University of Banja Luka
Faculty of Mechanical Engineering

DEMI 2019

14th International Conference on Accomplishments in Mechanical and Industrial Engineering

PROCEEDINGS

Banja Luka, 24 - 25 May 2019

Print:
Comesgrafika, Banja Luka

Circulation:
200

ISBN: 978-99938-39-85-9

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

621(082)(0.034.2)
621.3(082)(0.034.2)
007(082)(0.034.2)

INTERNATIONAL conference on accomplishments in mechanical and industrial engineering (14 ; 2019 ; Banja Luka)
Proceedings [Електронски извор] / [14th international conference on accomplishments in mechanical and industrial engineering] ; [editor in chief Petar Gvero ; executive editor Biljana Prochaska]. - Banja Luka : Faculty of mechanical engineering, 2019 (Banja Luka : Comesgrafika). - 1 elekronski optički disk (CD-ROM) : tekst, slika ; 12 cm

Sistemski zahtjevi nisu navedeni. - Nasl. sa nasl ekrana. - Tiraž 200. - Bibliografija uz svaki rad.

ISBN 978-99938-39-85-9
COBISS.RS-ID 8146456

14^{TH} INTERNATIONAL CONFERENCE ON ACCOMPLISHMENTS IN MECHANICAL AND INDUSTRIAL ENGINEERING

Supported by:
MINISTRY FOR SCIENTIFIC AND TECHNOLOGICAL DEVELOPMENT, HIGHER EDUCATION AND INFORMATION SOCIETY

Organizer and publisher:
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITY OF BANJA LUKA

Co-organizer:
FACULTY OF MECHANICAL ENGINEERING,
UNIVERSITY OF NIŠ, SERBIA

FACULTY OF MECHANICAL ENGINEERING PODGORICA,
UNIVERSITY OF MONTENEGRO, MONTENEGRO

FACULTY OF ENGINEERING OF HUNEDOARA
UNIVERSITY OF TIMISOARA, ROMANIA

For publisher:
Prof. Darko Knežević, PhD

Editor in chief:
Full Prof. Petar Gvero, PhD

Executive editor:
Biljana Prochaska, MSc

Editorial assistant:
Milivoj Stipanović

Vlada Gašić, Aleksandra Arsić, Milorad Pantelić, Dejan Kočović
CONSIDERATION OF STRUCTURAL ELEMENTS CHARACTERISTICS
ON THE STRESSES AT THE I-BEAM END-PLATE MOMENT CONNECTION 391

Aleksandar Radaković, Dragan Milosavljević, Gordana Bogdanović,
Milivoje Milanović, Dragan Čukanović
APPLICATION OF ANALYTICAL METHODS IN BENDING ANALYSIS
OF CROSS PLY SYMMETRIC LAMINATES 397

Stevan Maksimović, Katarina Maksimović, Ivana Vasović, Mirko Maksimović,
Dragi Stamenković
STRENGTH ANALYSIS OF HELICOPTER MAIN ROTOR BLADE MADE FROM
COMPOSITE MATERIALS 403

Nenad Miloradovic, Rodoljub Vujanac
DESIGN OF TOWER CRANE BASED ON CONSTRUCTION SITE LAYOUT PLANNING 409

Nenad Petrović, Nenad Kostić, Nenad Marjanović, Mirko Blagojević, Miloš Matejić
INFLUENCE OF BUCKLING CONSTRAINTS ON TRUSS STRUCTURAL OPTIMIZATION 415

Slobodanka Boljanović, Stevan Maksimović, Strain Posavljak
ANALYSIS OF TWO SYMMETRIC CRACKS AT A HOLE UNDER CYCLIC LOADING 423

Dragan Čukanović, Gordana Bogdanović, Aleksandar Radaković, Milivoje Milanović
DYNAMIC ANALYSIS OF FUNCTIONALLY GRADED PLATE USING HIGHER ORDER
SHEAR DEFORMATION THEORY 429

Ivan Grujic, Nadica Stojanovic, Oday I. Abdullah, Radivoje Pesic, Jovan Doric,
Sasa Vasiljevic
VERIFICATION OF NUMERICAL ANALYSIS FOR THE WORKING CYCLE OF
AN IC ENGINE BASED ON THE EXPERIMENTAL DATA 433

MECHATRONICS

Pavle Stepanić, Živko Murar, Aleksa Krošnjar
RETROFITTING A CONVENTIONAL HORIZONTAL MILLING MACHINE TO
CNC MACHINE TOOL 441

Vladislav Blagojević, Saša Ranđelović, Predrag Janković
TYPES OF ENERGY EFFICIENT CONTROL OF PNEUMATIC ACTUATOR SYSTEM 447

AUTOMOTIVE AND TRANSPORTATION ENGINEERING

Jovanka Lukić, Slavica Mačužić
SEATED HUMAN BODY RESPONSES TO DUAL-AXIS VIBRATION 455

Radoje Vujadinovic, Sreten Simovic, Milanko Damjanovic
OVERVIEW OF INCENTIVES AND POLICIES FOR ELECTRIC VEHICLES
IN THE EUROPEAN COUNTRIES 461

Slobodan Mišanović, Dragan Taranović, Jovica Vasiljević, Nenad Novaković
TECHNICAL AND ECONOMIC ASPECTS OF THE TEST DRIVE IVECO CNG BUS
IN BELGRADE, COMPARED TO DIESEL BUS AND E-BUS 471

University of Banja Luka
Faculty of Mechanical Engineering
DEMI 2019
Banja Luka, 24 - 25 May 2019
14th International Conference on Accomplishments in Mechanical and Industrial Engineering

INFLUENCE OF BUCKLING CONSTRAINTS ON TRUSS STRUCTURAL OPTIMIZATION

Nenad Petrović [1], Nenad Kostić [2], Nenad Marjanović [3], Mirko Blagojević [4], Miloš Matejić [5]

Summary: *In order to achieve the most practically applicable results the optimization model must have the most realistic variables, loading and constraints. One of the main constraints which is frequently overlooked in previously published research is bucking. Since this constraint is changing in each iteration of the optimization process it is very complex and is considered a dynamic constraint. This paper shows the implementation of such a constraint into the structural optimization process. A typical space truss example with 25 bars is optimized both with and without the use of buckling constraints for sizing, shape, topology and all their possible combinations, and a comparative analysis of the two cases is done. All models are optimized for minimal weight.*
Key words: truss, structural optimization, Euler buckling, continuous variables

1. INTRODUCTION

The problem of truss structural optimization is a complex engineering problem which is more and more finding its application in various types of applications. The goal of using as little material as possible in order to achieve applicable results has driven the development of this field which in a lot of research published to date has been focused on the difference in the heuristic optimization methods used. As the constructions being optimized should be applicable in the real world it is important to develop methodologies of truss optimization which will produce useful results. One very important, yet frequently overlooked aspect of truss structural optimization is buckling load of compressed elements. The addition of buckling loads to truss structural optimization means creating, so called, dynamic constraints which change in each iteration of optimization. This constraint drastically increases the complexity of the entire process and discretizes the search space making finding a global optimum very difficult.

A lot of research published in recent years does not consider buckling [1-3]. Tejani et al. [4] used multi-objective modified adaptive symbiotic organism search to

[1] MSc, Nenad Petrović, Kragujevac, Serbia, Faculty of Engineering, npetrovic@kg.ac.rs
[2] PhD, Nenad Kostić, Kragujevac, Serbia, Faculty of Engineering, nkostic@kg.ac.rs
[3] PhD, Nenad Marjanović, Kragujevac, Serbia, Faculty of Engineering, nesam@kg.ac.rs
[4] PhD, Mirko Blagojević, Kragujevac, Serbia, Faculty of Engineering, mirkob@kg.ac.rs
[5] MSc, Miloš Matejić, Kragujevac, Serbia, Faculty of Engineering, mmatejic@kg.ac.rs

minimize mass and maximize nodal deflection on five truss optimization problems without explicit use of buckling constraints. Authors in [5] applied fixed stress constraints for both compression and tension while using a novel hybrid method on discrete truss structures. Researchers in [6] have used fixed compressive stress limits for different bar groups in their examples to account for buckling failure. They used move limits definition with sequential linear programming to achieve optimal results for sizing and shape optimization of 20 problems. Simultaneous sizing, shape and topology optimization of planar and space trusses without considering buckling, but accounting for possible unacceptable topologies using Grubler's criterion was done in [7]. More recent papers have started using different dynamic constraints to overcome the problem of potential buckling failure of optimal structures. Degertekin et al. [8] conducted sizing, layout and topology optimization on truss structures using a constraint for buckling which has a higher limit than Euler buckling. Authors in [9-11] compared results of various optimization types with and without using Euler buckling constraints.

The main focus of this research is to show the difference in results for minimal weight optimization with and without the use of dynamic constraints for Euler buckling. The test example used is a standard 25 bar truss problem. The example is optimized for sizing, topology, shape and all their possible combinations.

2. TRUSS STRUCTURAL OPTIMIZATION PROBLEM

Structural optimization of trusses in the majority of cases has the goal of minimizing overall construction weight while maintaining structural stability. The weight minimization problem is defined by the total weight of all used elements, and generally does not account for the additional weight of joints. This is done because in most truss analyses used for optimization bar elements are represented in finite element analysis as one-dimensional elements and therefore there is a certain overlap between elements which accounts for the added weight of joints. Structural optimization for trusses can be divided into three categories, according to the aspect of the construction which is being optimized. Sizing optimization considers cross-section area (dimensions and types) as variables. Topology optimization considers the utilization of bars as variables (adding or removing bars). Shape optimization views the position of nodes (joints) as variables, and depending on the type of problem it can vary one to all three coordinates of nodes which are allowed to be displaced. These optimization types can be combined to optimize two, or even all three aspects in order to achieve even better results, either sequentially or, ideally, simultaneously. This combination additionally complicates the optimization process as the search-space becomes larger and more variables are added to an already complex problem. The goal function for minimal weight optimization is defined as follows:

$$\begin{cases} minW\left(A\right)=\sum_{i=1}^{i=n}\rho_i\,A_i\,l_i \quad \text{with} \quad A=\left(A_1,\ldots,A_n\right) \\ \text{subjected to} \begin{cases} A_{min}\le A_i\le A_{max} & \text{for } i=1,\ldots,n \\ \sigma_{min}\le\sigma_i\le\sigma_{max} & \text{for } i=1,\ldots,n \\ u_{min}\le u_j\le u_{max} & \text{for } j=1,\ldots,k \\ \ldots \end{cases} \end{cases}$$

where n is the number of truss elements, k is the number of nodes, li is the length of the i^{th} element, A_i is the area of the i^{th} element cross section, σ_i is the stress of the i^{th} element, and u_j is displacement of the j^{th} node. More constraints can be added depending on the problem in order to achieve desired results. In order to test compressed bars for buckling this paper uses the following expressions to define the constraint for Euler buckling.

$$\sigma_{Ai}^{P} \leq \sigma_{ki}$$

$$\text{for } \sigma_{Ai}^{P} = \frac{F_{Ai}^{P}}{A_i} \quad \text{and} \quad \sigma_{ki} = \frac{F_{ki}}{A_i},$$

$$F_{ki} = \frac{\pi^2 \cdot E_i \cdot I_i}{l_{ki}^2}$$

$$\left|F_{Ai}^{P}\right| \leq F_{ki} \text{ for } i = 1, ..., n.$$

where σ_{Ai} is axial compression stress, and σ_{Ki} is critical buckling stress of the i^{th} element. F_{Ai}^{comp} is axial compression force, F_{Ki} is Euler's critical load, E_i is modulus, and I_i is minimum area moment of inertia of the cross section of the of the i^{th} element.

As the cross section area changes in each iteration of sizing optimization and lengths change in each iteration of shape optimization this constraint is considered a dynamic constraint. It should also be noted that both shape and topology optimizations can result in the changes of load types in certain bars, so some bars which were subjected to compression in certain iterations might be subjected to tension in other iterations. This is an additional problem in finding global optima in an already hard to navigate search-space. Such complex problems require the use of heuristic optimization methods, and in this paper the method used is genetic algorithm due to its availability and ease of use.

3. TEST EXAMPLE

For the purposes of this research a typical 25 bar truss problem was optimized for sizing, topology, shape, and all possible combinations of two as well as all three simultaneously. The layout of the 25 bar truss problem is shown in figure 1. Bars are made from Aluminium 6063-T5 which has a Young modulus of 68947 MPa, and a density of 2.7 g/cm^3. Forces are distributed on the following nodes with vectors: node 1 (4.448, -44.48, -44.48) kN, node 2 (0, -44.48, -44.48) kN, node 3 (2.224, 0, 0) kN, and node 6 (2.6688, 0, 0) kN.

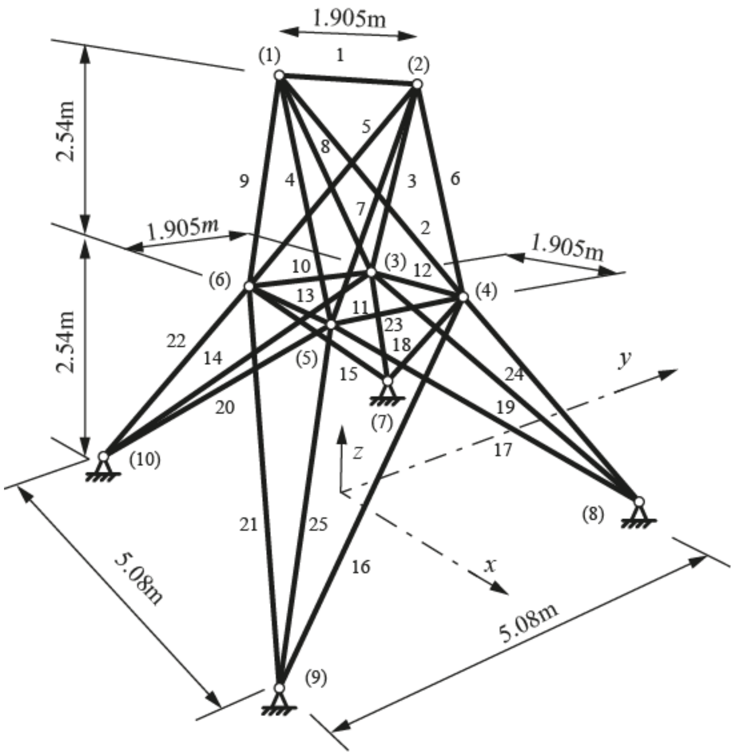

Fig. 1 *Layout of 25 bar truss problem.*

Truss member cross-sections for this problem are grouped as follows: 1 (A_1), 2 (A_2 – A_5), 3 (A_6 – A_9), 4 (A_{10} – A_{11}), 5 (A_{12} – A_{13}), 6 (A_{14} – A_{17}), 7 (A_{18} – A_{21}), 8 (A_{22} – A_{25}). The constraints for this problem are: tensile stress limit for all bar groups of 40kN, and a maximal displacement of ±0.00889m for all nodes in all directions, as well as Euler buckling constraints for all bars. Optimization types where topology is considered, can eliminate only entire groups of elements. For the optimization considering shape, the node coordinate constraints are as follows:

$$0,508m \le x_4,\ x_5,\ -x_3,\ -x_6 \le 1.524m;$$

$$1,016m \le y_3,\ y_4,\ -y_5,\ -y_6 \le 2,032m;$$

$$2,286m \le z_3,\ z_4,\ z_5,\ z_6 \le 3,302m;$$

$$1,016m \le x_8,\ x_9,\ -x_7,\ -x_{10} \le 2,032m;$$

$$2,540m \le y_7,\ y_8,\ -y_9,\ -y_{10} \le 3,556m.$$

Optimization without the use of buckling constraints is done using continuous variables and has a minimal diameter limit of 1.433mm. For the optimization using buckling constraints in order to achieve the most realistic results discrete variables are used for full round cross-section of Aluminium 6063-T5. A list was compiled with available standard dimensions from several vendors. There are 50 possible cross-section profiles diameters ranging from 12mm (1.131 cm^2) to 356mm (995.382 cm^2). The list of possible diameters of bars is as follows: 12, 16, 20, 25, 30, 34, 35, 40, 45, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 140, 145, 150, 152, 160, 165, 170, 175, 178, 180, 190, 200, 210, 220, 230, 240, 250, 254, 260, 270, 278, 280, 300, 305, 356, given in mm.

4. RESULTS

For the purposes of this research optimization was conducted in an original software developed in Rhinoceros 5.0, Grasshopper using the Karamba plugin. The optimization module used is Galapagos which uses genetic algorithm as the optimization method. Optimal results for topology and shape for the case without considering buckling constraints uses a cross-section area derived from optimizing the model firstly, in its original configuration, for a single cross-section for all bars. The example which considers buckling constraints uses different cross-sections for topology and shape as the optimal cross-section in the case where all the bars are the same does not allow for exclusion of bars, so the topology optimized solution uses larger bars.

The optimal weight and cross-section areas of bar groups for all optimization types are given in table 1 for the example not using buckling constraints, and in table 2 for the example with buckling constraints added. Node coordinates depending on the constraints used are given in table 3.

Table 1 *Cross-section areas of bar groups and weight according to optimization type without the buckling constraint*

Cross-section area of bar group [cm^2]	Sizing	Topology	Shape	Sizing and topology	Sizing and shape	Topology and shape	Sizing. shape and topology
1	1.131	-	19.635	1.131	1.1314	-	1.1310
2	1.131	19.635	19.635	6.716	1.131	19.635	1.1310
3	23.495	19.635	19.635	18.960	7.208	19.635	8.553
4	1.131	-	19.635	-	1.131	-	-
5	3.005	-	19.635	-	1.136	-	-
6	3.774	19.635	19.635	7.282	1.131	19.635	1.131
7	12.399	19.635	19.635	5.561	1.131	19.635	1.131
8	20.205	19.635	19.635	31.188	8.513	19.635	7.411
Weight [*kg*]	233.299	396.957	394.671	259.556	67.599	352.027	64.303

Table 2 *Cross-section areas of bar groups and weight according to optimization type with the buckling constraint*

Cross-section area of bar group [*cm*^{2}]	Sizing	Topology	Shape	Sizing and topology	Sizing and shape	Topology and shape	Sizing. shape and topology
1	1.131	44.179	33.183	-	1.131	38.485	-
2	23.758	44.179	33.183	23.758	23.758	38.485	12.566
3	33.183	44.179	33.183	33.183	33.183	38.485	33.183
4	2.011	44.179	33.183	-	1.131	38.485	-
5	4.909	44.179	33.183	28.274	4.909	38.485	-
6	28.274	44.179	33.183	28.274	7.069	38.485	4.909
7	38.485	44.179	33.183	38.485	28.274	38.485	9.621
8	44.179	44.179	33.183	44.179	28.274	38.485	38.486
Weight [*kg*]	687.111	893.153	666.993	679.37	413.612	689.972	328.893

Table 3 *Node coordinates according to type of constraints used*

Node coordinate	Buckling constraint	Shape	Sizing and topology	Sizing and shape	Sizing, shape and topology
$-X_3, X_4, X_5, -X_6$ [*m*]	without	0.508	0.508	0.640	0.818
	with	0.508	0.508	0.508	0.995
$Y_3, Y_4, -Y_5, -Y_6$ [*m*]	without	1.016	4.220	1.016	1.196
	with	1.016	1.016	1.300	1.224
Z_3, Z_4, Z_5, Z_6 [*m*]	without	2.286	3.120	2.286	3.163
	with	2.286	2.286	2.460	2.590
$-X_7, X_8, X_9, -X_{10}$ [*m*]	without	1.016	1.016	1.016	1.016
	with	1.016	1.016	1.016	1.016
$Y_7, Y_8, -Y_9, -Y_{10}$ [*m*]	without	2.540	2.713	2.540	2.684
	with	2.540	2.540	2.540	2.540

5. CONCLUSION

Structural optimization of trusses is a powerful tool in the design process of any truss structure. Through the use of various types of optimization it is possible to derive a structure which would otherwise require a lot more time end experience to achieve, or even create a structure with a geometry unfathomable by human calculation. This way substantial savings can be achieved through the minimization of weight, thereby the amount of material used to create a structure with certain geometrical, spatial, loading and deformation constraints.

This paper analyses the results of structural optimization results and shows the difference in overall weight of various types of optimizations when accounting for buckling constraints as opposed to not considering them. It is evident that there is a substantial difference in construction weight for examples which do not consider buckling. These models, while lighter, in real world application would buckle under the set loads. The examples which do use Euler buckling constraints give solutions with a larger overall weight, but they are sized so as to handle the compressive forces without buckling. In addition to this, a common error in some truss optimization research has also been addressed, which is the use of continuous variables for cross-section areas. As it is impractical, and virtually impossible to create cross-sections of non-standard dimensions to a certain tolerance this research for the example which uses buckling constraints also uses discrete variables for cross-section sizing. Optimization using sizing, topology and shape as well as all their possible combinations show the range of abilities in minimizing weight. It is not always possible to optimize all three aspects of a construction, but comparative analyses such as this show the difference in their combinations or individual use.

It has also been found, even though the bars are grouped in this particular example, that a large number of different cross-sections are used for optimal solutions. Further research in this field will include the possibility of limiting the number of different cross-sections used in a truss construction so as to create more practical constructions.

Acknowledgment

This paper is a result of the TR32036 and TR33015 projects, which are investigations of the Technological Development of the Republic of Serbia. The projects are titled “Development of software for solving the coupled multi-physical problems” and “Research and development of a Serbian net-zero energy house” respectively. We would like to thank to the Ministry of Education, Science and Technological Development of the Republic of Serbia for their financial support during this investigation.

REFERENCES

[1] K.S. Lee, Z.W. Geem, A new structural optimization method based on the harmony search algorithm, Computers & Structures, 82 (2004) 781-798.
[2] A. Kaveh, M. Ilchi Ghazaan, Hybridized optimization algorithms for design of trusses with multiple natural frequency constraints, Advances in Engineering Software, 79 (2015) 137-147.
[3] C.-Y. Wu, K.-Y. Tseng, Truss structure optimization using adaptive multi-population differential evolution, Structural and Multidisciplinary Optimization, 42 (2010) 575-590.
[4] G.G. Tejani, N. Pholdee, S. Bureerat, D. Prayogo, A.H. Gandomi, Structural optimization using multi-objective modified adaptive symbiotic organisms search, Expert Systems with Applications, 125 (2019) 425-441.
[5] D.T. Le, D.-K. Bui, T.D. Ngo, Q.-H. Nguyen, H. Nguyen-Xuan, A novel hybrid method combining electromagnetism-like mechanism and firefly algorithms for constrained design optimization of discrete truss structures, Computers & Structures, 212 (2019) 20-42.
[6] L. Lamberti, C. Pappalettere, Move limits definition in structural optimization with sequential linear programming. Part II: Numerical examples, Computers & Structures, 81 (2003) 215-238.
[7] G.G. Tejani, V.J. Savsani, V.K. Patel, P.V. Savsani, Size, shape, and topology optimization of planar and space trusses using mutation-based improved

metaheuristics, Journal of Computational Design and Engineering, 5 (2018) 198-214.

[8] S.O. Degertekin, L. Lamberti, I.B. Ugur, Sizing, layout and topology design optimization of truss structures using the Jaya algorithm, Applied Soft Computing, (2017).

[9] N. Petrovic, N. Marjanovic, N. Kostic, M. Blagojevic, M. Matejic, S. Troha, Effects of introducing dynamic constraints for buckling to truss sizing optimization problems, FME Transaction, 46 (2018) 117-123.

[10] N. Petrović, N. Kostić, N. Marjanović, V. Marjanović, Influence of Using Discrete Cross-Section Variables for All Types of Truss Structural Optimization with Dynamic Constraints for Buckling, Applied Engineering Letters : Journal of Engineering and Applied Sciences, 3 (2018) 78-83.

[11] N. Petrovic, N. Kostic, N. Marjanovic, DISCRETE VARIABLE TRUSS STRUCTURAL OPTIMIZATION USING BUCKLING DYNAMIC CONSTRAINTS, Machine Design, 10 (2018) 51-56.