Optimization of Steel Trapezoidal Box-Girders Using Genetic Algorithm

Abbas H. Mohammed
University of Diyala, Civil Engineering Department, Diyala, 32001, Iraq
*Corresponding author: abbas_mohammed_eng@uodiyala.edu.iq

Abstract:
The goal of the structural design is to select sizes of member with an optimum proportion of the overall structural geometry in order to achieve the lowest initial cost design. Traditional steel box-girders, generally made of two plate flanges, two webs and a number of internal diaphragms, were used in many different fields, such as the structural, architectonical and bridge engineering industries. This study aims to establish a three-dimensional finite element model to minimize the total volume of a steel trapezoidal box-girder. The finite element ANSYS program package was used to determine the optimum total volume of the steel trapezoidal box-girder. ANSYS program has been coupled to MATLAB software. The genetic algorithm method of optimization is considered. In this analysis, the objective function is the total volume minimization. The design variables are the top flange width, bottom flange width, top flange thickness, bottom flange thickness, web height and web thickness. The constraints in this study include normal stress, shear stress and the displacement. The results of optimization for box-girder show a reduction in the total volume of a steel trapezoidal box-girder of about 38%.

Keywords: finite element; ANSYS; optimization; trapezoidal; steel girder; genetic algorithm.

1. Introduction

When design a bridge, the engineers will consider several requirements and considerations. A bridge that must meet to all design codes is necessary for its serviceability and safety, and coincidental consideration of the other design factors. In general, the bridge was designed to select the members and structural geometry so that minimum cost were achieved.
Optimization shall be a method that obtains the finest possible values of the status variables under the defined constraints and with a set of objective functions.

A structural design which maximizes reliability or reduces overall costs or any specific objective function is the most optimization approach. Science, Engineering, and business all have problems to be optimized [1].

In the literature numerical studies of the various kinds of steel bridges have been carried out subject to different loads and boundary conditions [1-7]. Numerical research has proposed finite-element designs of steel girders have been developed for better analyse and understand the stability and behavior of different girders [8]. Additional researchers have also developed theoretical and computer modeling for optimal structural design [1, 6, 8, 9-12].

In the last three decades heuristic approaches have been rapidly developed to solve optimization problems. Most of these approaches are intuitive and without theoretical support. However, Genetic Algorithm (GA), simulated annulation and tablu search are general methods of finding the best solution.

Sharifi and Paik[4] developed a procedure for the ultimate reliability of box girder bridge in the context of plate degradation due to general corrosion . The work involves selection and reliability analyses of the selected bridges as well as developing resistance patterns for corroded steel-box girders, load models, reliability analysis and reliability profiles that are dependent on time, including deteriorations of corrosion. The results can be used for the estimate of the optimal reliability maintenance and the service life of the deteriorating steel girder bridges.

Topkaya [5] studied the girders behavior during construction. An outline of concrete- steel interface behavior is presented at early ages of concrete as well as an analytical tools to estimate the reactions of semi-concrete systems. Two bridges are presented during construction field monitoring. The results were compared with theoretical predictions obtained from program developed specifically in this study in order to address shortcomings with current analysis tools.

Shin et al.[6] derived load carrying curves for the rehabilitation and repair of bridge members and carried out the optimal design of the girder bridge consisting up of steel box-girder, concrete deck and pier design that took account of the cost of the life-cycle. The optimization process is used for the design of low cost bridge members. The objective is the annual cost. Although different cost factors cannot be reliably taken into consideration, the results show that certain cost factors affecting by the various environment conditions and uncertainty should be taken into consideration.
Manoharan and Shanmuganathan [15] used four different mechanisms of search of virtual annealings, genetic algorithms, tabu search and branch and bound technique to design optimization of three truss problems and compare them. They concluded that all three heuristic methods of search simulated annealing, tabu search and genetic algorithms, worked well and delivered an acceptable solution within a timeframe.

The finite element modelling for the optimization of the steel trapezoidal box-girder was developed by Mohammed and Abdul-Raszaq (17). The finite element program ANSYS was used to find the optimal area of section the girder. The sub-problem approximation method is considered. The sub-problem method is one of the methods that in-built within the ANSYS program. In this study, total volume and strain energy of the steel box-girder are used as objective functions. The design variables consist of the width and thickness of the flanges and the height and thickness of the web of the girder. The results show that the optimum sectional area for strain energy optimisation is 6 percent higher than the optimal area for volume optimization.

In this paper the finite element ANSYS program package was considered to analyze and optimize Steel Trapezoidal Box Girder (STBG). Three dimensional finite element model was developed. The optimal girder volume was determined. The research was carried out with ANSYS program. ANSYS program has been coupled to MATLAB software. The MATLAB software helps to finite element model using a text file to automate the methodology for optimization. In this analysis, the objective function is total volume minimization.

2. Finite Element modeling
The ANSYS [13] computer program is considered to analyze and optimize the STBG. 4-node shell element is used in order to model the STBG in finite element. The STBG was modeled by 4-node Shell181 element. The shell element has 4- nodes at each node with 6- degrees of freedom: three rotations in x-axis, y-axis and z-axis and three translations in x-axis, y-axis and z-axis direction. For linear and non-linear analysis the element is used. It also has plasticity, stress stiffening and large deflections [13].

In the analysis of ANAYS, the properties of the material have a significant role. The precise values of material properties must be inserted in the ANSYS software as data. In this analysis, the bilinear stress curves for steel are used in this research.

3. Optimization of STBG using genetic algorithm.
In this research, seven design variables are considered. The design variables are BFW, which is the bottom flange width, BFT that is the bottom flange thickness, TFW, which is the top flange width, TFT, which is the top flange thickness, WT that is the web thickness and WH, which is the web height of the girder as shown in Figure 1.

![Cross section of STBG](image1)

**Figure 1. Cross section of STBG.**

The aim of the optimization procedure is to optimize the total volume of STBG. The objective functions used in this analysis is minimization of the volume of the STBG. The constraints include normal stress and shear stress in steel and mid-span displacement. In this analysis, the proposed STBGs are simply supported. Figure 2 shows the boundary conditions.

The mesh and loading considered for the modeling the STBG are shown in Figures 3.

![Loading and geometry for the proposed STBG](image2)

**Figure 2. Loading and geometry for the proposed STBG**
3.1. Optimization strategy

Holland implemented genetic algorithms in the 1960s for the first time. In his book "Adaptation in natural and artificial systems" (Holland [18]) he developed the algorithm in the 1970s and outlined the results of his work. Genetic algorithm is a technology of numerical optimisation inspired by natural laws.

The aim is to minimize the total amount of STBGs under the allowable limiting the stress. The ANSYS program was used to optimize the STBGs. The program ANSYS was linked to the MATLAB software. The MATLAB software helps to automate the optimization methodology with the ANSYS application using a text file. For the pairing of ANSYS MATLAB, a line-code was used. A whole model can be created and solved either by choosing on the various menus or through the ANSYS parametric design language.

The ANSYS parametric design language provides the main advantages of model designing and solution. The model can be described as variables and a parametric model can be established. Figure 4 shows each stage optimization loop and output. It is shown that the couples between ANSYS program and MATLAB software based on overwritten text files in any loop. In one folder all written files must be saved.
3.2. Optimization result

Table 1 illustrates optimization result obtained by ANSYS program and MATLAB software interfacing with genetic algorithms method. Directly from the MATLAB software toolbox, the optimal values of all design variables were given. The optimum value is also shown. The toolbox also shows the number of iterations. Table 1 displays optimized parameters for the STBG. The result of optimization shows that a 38 % reduction in the total volume of STBGs is achieved by interfacing between MATLAB and ANSYS for the given design constraints.

In Figure 5, the evolution of the best total volume of STBG versus the number of iteration of genetic algorithm optimization method is shown. From this figure, three distinctive zones can be identified. The first consists of the first to fifth iterations, which are characterized by a relative high total volume of STBGs close to the initial total volume of STBGs (1174094391 mm$^3$). The second is the incertitude zone between 5th and 9th iterations and the third zone in which total volume value is stable, which is 723440795 mm$^3$. This optimization processes reduces the total volume of the steel box-girders by almost 38 %.
Table 1: Objective function, design variables and constraints for the volume minimization of the STBG.

| Objective function | Minimum | Initial value | Maximum | Optimum    |
|--------------------|---------|---------------|---------|------------|
| Volume (m$^3$)     | ---     | 1174094391    | ---     | 723440795  |

| Design variables (mm) | Minimum | Initial value | Maximum | Optimum |
|-----------------------|---------|---------------|---------|---------|
| TFW (mm)              | 12      | 21            | 24      | 12.5    |
| BFW (mm)              | 12      | 21            | 24      | 14.2    |
| TFT (mm)              | 300     | 410           | 500     | 303     |
| BFT (mm)              | 200     | 310           | 400     | 226     |
| WT (mm)               | 12      | 15            | 24      | 12.1    |
| WH (mm)               | 800     | 1000          | 1100    | 870     |

| Constraints          | Minimum | Initial value | Maximum | Optimum |
|----------------------|---------|---------------|---------|---------|
| Max. $f_c$ (MPa)     | -150    | -132          | 0       | -149.8  |
| Max. $f_t$ (MPa)     | 0       | 116           | 150     | 122     |
| Max. $U_y$ (mm)      | 0       | 5             | 75      | 10      |

Figure 5: Optimization with genetic algorithm.

A new design of the retrofitting STBG would be achieved after optimization as the total volume will be reduced. The numerical total load versus to the maximum mid-span deflection curves of the STBG is shown in Figure 6 before and after optimisation. It is obvious that, compared to a girder prior to optimisation, the controlled load of the optimized STBG is relatively increased. At the maximum mid-span deflection, the ultimate load was found to be 1875 kN for the optimized girder against 2398 kN for the not optimized girder. This means a 22% decrease in the controlled load compared with the total optimized volume (nearly 38%).
In addition, we conclude that optimizing the STBG is important since it enables us to find the optimum total volume in a low cost and adequate service conditions.

![Figure 6: Load versus mid-span deflection before and after optimization.](image)

**Figure 6**: Load versus mid-span deflection before and after optimization.

### 5. Conclusion

Genetic algorithm coupling MATLAB software and ANSYS program is implemented in this study as a technique of optimization. Thus, in the MATLAB software search algorithm, finite element analysis of ANSYS program can be effectively applied. In this study, the above methodology is used to optimize the steel trapezoidal box-girders. It helps to achieve an optimal design that meets the design requirements. Under constraint of stresses limited to the acceptable stresses the total volume of STBGs is optimized.

The following conclusions can be drawn, based on the analysis of the finite element and optimization for the steel trapezoidal box-girders:

Based on the finite element analysis and optimization for STBG, the following conclusions are drawn:
1- The data developed from this study showed that the total volume reduction of an optimized steel trapezoidal box-girders was more obvious than the unoptimized girder. The result was a reduction of approximately 38% in the total volume of steel trapezoidal box-girders. There was also a significant decrease in TFT and BFT, respectively of about 40% and 32%.

2- It is evident that the web height is reduced significantly from 1000 mm for the initial state to 870 mm for the converged solution. This decrease (approximately 13 percent of the initial height) is important.

3- The optimized girder had a load of 1875 kN, while before optimization the load was 2398 kN. The load reduction is 22%, but the total volume of girder decrease is almost 38%. Therefore, it can be concluded that the total volume of STBGs is important because it leads us to find the optimum total girder volume in a low cost and adequate service conditions.

REFERENCES

[1] Faluyi, F. and Arum, C., 2012. Design optimization of plate girder using generalized reduced gradient and constrained artificial bee colony algorithms. *International Journal of Emerging Technology and Advanced Engineering*, 2(7), pp.304-312.

[2] Earls, C. J. (2000). Influence of material effects on structural ductility of compact I-shaped beams, *Journal of Structural Engineering*, 126(11), 1268-1278.

[3] Ren, Y., Cheng, W., Wang, Y., Chen, Q. and Wang, B., 2017. Distortional analysis of simply supported box girders with inner diaphragms considering shear deformation of diaphragms using initial parameter method. *Engineering Structures*, 145, pp.44-59.

[4] Sharifi, Y. and Paik, J.K., 2011. Ultimate strength reliability analysis of corroded steel-box girder bridges. *Thin-Walled Structures*, 49(1), pp.157-166.

[5] Topkaya, C., Williamson, E.B. and Frank, K.H., 2004. Behavior of curved steel trapezoidal box-girders during construction. *Engineering Structures*, 26(6), pp.721-733.

[6] Shin, Y.S., Park, J.H. and Ha, D.H., 2009. Optimal design of a steel box girder bridge considering life cycle cost. *KSCE Journal of Civil Engineering*, 13(6), pp.433-440.

[7] Koller, R.E., Stoecklin, I., Weisse, B. and Terrasi, G.P., 2012. Strengthening of fatigue critical welds of a steel box girder. *Engineering Failure Analysis*, 25, pp.329-345.

[8] Rana, S., Ahsan, R., Ghani, SN. (2010, August). Design of prestressed concrete I-girder bridge superstructure using optimization algorithm, *In IABSE-JSCE Joint Conference on Advances in Bridge Engineering-II*.
[9] Mohammed, A.H., Nassani, D.E., Tayşi, N. and Hussein, A.K., 2018. Nonlinear Finite Element Model for the Optimization of Post-Tensioned One-Way Concrete Slab. KSCE Journal of Civil Engineering, 22(7), pp 2519–2527.

[10] Mohammed, A. M. and Tayşi, N. “Modelling of Bonded and Unbonded Post-Tensioned Concrete Flat Slabs under Flexural and Thermal Loading”, Structural Engineering and Mechanics (June 2017), Vol. 62, No. 5, 595-606. doi: 10.12989/sem.2017.62.5.595.

[11] Mohammed, A.H., Tayşi, N., Nassani, D.E. and Hussein, A.K., 2017. Finite element analysis and optimization of bonded post-tensioned concrete slabs. Cogent Engineering, 4(1), p.1341288.

[12] Abbas, A.L., Mohammed, A.H. and Abdul-Razzaq, K.S., 2018. Finite Element Analysis and Optimization of Steel Girders with External Prestressing. Civil Engineering Journal, 4(7), pp.1490-1500.

[13] ANSYS (2012), “ANSYS Help”. Release 14.5, Copyright.

[14] Faluyi, F. and Arum,C. 2012. Design optimization of plate girder using generalized reduced gradient and constrained artificial bee colony algorithms”, International Journal of Emerging Technology and Advanced Engineering, 2(7), 304-312.

[15] Manoharan, S., Shanmuganathan, S. (1999). A comparison of search mechanisms for structural optimization, Computers & Structures, 73(1-5), 363-372.

[16] Mohammed, A.H. and Abdul-Razzazq, K.S., 2018. Optimum Design of Steel Trapezoidal Box-Girders Using Finite Element Method. International Journal of Engineering & Technology, 7(4.20), pp.325-328.

[17] Holland, J.H. (1975), “Adaptation in natural and artificial systems”, University of Michigan, Ann Arbor.