

Index Terms— Deck slab, R.C.C T-Beam girder, Reinforced Concrete, Structural optimization.

I. INTRODUCTION

Reinforced concrete is well suited for the construction of highway bridges in the small and medium span range. These bridges gained popularity due to their versatility in construction and economy in cost and maintenance; also they can be cast in any convenient shapes and forms to meet architectural requirement as well as can utilize locally available materials such as stone chips, gravels, sand etc. it can be cast at site thereby eliminating carriage of heavy bridge components hence are widely used in construction of small to medium span bridges. Slab and girder bridges are used when the economical span limit of solid slab bridges is exceeded. T-beam bridge is by far the most commonly adopted type in the span range of 10 meters to 30 meters. The structure so named because the main longitudinal girders are designed as T-beams integral with the part deck slab, which is cast monolithically with the girders. T-beams bridges are usually cast-in-situ.

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.

Iqbal motiwala in 1969 described, Design of simple span R.C.C. T-beam Bridge by working stress design method and by ultimate strength design method – and economical comparison of both methods. The aim of the project was to simply know which method requires more material when all other factors such as length, width of bridge, other cross-sectional properties, and the site of the bridge as well as difficulties arising during erection are assumed to be constant. Also various factors affecting life of a bridge such as continued application of moving loads, control of cracking and deflection, stresses distributed in steel and concrete etc. were studied and advised how to control it.

II. 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.

III. 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 pre-assigned 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:

X1 = Depth of deck slab.
X2 = Width of web.
X3 = Overall depth of girder.

Manuscript received January 15, 2014.

Mr.Rajesh F. Kale, (M.E. student) Civil Engg. Dept., M.G.M's. College of Engineering & Tech., Kamothe, Navi Mumbai, India
Prof. N. G. Gore, (Guide) Civil Engg. Dept., M.G.M's. College of Engineering & Tech., Kamothe, Navi Mumbai, India
Prof. P. J. Salunke, (Guide) Civil Engg. Dept., M.G.M's. College of Engineering & Tech., Kamothe, Navi Mumbai, India

IV. 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 constraint equations considered in process of optimization of R.C.C. T-beam girder are

1) Depth of deck slab constraint
   G1 = (dsmax/X1)-1 < 1
2) Shear stress constraint for deck slab
   G2 = (Tv/Tc)-1 < 1
3) Steel constraint for deck slab
   G3 = (AstminSLAB/Ast)-1 <1
4) Shear stress constraint for longitudinal girder
   G4 = (TvmaxIG/Tvlimit)-1 < 1
5) Shear stress constraint for cross girder
   G5 = (TvmaxCG/Tvlimit)-1 < 1
6) Steel constraint for longitudinal girder
   G6 = (AstminGIRDER/AstproLG)-1 < 1
7) Steel constraint for cross girder
   G7 = (AstminGIRDER/AstproCG)-1 < 1
8) Compressive stress constraint for girder
   G8 = (O1/Ocbc)-1 < 1
9) Tensile stress constraint for girder
   G9 = (O2/Ost)-1 < 1
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 girder, AstminGIRDER = 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.

V. 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 girder into 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 → 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 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.

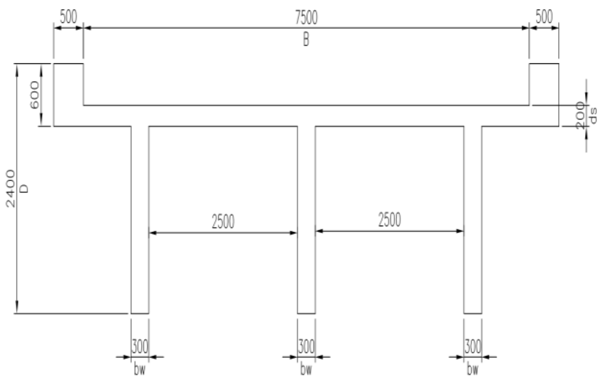

Fig. 1 **Cross-section of bridge deck girder**

As shown in above figure X1 = ds, X2 = bw, X3 = D

VI. OBJECTIVE FUNCTION

The main objective in the 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 m3
QS= Quantity of steel in Kg
RATECONC= Cost of concrete/ m3
RATESTEEL= Cost of steel/
Kg

VII. VARIOUS METHODS OF OPTIMIZATION

Mathematical programming techniques	Stochastic process techniques	Statistical methods
1.Calculus method 2.Calculus of 3.variations Non-linear 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.Network problems- CPM & PERT 13.Game theory 14.Simulated annealing 15.Genetic algorithms Neural networks	1.Statistical decision theory 2.Markov processes 3.Queuing theory 4.Renewal theory 5.Simulation 6.methods Reliability theory	1.Regression analysis 2.Cluster analysis 3.Design of experiments 4.Factor analysis

Table.1 Various Methods of optimization

VIII. ILLUSTRATIVE EXAMPLE

For different conditions and start from starting point and end with optimized point the result shown in graphical form as below, the below fig illustrates graphical representation of 12m span M25 fe415 Typical format of graph is shown below

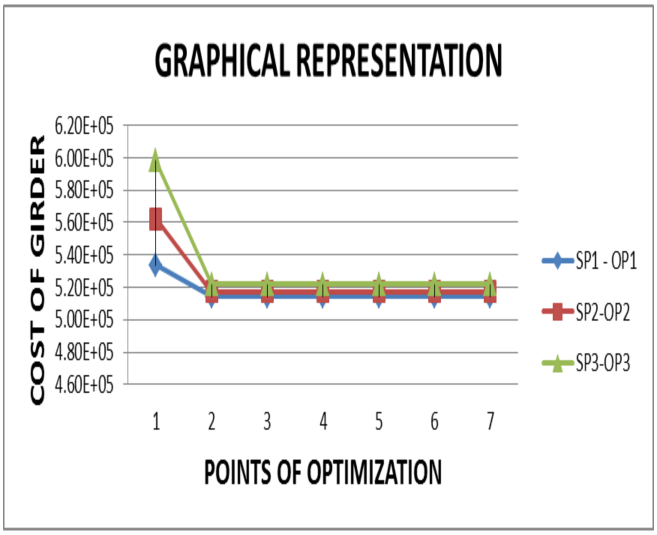

Fig.2 Graphical representation

IX. SUMMARY

The objective of this study is to investigate the appropriate optimization method of the minimum cost of a R.C.C. T-beam girder. Parametric study with respect to different type of spans and grade of concrete and steel for combinations of R.C.C. T-beam girder sections have been carried out. The results of optimum design for R.C.C. T-beam 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

X. CONCLUSION

1. It is possible to formulate and to obtain solution for the minimum cost design for R.C.C. T-beam girder.
2. 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.
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. The minimum cost design of R.C.C. T-beam 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.
5. Actual percentage of the saving obtained for optimum design for R.C.C. T-beam girder depend upon the deck slab thickness, depth of girder, grade of steel and grade of concrete.
6. The optimum cost for a R.C.C. T-beam girder is achieved in M25 grade of concrete and fe415 grade of steel.
7. The cost of R.C.C. T-beam girder unit increased rapidly with respect grade of concrete increases and grade of steel increases whereas cost of R.C.C. T-beam girder 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 R.C.C. T-beam girder depend upon the span of slab and grade of material.
9. The cost of girder is directly proportional to grade of concrete.

ACKNOWLEDGEMENT

I take this opportunity to thank staff members of Civil Engineering Department, Mahatma Gandhi Mission's College of Engineering and Technology, Kamothe, library staff for their assistance useful views and tips. A word of thanks is also reserved for all my batch mates for their selfless help, support and entertaining company.

REFERENCES

1. IRC: 21-2000-"Standard Specifications and Code of Practice for Road Bridge Section III – Cement Concrete (Plain and Reinforced - Second Revision)", Indian Road Congress.
2. IRC: 06-2010-"Standard Specifications and Code of Practice for Road Bridges, Section II - Cement Concrete (Loads and stresses – 5th Revision)", Indian Road Congress.
3. IS: 456-2000 – "Code of Practice for Plain and Reinforced Concrete", Indian Standards Institution.
4. Ministry of Shipping and Transport (Road Wings), "Standard Plans for Highway Bridges, Volume III", Concrete T-beam Bridges.
5. Krishna Raju N., "Advanced Reinforced Concrete Design", 2nd edition.
6. Ramamrutham, S.,"Design of Reinforced Concrete Structures", Dhanpat Rai & sons, New Delhi, 1982.
7. Victor D.J. – "Essentials of Bridge Engineering" – Oxford & IBH Publishing Co., Calcutta.
8. Rakshit K.S. – "Load Distribution in Bridge Decks: A comparative Study" Construction Engineers of India, 1966 State Engineers Association, Calcutta.
9. Dr. V. K. Raina – "Raina's Concrete Bridge Practice Analysis, Design & Economics, Third edition", Shroff Publication New Delhi 2009.
10. "Engineering Optimization" by S.S. Rao.
11. M. Z. Colin and A. J. Mac Rae "Optimization Of Structural Concrete Beams", Journal Of Structural Engineering - American Society of Civil Engineering, pp.1573-1588 (1984).
12. Iqbal motiwala "Design of simple span R.C.C. T-beam bridge by working stress design method and ultimate strength design method- an economical comparison of both methods", Brigham young university 1969.