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Optimization of Prestress U-Tub Girder of Lahore Orange Line Metro Train

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Abstract — *This research is based on the design and analysis of prestress girder and then cost optimization is performed using optimization technique. Constraints are set in optimization technique in order to achieve design which are feasible. Two different types of constraints are set; one is based on the restrictions on design variables whereas the other depends on the design variables called implicit constraint, which are formulated using stresses and flexural strength requirements. A computer programming code is established for design and analysis of girder in separate subroutine whereas for optimization another subroutine is developed. Both of them are then linked together to get the final result which are the cost effective design.*

Keywords*-girder; prestress; optimization; constraint; cost effective; visual basic*

I. INTRODUCTION

The orange line of the Lahore metro is a part of China-Pakistan Economic Corridor (CPEC). It is a 27 km long fast transit line which is in the process of construction in Lahore, Pakistan. Out of 27.1 km, around 25 km of the project will be elevated, whereas the remaining will be below the ground. There will be a total of 36 stations whereas initially the whole capacity of passengers is estimated to reach 250,000 daily which will rise to 500,000 travelers per day after three years when it is fully functional., The train will stop at every station for about 20 seconds.

The cost optimization of Pre-stressed girder is noticeably change from other structures because of different characteristics. The Pre-stressed girder comprises of different components which directly effects it's all cost, which contains the concrete cost, reinforcement steel cost and the prestressing strands cost. Therefore, in design of pre-stressed girder the cost effective design is not similar as the optimum weight design. In fact, the cost of pre-stressed girder comprises of usage of concrete, prestressing strands and the steel reinforcement which group together and effect the total cost of the structure and optimize it after satisfying all the design constraints. It is very hard to find cost effective design of a precise and simple reinforced concrete structure of a little garage by skill designer, (Burge and Schneider, 1994). Optimization techniques can be used to find a best possible design which are economical and safe also.

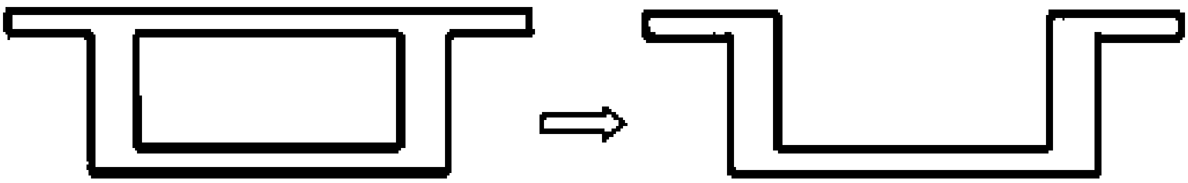

Figure 1. cross-section of Box girder and U-shaped girder

II. Methodology

A software will be developed for the optimization of girder. Three main steps are included in the whole process of optimization.

1) An analysis and design of girder is performed separately and coded in software
2) Code for optimization is developed
3) Both the codes are linked together to get the final output which is the optimized design

Some terminologies which are involved in Optimization methods are as follow.

2.1. Design Variables.

Design variable are those which control the overall cost of the girder and it is varying throughout optimization problem until optimized design is evaluated, which are feasible.

The design variable contains dimensions of the girder, number of prestressing cables and steel.

2.2. Constraints.

Two types of constraints are generally involved in optimization problem.

Explicit and Implicit constraints. Implicit constraints are the restriction on the design variables whereas implicit constraint directly or indirectly related to design variables.

The implicit constraints are mathematically formulated as
$g_j \leq 0$ where j= 1,2,3, 4,………….,m
m= Number of implicit constraints.
Whereas g represents implicit constraints which is either constants or dependent functions of the explicit independent variables $x_1, x_2, x_3, x_4 \ldots\ldots x._n$

2.3. Objective value.

The objective value is the output we get at the end of optimization of girder. In this study the objective value is the cost of the girder which comprises of cost of concrete, cost of steel reinforcement and cost of cables.

Cost function = Cost of concrete + cost of steel + Cost of Cables

III. Analysis and Design of Girder

The girder is design for metro train loading. Both the flexural strength and the shear strength of the girder are calculated and then compared with its respective demands coming from the external applied loads.
Programming language Code is developed for analysis and design of girder which takes place through conventional method. The girder is considered as simply supported. The moment and shear due to different loads are formulated in programming language in a software in order to get the desire result. The live load moments and shear are calculated from influence line using moving load analysis for simply supported beam.
Design formulations of prestress girder are also coded in programming language.

Iv. Constraint formulation

4.1. Top fiber stresses at transfer

g(1) = (f_top - f_limit) <= 0

4.2. Bottom fiber stresses at transfer

g(2) = (f_bottom - f_limit) <= 0

4.3. Flexure strength

g(3) = (Mu – Mn) <= 0

4.4. Shear strength

g(4) = (Vu – Vn) <= 0

V. Optimization Procedure

There are two steps involve in optimization process
In first step there is a module for calibration of analysis and design procedure. The logic diagram for calibration of analysis and design module is as follow.

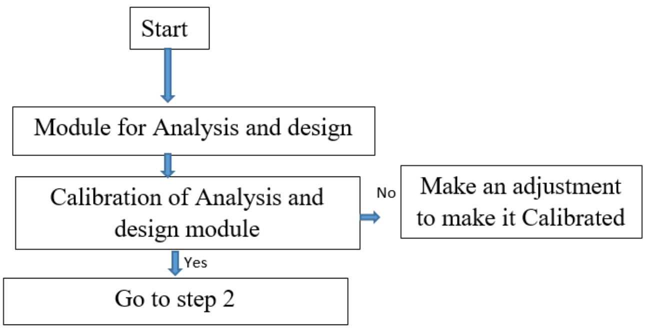

Figure 2: Logic diagram for Calibration of Analysis and design module

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After successfully calibrating the analysis and design module, the optimization phase started. Initially a design points are generated and selection of feasible design points takes place, then further proceed to objective value evaluation and the process stops when termination criteria reached. The logic diagram for optimization phase is as follow

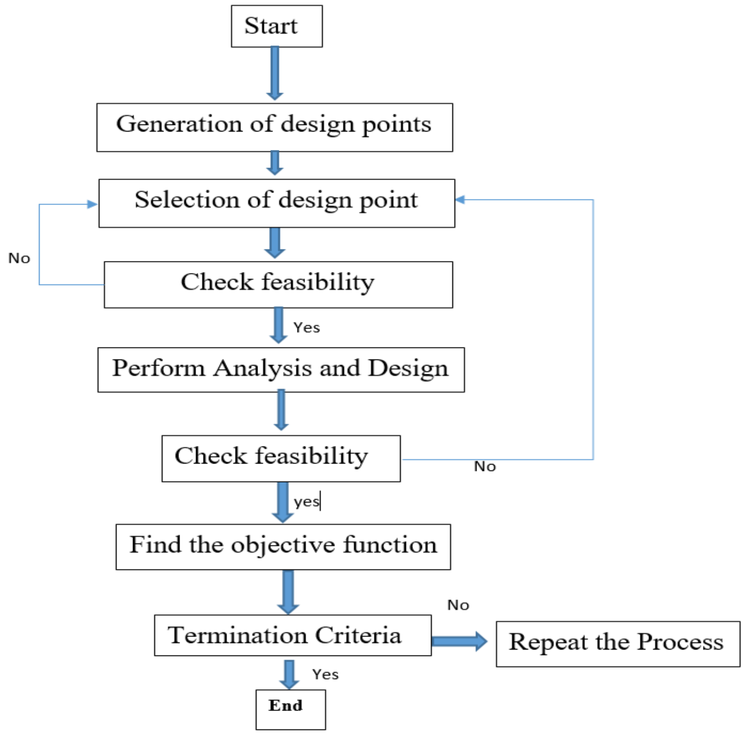

Figure 3: Logic diagram for Optimization process

VI. Results Evaluation of optimization problem

After successfully running the optimization model, the optimized objective value is evaluated after 400 iterations and then it is compared with the initial design cost. Also the fiber stresses in each iteration is checked against its respective limiting value.

Optimized cost = 1.5 million Pkr

Initial cost = 19 million pkr

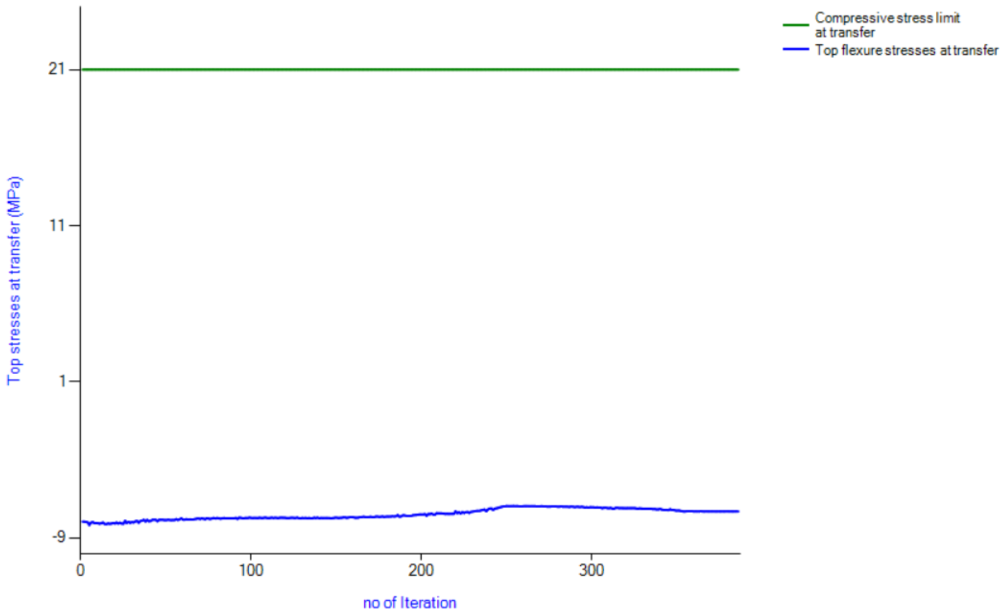

Figure 4. History of Top fiber stresses at transfer

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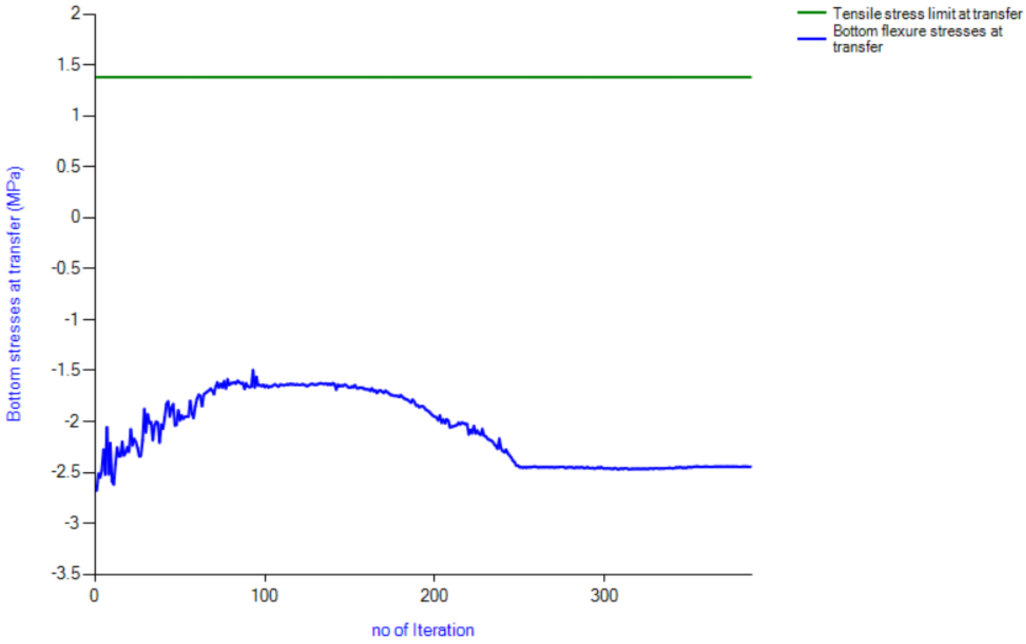

Figure 5. History of bottom fiber stresses at transfer

VII. Conclusions

After successfully running the optimization data, it was concluded that

- The optimized objective value is 21.06% less than the cost of initial design.
- This procedure can be adopted in order to get rid of conventional design methods which are tiresome and it is not necessary that the results getting through conventional method are optimize.
- Optimized design lead to considerable cost saving as compared to conventional design method.
- Optimization methods can effectively search for optimized design in a given space.
- Optimized design also leads to lighter structure.

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