International Journal of Engineering & Technology, 7 (4.20) (2018) 325-328

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper



Optimum Design of Steel Trapezoidal Box-Girders Using Finite Element Method

Abbas H. Mohammed[1*], Khattab S. Abdul-Razzaq[2]

[1,2]University of Diyala, Civil Engineering Department, Diyala, 32001, Iraq
**Corresponding author E-mail: a-mohammed@engineering.uodiyala.edu.iq*

Abstract

The target of basic plan is to choose part sizes with the ideal proportioning of the in general auxiliary geometry. Regular steel trapezoidal box-supports have been utilized generally in different designing fields. The target of this examination is to create three-dimensional limited component display for the size improvement of steel trapezoidal box-braces. The limited component programming bundle ANSYS was utilized to decide the ideal cross segment measurement for the steel trapezoidal-box support. Two target capacities were considered in this investigation which are: minimization of the strain vitality and minimization of the volume. The plan factors are the width of the best spine, the width of the base rib, the thickness of the best rib, the thickness of the base rib, the stature of the support and the thickness of the networks. The imperatives considered in this examination are the ordinary and shear worry in steel brace and the dislodging at mid-length of the support. Improvement consequences of steel brace show that the ideal territory of cross segment for the strain vitality minimization is more noteworthy than the ideal for volume minimization by 6 %. The base cross area is the financial structure, hence the volume minimization is more pertinence for steel brace advancement.

Keywords: *Ansys; finite element; optimization; steel girder; trapezoidal.*

1. Introduction

In the design of a steel bridge, design engineers must take many details and factors into consideration. Serviceability and safety of a bridge thatimust meet all design codes are important and the other design factorssshould be considered accordingly. Generally, the bridge designiwas performed to select member sizes and structural geometry to achieve minimum cost.

Optimization is a process through which the optimum possible values of state variables are obtained under the given set of limitations and in accordance to a selected objective function.

The most common process of optimization procedure applies to the design of structure that will maximize the possible reliability or decrease the total cost or any specific objective function. Fields of engineering, science and business are all rich in problems that require the application of optimization approach [1].

Many numerical researches were developed in the literature highlighting the structural behavior of different kinds of steel bridges subjected to different boundary conditions and loadings [1-7] .The numerical researches proposed finite element models for the analysis of steel girder which were developed to provide better analyses and understanding for the behavior and stability of different steel girders [8].

Theoretical and numerical models have been previously established by other researchers to study the optimum design of structures [1, 6, 8, 9-12].

Ren et al. [3] assessed the distortion of girders (simply supported withiinner diaphragms) by applying concentrated eccentric loads using the initial parameter method (IPM). A statically indeterminate structure was simulated using application of innerrredundant forces, where the interactions present between the girder and diaphragms were highlighted by distortional moments. The validity of the IPM approach was corroborated via a finite element analysis and distortional investigations. Parametric experiments were subsequently conducted to assess the influence of diaphragm number on angle of distortion, warping displacementsiand stresses under varying height to girder span and diaphragm thickness ratios. Outcomes indicated that the local web plate will give way prior to overall yielding with incremental loading of eccentric loads Pj, although the mid-span diaphragm remains stable throughout the entire deformation pathway.

The behavior of curvedsgirders during construction was studied by Topkaya [5]. Data collected for this study illustrate important differences between the predicted and measured quantities, mostly for laterrpours.

Load carrying capacity curves, which included repair and rehabilitation histories for bridge members, as well as optimal steel box girder bridge design comprising concrete deck, steel box girders and piers, were derived by Shin et al. [6] to take into consideration life cycle costings. Total life cycle costs for bridge service life is determined from a sum of initial costs, damage costs, maintenance costs, repair and rehabilitation costs and user costs. The optimization approach facilitates design of bridge members with minimal incurred costs, in line with the objective function of minimising annual costs. The findings indicate that despite the fact that it is not simple to take all the various cost factors into consideration accurately, those which are impacted by various environmental parameters and uncertainties should be always be considered.

Abbas et al. [12] built up a limited component display for the advancement of a steel I-brace with outside prestressing. The AN-

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

SYS limited component programming packageewas used to locate the ideal cross segment measurement for the steel I-brace. Two target capacities are considered in this examination which are streamlining of the strain vitality and aggregate volume of the support. The structure factors are the thickness of best rib, the width of best rib, the width of base rib, the stature of the web, the thickness of base spine, the width of the web and region of pre-stressing ligaments. Two sorts of steel support were viewed as which are steel brace without prestressing and steel brace with prestressing. The outcomes for volume minimization demonstrate that the ideal cross area for steel brace with prestressing is littler than that for steel support without prestressing.

In this paper, three-dimensional finite element model was introduced usingiANSYS software to study theioptimum design of steel trapezoidal box-girders. The optimum size of girder was calculated. Optimization routines in ANSYS use three kinds of variables that describe the design optimizatoin process which are : the objective function, design variablessand constraints. ANSYS Parametric DesignnLanguage (APDL) represents the objective function these variablessby scalar the objective function parameters. The use offAPDL is a important step in the optimizationnprocedure.

2. Finite element modeling

ANSYS computer program [13] is used to model and analyze steel trapezoidal box-girders. To represent the steel trapezoidal-box girder in finite element, 4-node shell element needed. For this purpose, a Shell181 element was used to model the steel trapezoi-dal-box girder. This element has four nodes with six degrees of freedom at each nodes: rotations about the x, y, and z-axes and translations in the x, y, and z directions. This element is used for linear and nonlinear applications. The element has also stress stiff-ening, plasticity and large deflections [13].
Material properties show a significant role in ANAYS analysis. Accurate values of material properties have to be given as input in ANSYS program. Modeling of steel material in finite element is simple. Theebilinear strain-stress curves is considered forrsteel in this study. The yield strength (Fy), poisson's ratio (υ) and modulus of elasticity (Es) of the steel were 400 MPa, 0.3 and 200000 MPa, respectively.

3. Finite element modeling

Numerous studies regarding the optimization of steel structure were available in literature. Few studies were interested with the design optimization of steel trapezoidal-box girder. In this paper, finite element analysis is used to minimize the cross section of steel trapezoidal-box girder subjected to static loading.
Seven design variables are used in this study which are: the width of top flange (FW1), the width of bottom flange (FW2), the thick-ness of top flange (FT1), the thickness of bottom flange (FT2), the height of the girder (WH,) , and the thickness of the web (WT,) as shown in Figure 1.
The objective of the optimization method is to optimize the sec-tion area of steel trapezoidal-box girder while satisfyingiall applicable strength and serviceability limit states according to the design code.
Two objective functions are considered in this study as follows:
-Minimization of strain energy of the girder.
-Minimization of total volume of the girder.
The constraints considered in this study are:
- Maximum stressiin steel.
- Maximum shearistress in steel.
- Maximum deflection at midspan of the steel trapezoidal-box girder.

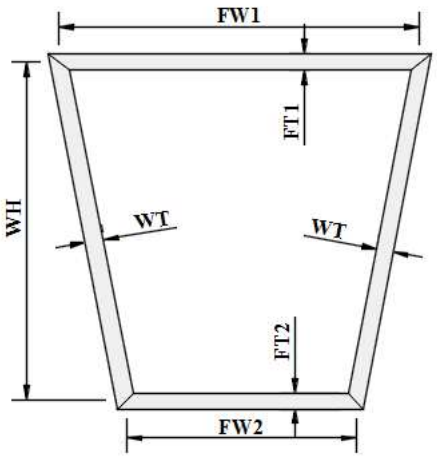


Fig. 1: Cross section of steel trapezoidal-box girder with design parame-ters used in the optimizations.

The simply supported steel trapezoidal-box girders is considered. The description and boundary conditions was illustrated in Figure 2. The loads was applied as a concentratediloads at midspan and the total length of the steel trapezoidal-box girders is L = 21 m as shown in Figure 2.

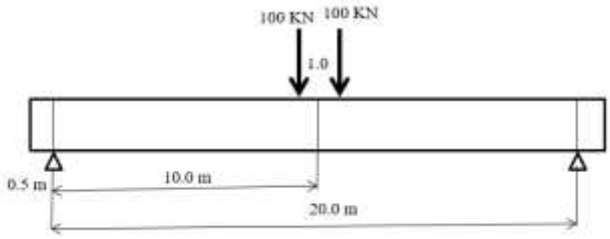


Fig. 2: Geometry and loading conditions for the proposed steel trapezoi-dal-box girder.

In the finite element analysis, the point load is distributed on the flange width to avoid numerical problems. The mesh of steel trap-ezoidal-box girder are illustrated in Figure 3. The meshed cross section of steel trapezoidal-box girder are shown in Figure 4. The meshing and boundary conditions considered in this study for modelling the steel trapezoidal-box girder are shown in Figures 3 and 4. Two concentrated point loads were applied to the girder close to the centre whilst it was simply supported at both ends. The present study utilized 3D solid elements in order to model the steel trapezoidal-box girder.

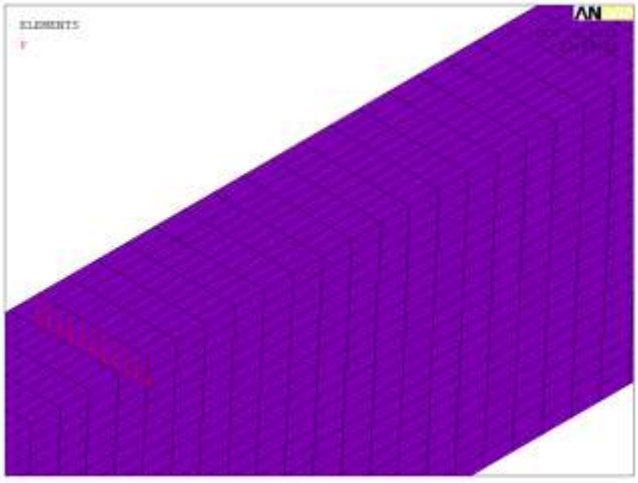


Fig. 3: Finite element meshing and boundary condition of the girder.

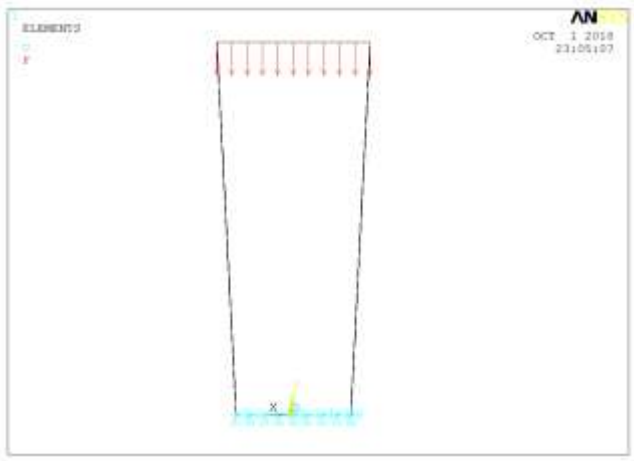


Fig. 4: Meshed cross section of steel trapezoidal-box girder.

3.1. Optimization strategy

A couple of optimisation procedures are outlined in the ANSYS package [13]: the sub-problem approximation approach and the first order approach. The first-order approach utlilises gradients of dependent variables in relation to design variables. The sub-problem approximation approach can be considered a zero-order methodology which needs only the variable values, and does not require their derivatives.

Optimization of steel trapezoidal-box girder is a thorough process in several steps that usually requires many iterations until a satisfactory design can be found. The designer is often free to choose a structural solution and vary different parameters. Formulating an optimization problem for complex tasks like this can be challenging, and it usually requires extensive numerical modeling [1].

3.2. Optimization result

In this section the steel trapezoidal-box girder is considered for the optimization using two objective function which are the strain energy and total volume. The constraints are compression stress, tension stress and deflection.

Random design iterations are conducted against the material parameter limits in order to determine strain energy optimisation. The initial information from the random design calculations provides starting points on which the optimization approaches described above can be based. The values of initial data not affect the optimization result but it effect on the number of iteration. Figure 5 shows the evolution of optimal FW2 versus number of iterations for the steel trapezoidal-box girder. Because of strain energy is dependent on stress, the increased of FW2 reduces the stress at the bottom of the steel girder which is maximum stress. From this figure, it can be found that the values of FW2 for the strain energy minimization is greater than values for the volume minimization by 5.6 % and the number of iteration for volume minimization is greater than the number for strain energy minimization.

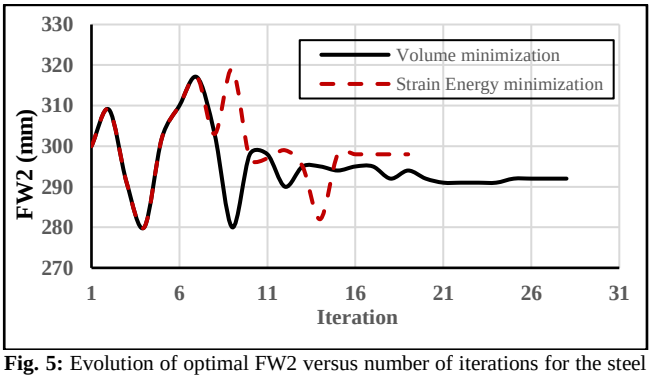


Fig. 5: Evolution of optimal FW2 versus number of iterations for the steel trapezoidal-box girder.

Tables 1 and 2 show the result of the initial and optimum design variables for volume and strain energy minimization of the steel trapezoidal-box girder respectively.

From Table 1, it can be noticed that the WH and the total volume are decreased through the total volume minimization processes.

From Table 2, it can be noticed that the FT2 is increased and tension stress at bottom is decreased through the strain energy minimization processes.

Table 1: Initial, optimum and limits. of design variables and constraints for the volume minimization.

		Minimum	Initial value	Maximum	Optimum
Objective function	Volume (mm^3)	----	714524672	---	680651612
Design variables (mm)	FT1 (mm)	20	22	30	21
	FT2 (mm)	20	22	30	20
	FW1 (mm)	375	400	425	377
	FW2 (mm)	275	300	325	282
	WT (mm)	10	14	20	11
	WH (mm)	950	1000	1050	955
Constraints	Max. *fc* (MPa)	-200	-151	0	-160
	Max. *ft* (MPa)	0	102	200	112
	Max. U_y (mm)	0	34	75	39

where: f_c is the compression stresses in steel; f_t is the tensile stresses in steel and U_y is the displacement at mid-span of the steel girder.

Table 2: Initial, optimum and limits of designs variables and constraints for the strain energy minimization of the steel trapezoidal-box girder.

		Minimum	Initial value	Maximum	Optimum
Objective function	SE (N.mm)	----	3318797	---	3112329
Design variables (mm)	FT1(mm)	20	22	30	20
	FT2 (mm)	20	22	30	23
	FW1 (mm)	375	400	425	407
	FW2 (mm)	275	300	325	298
	WT (mm)	10	14	20	11
	WH (mm)	950	1000	1050	978
Constraints	Max. *fc* (MPa)	-200	-151	0	-157
	Max. *ft* (MPa)	0	102	200	100
	Max. U_y (mm)	0	34	75	37
	Volume (mm^3)	----	714524672	----	722400569

where: *SE* is the stain energy

Table 3 shows the comparison of optimum values of designivariables for optimization of the steel trapezoidal-box girder for two objectives functions. From this table, it can be noticed that the value of optimum cross section area for the strain energy minimization is greater than the value for volume minimization by 6 %. This is because that the width of the top flange, the width of the bottom flange, and the height of the web are bigger. The minimum cross section is the economic design, therefore the volume minimization is more relevance for steel girder optimization.

From this table, it can also be noticed that the stain energy is reduced by almost 6 % and total volume is reduced by almost 5 % compared to the initial section.

Table 3: Comparison of optimum values of design variables and constraints for the steel trapezoidal-box girder.

	FT1 (mm)	FT2 (mm)	FW1 (mm)	FW2 (mm)	WT (mm)	WH (mm)	Area of section (mm^2)	Volume %	Strain energy %
Volume minimization	21	20	377	282	11	955	32412	5	---
Strain energy minimization	20	23	407	298	11	987	34400	---	6

After optimization, a different design of the steel trapezoidal-box girder was achieved because the area of the section is reduced. Figure 8 show a comparison of the finite element load versus displacement curvessof the steel trapezoidal-box girder after optimization for the two objective functions. Form Table 3, it can be noticed the optimum cross section for strain energy minimization is greater than for volume minimization. Therefore, form Figure 6 it is obvious that the failure load of the optimized steel trapezoidal-box girder for the strain energy optimizition is higher.

At the maximum midspan deflection, the failure load for the steel trapezoidal-box girder with strain energy minimization was found to be 1042 kN against 959 kN for the volume optimization.

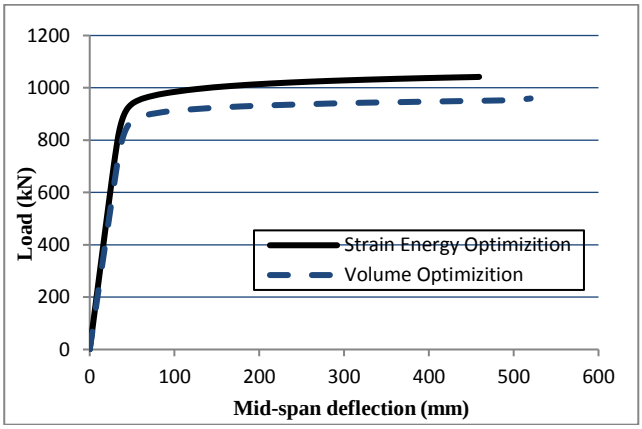


Fig. 6: Load-deflection curve for the steel trapezoidal-box girder after optimization for the two objective functions.

4. Conclusion

This study presents a 3-D finite element model using ANSYS to investigate the optimum steel trapezoidal-box girder design and determine optimum girder size. ANSYS optimization approaches utilising three variable types which describe the design optimisation process: constraints; design variables and the objective function. ANSYS APDL defines these variables by parameters.

Based on the finite element analysis and optimization for the steel trapezoidal-box girder, the following conclusionsscan be stated:

1- The optimization results of steel trapezoidal-box girder indicate that the optimum area of cross section for the strain energy minimization is greater than the optimum for volume minimization by 6 %. The minimum cross section is the economic design, therefore the volume minimization is more relevance for steel girder optimization.

2- As the result, the strain energy was reduced approximately 6 %. A reduction in the total volume was also reached which was approximately 5 %.

3- It issobvious that the controlledlload of the optimized steel trapezoidal-box girder for the strain energy minimization is higher for the total volume minimization.

References

[1] Faluyi F & 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.

[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 & 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 & Paik JK (2011), Ultimate strength reliability analysis of corroded steel-box girder bridges. *Thin-Walled Structures* 49(1), pp.157-166.

[5] Topkaya C, Williamson EB & Frank KH (2004), Behavior of curved steel trapezoidal box-girders during construction. *Engineering Structures* 26(6), pp.721-733.

[6] Shin YS, Park JH & Ha DH (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 RE, Stoecklin I, Weisse B & Terrasi GP (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), Design of prestressed concrete I-girder bridge superstructure using optimization algorithm, *In IABSE-JSCE Joint Conference on Advances in Bridge Engineering-***II** .

[9] Mohammed AM & Tayşi N (2017), Modelling of Bonded and Unbonded Post-Tensioned Concrete Flat Slabs under Flexural and Thermal Loading. *Structural Engineering and Mechanics*, Vol. 62, No. 5 , 595-606.

[10] Mohammed, AH, Tayşi N, Nassani DE & Hussein AK (2017), Finite element analysis and optimization of bonded post-tensioned concrete slabs. *Cogent Engineering* 4(1), p.1341288.

[11] Mohammed AH, Nassani DE, Tayşi N & Hussein AK (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.

[12] Abbas AL, Mohammed AH , Khalaf RD & Abdul-Razzaq KS (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.