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SHAPE AND COST OPTIMIZATION OF POST-TENSIONED I-GIRDER

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Abstract*— Nowadays in India most of the bridge girders are designed as prestressed concrete (PSC) girders. The reason behind wide use of PSC girders is its facileness of fabrication, modest self-weight, structural proficiency and reasonable maintenance etc. Now in order to use PSC girders over reinforced concrete girders or steel girders, it is mandatory to use the materials more economically as compared to RCC or steel girders. This paper presents an optimization of PSC I-girder with respect to economical use of materials. The intent of the present study is to lessen the total cost of girder with respect to materials in the design process of PSC I-girder. In order to optimize the cost, the c/s parameters of girder namely width of web, width of top flange, width of bottom flange, girder depth, thickness of top and bottom flange are considered as variables in the optimization program. The whole design of the optimized girder is done using Matlab function with nested for loops and the designed section is checked against certain constraints as per IS:1383-1980 and American association of State Highway and Transportation Officials (AASHTO) specifications. Optimum design of I-girder is done by the Matlab program which leads to give the optimum cost of the girder.

Keywords: shape optimization, cost optimization, PSC I-girder, Program, Matlab.

I. INTRODUCTION

In highway bridges of short to moderate span (about 20m to 40m) post-tensioned I-girders are extensively used. In reinforced concrete sections, the placement of gravity load activates the reinforcing steel. However one the tensile capacity of the concrete is exceeded, the cracks appear in the concrete. Now in case of prestressed concrete, the steel is activated prior to gravity loading through prestressing the reinforcements. Hence the cracks at service load stage are prevented. Also as compared to reinforced concrete sections, the high strength materials are used more productively by the prestressed concrete sections.

In order to design a presterssed I-girder, a bridge engineer follows an iterative process. This design is dine as per the IRC loading and checked as per IS specifications. If the design is not competent, the above process is recapitulated by modifying its c/s parameters. This design process is time consuming and also requires a lot of experience in order to decide the c/s parameters, still the resultant section obtained is not economical. Also the materials are not getting used to their full efficiency. Thus the traditional design process exclusively depends on the designers experience, creativity and results into high cost, time consumption and human efforts.

The optimum design is one of the solution for the construction of post-tensioned I-girder with higher efficiency. An optimization technique saves the human efforts of iterative design process and gives reliable and cost efficient results.To derive the user defined function on MATLAB to design and optimize the girder c/s. The function will be based on designers inputs and based on those inputs the program will design the I-girder and to find out suitable grade of concrete as well as suitable span for optimum design of the PSC I-girder.

Devashree U Sawant (2014) presented cost optimization of girder using Sequential Unconstrained Minimization Technique (SUMT) in Matlab software which is capable of locating the minimum design variables with high probability which conclude the use of M-50 grade of concrete for optimization of a girder. Rana et al (2010) presented a global optimization algorithm named Evolutionary Operation (EVOP) and a comparison was made between live project of Teestabridge and the optimum design from his program. The comparison shows 35% of savings. Salman Saeed (2015) has done cost and performance optimization of post-tensioned I-girder and has obtained the relationship between slab thickness and total bridge width also between spacing of girders and total bridge width using optimization technique.

II. OPTIMIZATION PROGRAM

The program is written on Matlab to design the I-girder as per IS specifications. To optimize it the program is set into nested for loop which will do the iterative design process of deciding optimum c/s parameters. Further the cost of the girder is calculated by the program.

A. Program Inputs

In this program the inputs are given by the designer which will be the design parameters obtained by the design of deck slab and the loadings on the slab as per the IRC 18-2000. The design of the girder will be done on the basis of moments transferred from the slab to the girder.The designer has to give following inputs to the program in order to get optimized section shown in Table I.

TABLE I
INPUTS OF THE PROGRAM

L	Effective span
Mq	Live load bending moment
Mg1	Dead load bending moment (Excluding self-weight)
Fcu	Cube strength of concrete
Fci	Cube strength of concrete at transfer
Ft	Tensile strength of concrete
Vq	Shear force due to Live Load
n	Prestress loss ratio
Fu	Characteristic tensile strength of prestressing wires
Vg1	Shear force due to Dead Load (Excluding self-weight)

The program will run under different variable parameters of c/s for the above values and will give the value of the c/s parameters.The nomenclature of the output c/s parameters is shown in the Fig 1.

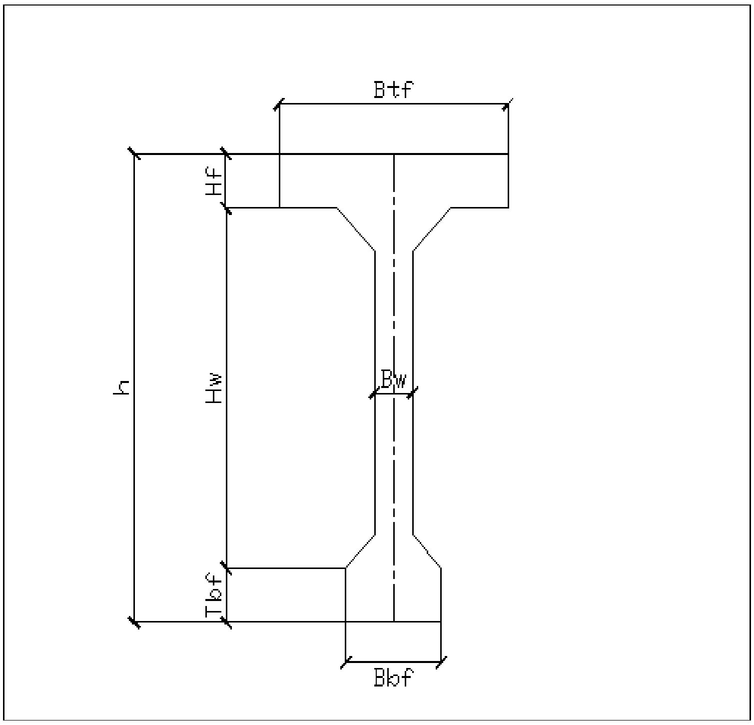

Fig. 1 Nomenclature of I-girder

The value of width of web is kept constant in the program to 200mm. The variable parameters of c/s are shown in Table II.

TABLE II
RANGE OF VARIABLES

Parameters	Range (in mm)
Thickness of top flange (Hf)	130 to 500
Thickness of bottom flange (Tbf)	250 to 600
Width of bottom flange (Bbf)	250 to 800

B. Constraints in Program

The section obtained by these parameters will be checked for different conditions like section modulus, stresses at top and bottom of the section at working and transfer stage flexure, shear, deflection etc. If the section satisfies all these criteria then the parameters are selected for the optimization by the program. From all these parameters, the parameters which give least c/s area are selected by the program. In the end the program will display the value of the optimized parameters of c/s, optimized c/s area, optimized cost of girder.

III. OPTIMIZATION MODELS

Two models are optimized by this program for spans of 20m, 30m and 40m and for different grade of concrete varying from M-30 to M-60. The percentage optimization in cost as well as c/s area is computed. From the results, the suitable span and grade of concrete will be computed for the design of the PSC I-Girder.

IV. RESULTS

The results obtained from program for both the models are tabulated in spread sheets and graphs are drawn to see the suitable grade of concrete as well as suitable span for the optimization purpose. The percentage optimization for span of 20m, 30m and 40m are compared to decide the suitable span for optimization. The graphical comparison of percentage optimization for these spans for both the models is shown below in Fig 2 and Fig 3.

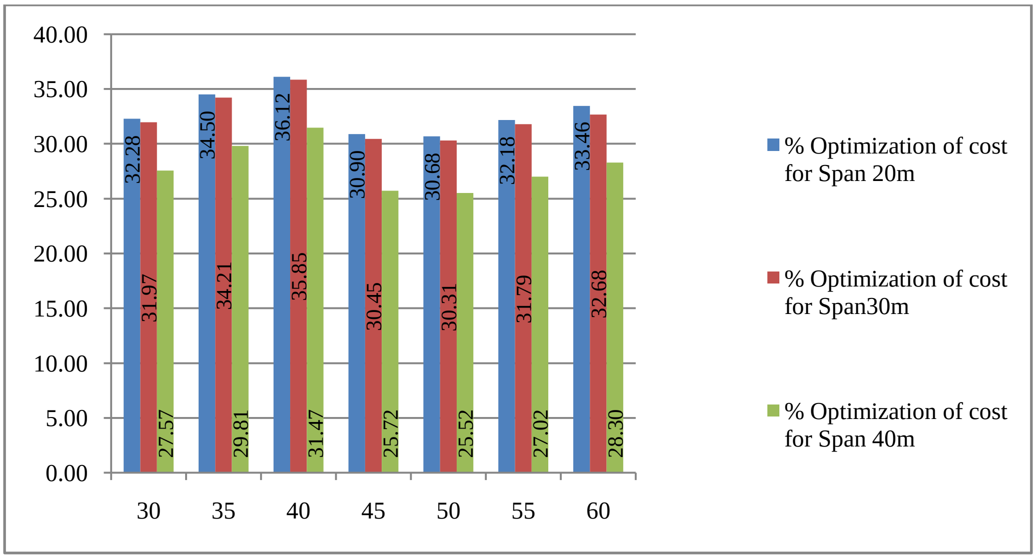

Fig 2 Graphical comparison of percentage optimization for different spans and for different grade of concrete for model-1.

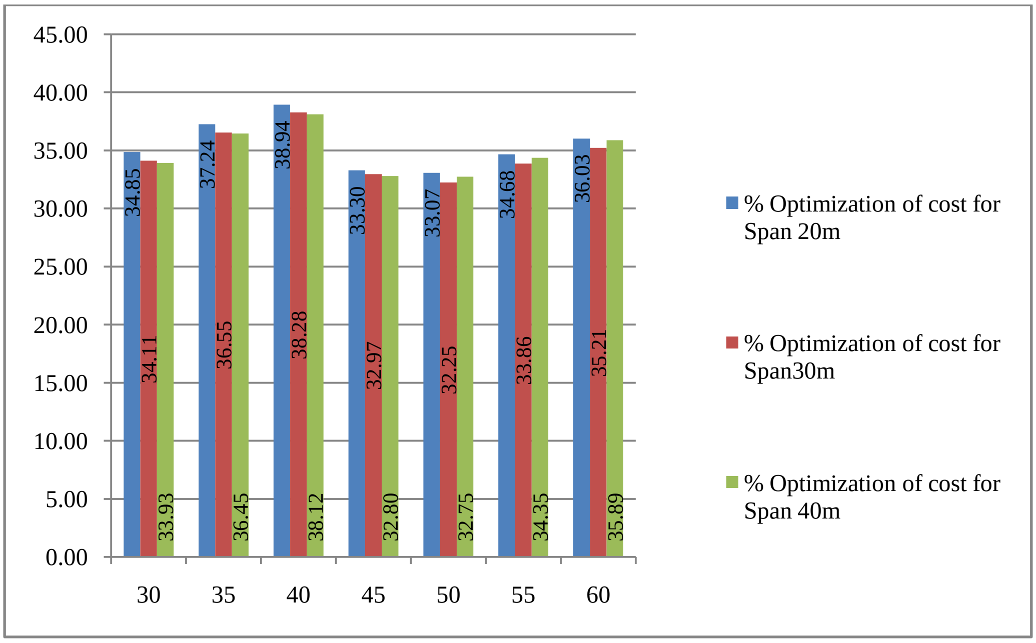

Fig 3 Graphical comparison of percentage optimization for different spans and for different grade of concrete for model-2.

Maximum optimization is seen for span of 20m and for M-40concrete grade. The variation of cost for both the models according to the grade of concrete for span of 20m is shown below on Fig 4 and Fig 5.

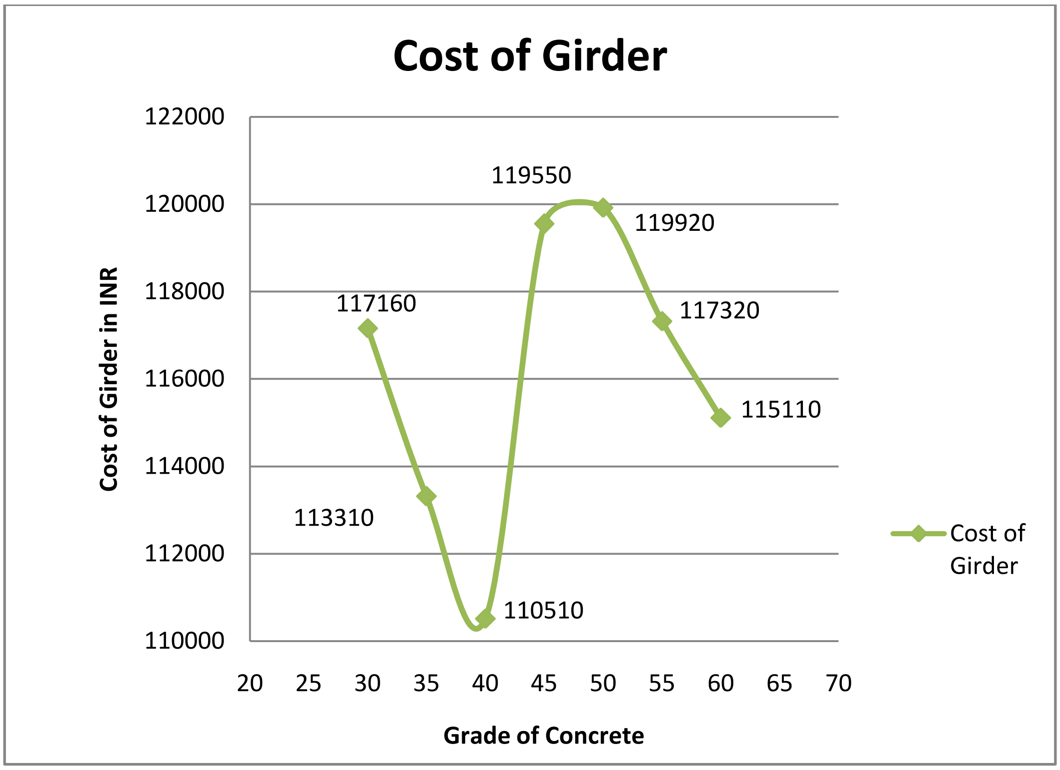

Fig 4 Cost variation of model-1 for span of 20m according to varying concrete grade.

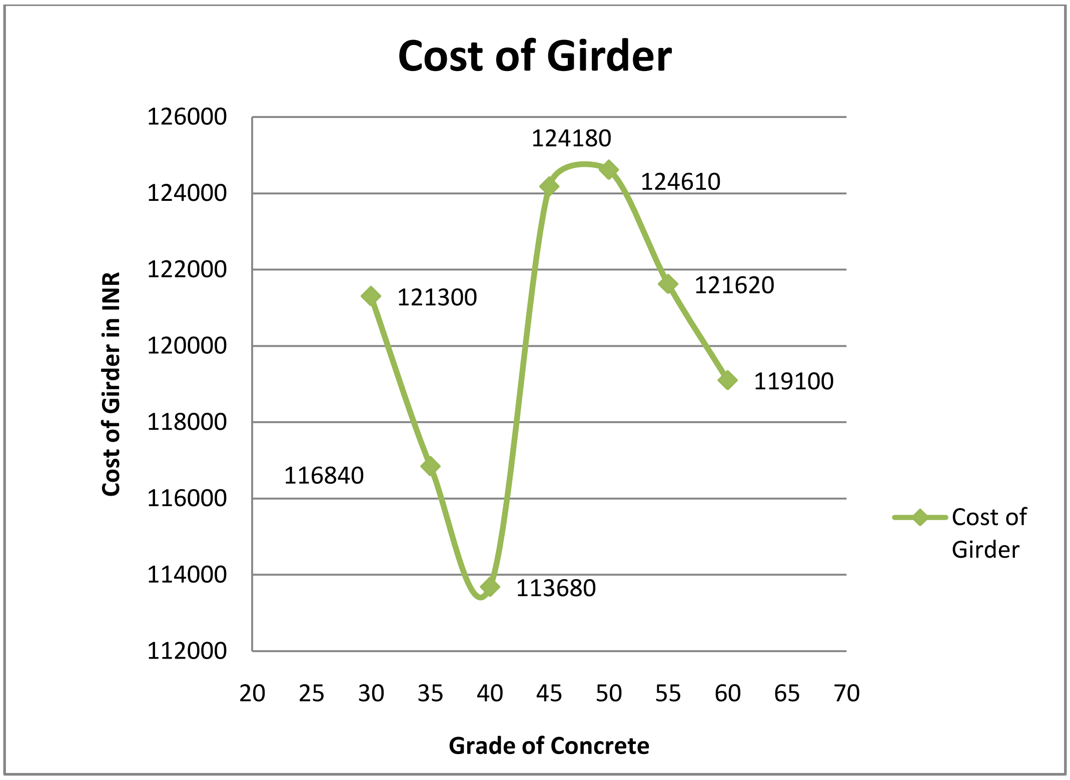

Fig. 5 Cost variation of model-2 for span of 20m according to varying concrete grade.

V. CONCLUSIONS

Both models are analysed by the optimization program and the results are compared on the spread sheets. Following conclusions are drawn from the results:

- The depth of the girder as well as the C/S area of the girder goes on decreasing from M-30 to M-60 grade of concrete for all the spans, while other C/S parameters remains the same.
- Maximum optimization of depth is obtained for M-60 grade of concrete.
- Maximum optimization in C/S area is obtained for M-60 grade of concrete.
- The cost of the girder goes on decreasing from M-30 to M-40 and increases for M-45 and M-50 grade and again it decreases for M-55 and M-60 grade for all spans.
- Maximum optimization in cost is obtained for M-40 grade of concrete and for the span of 20m.
- An increase in number of cables is observed after M-40 grade of concrete for all the spans.
- The total cost of optimized girder comprises of 38 to 46 percent of cost of concrete and 62 to 54 percent of cost of steel.
- Minimum deflection is observed for the span of 20m and higher deflection is observed for span of 40m.
- Cost of steel increases with decrease in the girder depth.
- Percentage optimization of cost goes on decreasing with increase in the span length.

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