Analysis of Cable Structures through Total Potential Optimization using Meta-heuristic Algorithms

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Abstract

Cable and tensegrity structures give an ability to create new structural forms in the architectural designs which are light and flexible. Since their flexibility allows large structural displacements, a geometrically nonlinear solution method has to be used during the analysis of this type of structures. A further reason for adopting a nonlinear method is the unsymmetrical stress-strain behavior of the cables, since they do not carry compressive forces. It is also to be noted that these structures are usually designed in such a way that the elements are all pre-tensioned.
In this study, the analyses of cable and tensegrity structures are carried on by Total Potential Optimization using Meta-heuristicAlgorithms (TPO/MA) which is an emerging method applied especially to trusses and truss-like structures. The TPO/MA method searches the displacements of structure where the minimum potential energy has been achieved. Energy equations are derived on the deformed shape of the structure. Thus, geometric nonlinearity has already been taken care of. The method has already been applied with various meta-heuristic algorithms. In the present study, Harmony Search (HS) algorithm is employed for the optimization process, and it has been shown that the applied technique is robust with respect to parameters adopted and the problems tackled.

Keywords: *Cable structures, total potential optimization using meta-heuristic algorithms (TPO/MA), Harmony search.*

1 Introduction

Cable structures are structural systems that consist from only pre-tensioned cables. Because of member properties, members can only carry tensile forces and if happens that compressive stresses take place in any member, relevant member or members is disabled. Tensile integrity or tensegric structures are combination of two structural members, cables and trusses. In the main idea of these systems is to use pre-tensioned cables for tensile stresses and trusses for compressive stresses.

In this paper, analyses are presented based on Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) method (Toklu 2004; Toklu et al. 2013; Toklu and Toklu 2013) for cable and tensegric structures. In the minimization process harmony search (HS) algorithm is employed as the meta-heuristic algorithm. Total potential energy principle, is a well-known principle of mechanics; many a of methods of analysis in structural mechanics have been developed according to this principle. The potential energy of the system is equal to the difference between the strain energy of the system and sum of the work done by external loads and it is assumed that the system is in equilibrium state, when this difference is minimal. In the most of the conventional methods, this equilibrium state is investigated by the help of closed form expressions (or matrices obtained from this expression) that derived from the some mathematical operation. Although this matrix based process seems suitable for linear analyses, because of conducting iterative analyses for nonlinear analyses some minor or major errors can occur for nonlinear analyses.

In the TPO/MA method, the equilibrium state of the systems is searched by the help of the meta-heuristic algorithms instead of mathematical operations. Advantage of the TPO/MA arises from conducting the calculation of the potential energy of the system on the deformed shape. Thus, linear or nonlinear analyses can be performed easily and accurately in TPO/MA (Toklu & Toklu, 2013). In the following section the methodology of the TPO/MA and some numerical examples is presented.

2 Methodology

Harmony search (HS) algorithm developed by Geem et al. (2001) is memory based method, imitates the process of music improvisation. Being a meta-heuristic algorithm, it obeys the general rules of such algorithms (Toklu 2014). The basic steps of the HS algorithm used in minimization of total potential energy can be summarised as the flowchart shown in Fig. 1.

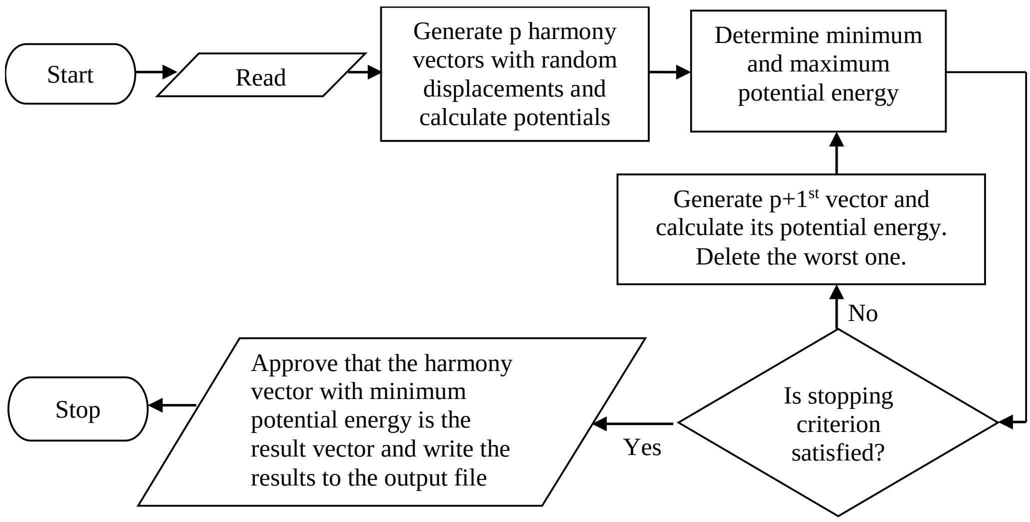

Figure 1. Flow chart of the program

Mainly the minimization process can be divided into two parts, first calculations and iteration process. In the first calculation part the geometrical and material properties of the system is defined. Then, first group of harmony vectors (the number of these vectors (p) is defined by user) is generated and stored in a matrix called harmony memory (HM) matrix. These vectors contain randomly generated displacements and potential energy of the system that calculated according to these displacements. After that, iteration process is begun. This iterative process consist from there steps;

i) Generate a new vector ($p+1^{st}$ vector) and calculate its energy,
ii) Check the stopping criteria
iii) Add new vector in HM matrix and delete the worst vector, (the biggest potential energy one).

This iterative process continues until the stopping criterion is satisfied. The stopping criterion is desired number of iteration number that defined by user. The aim of this process can be summarised as to find the nodal displacements that make the potential energy of the system minimum by the help of randomly generated displacements.

3 Numerical Examples

The proposed method is applied two numerical examples. These examples are selected within the frequently presented ones at the documented methods. Thus, presented method is compared with these methods. The comparison is made based on energy values of presented and other methods.

Example 1: Flat cable net 1 x 1

The first example is a cable grid with one free and four fully constrained joints that are joined by four cables (Fig. 2). The cross-sectional area of each cable is 0.785 mm^2 and the modulus of elasticity is 124800 N/mm^2. The pretension force at each cable is 200 N, and it is applied a downward load on the node number 3 with intensity of 15 N. The displacement of the node 3 and the total potential energy values of the system for presented method and other two documented method can be seen in Table 1. Also, energy and displacement changing vs. iteration number is given in Figs. 3 and 4.

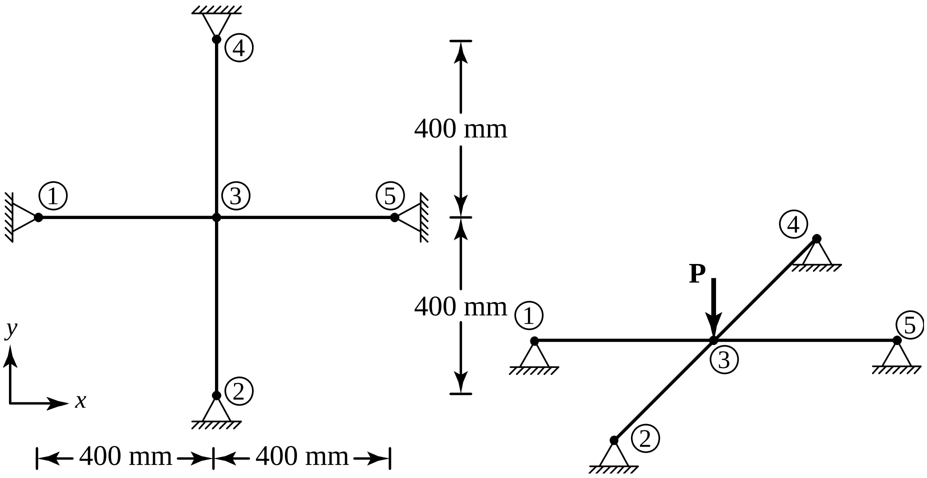

Figure 2. System consist for four cables (Lewis, 1989)

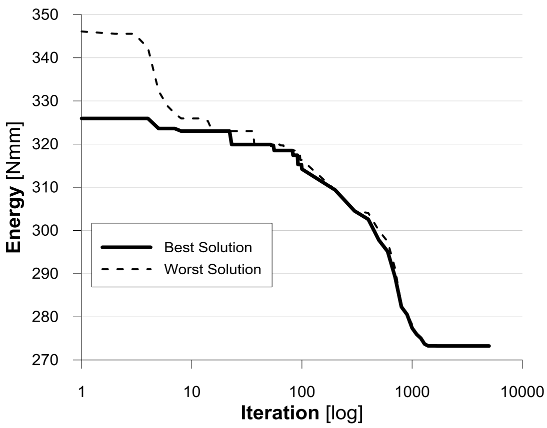

Figure 3. Energy vs iteration number for the best and worst solutions

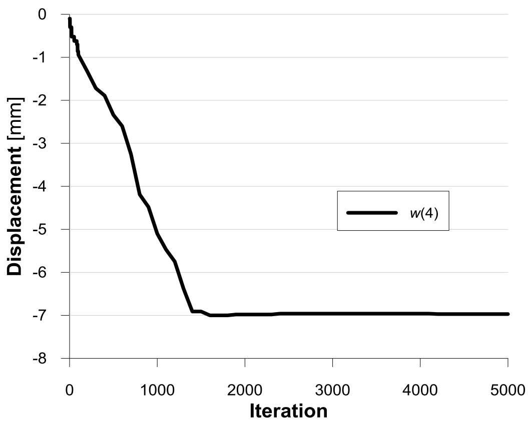

Figure 4. Vertical displacement vs iteration number of joints 4

Table 1. Total potential energy value for example 1

Node	Lewis (1989)			Halvordson (2007)			Presented method (5.000 Iteration)		
	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z
3	0	0	6.97	0	0	6.98	0	0	6.97
Energy [Nmm]	273			273			273		

Example 2: Flat cable net 2 x 2

The second example is 3x3 square grid with cell side lengths of 400 mm. System consist of 12 cables with four free and eight fully constrained joints (Fig. 5). Cross-sectional area (A) and the modulus of elasticity (E) multiplication of each member is 97.97 kN. The pretension force at each cable is 200 N, and loads on the nodes can be seen in figure. The displacement and the total potential energy values of the system is given in Table 2. Also, energy vs. iteration number graph is given in Fig. 6.

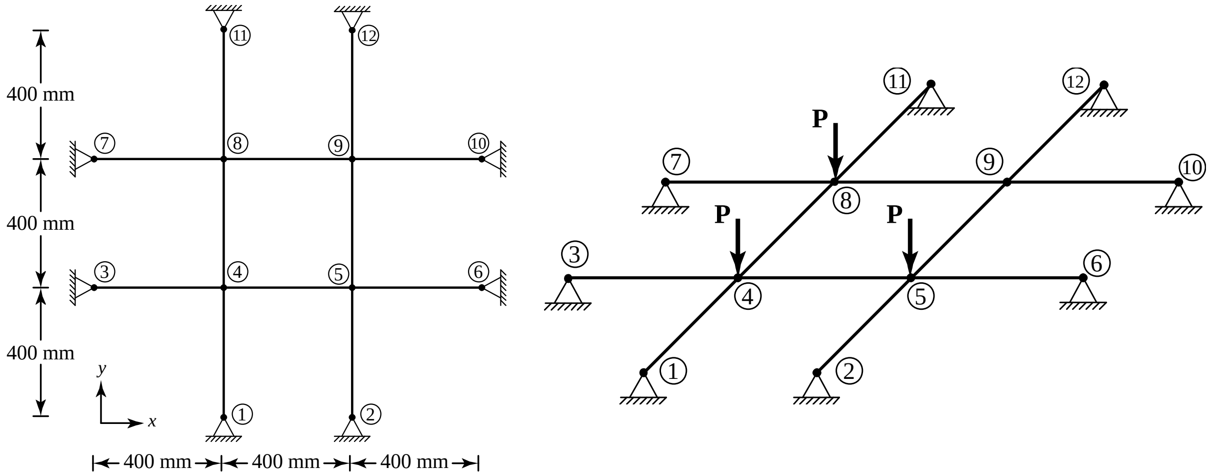

Figure 5. System with 3x3 square grid

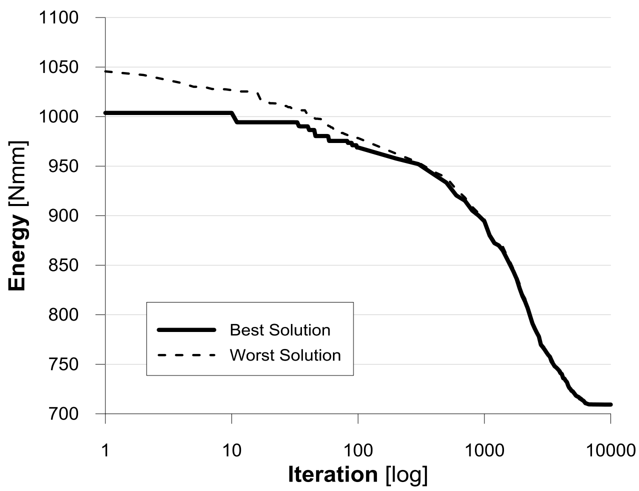

Figure 6. Energy vs iteration number for the best and worst solutions

Table 2. Total potential energy value for example 2.

Node	Lewis (1989)			Kwan (1998)			Halvordson (2007)			Presented method (10.000 Iteration)		
	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z	δ_x	δ_y	δ_z
4	-0.1	-0.1	-12.2	-0.08	-0.08	-12.17	-0.07	-0.07	-12.2	-0.07	-0.07	-12.15
5	0	-0.1	-11.2	0.04	-0.08	-11.18	0.04	-0.08	-11.2	0.04	-0.08	-11.16
8	-0.1	0	-11.2	-0.08	0.05	-11.18	-0.08	0.04	-11.2	-0.08	0.04	-11.16
9	0	0	-5.6	-0.04	-0.04	-5.59	-0.04	-0.04	-5.59	-0.04	-0.04	-5.58
Energy (Nmm)	711.3974			709.3901			709.3227			709.3182		

4 Conclusions

In the study, it has been shown that cable structures can be analysed by using a technique called TPO/MA, with harmony search algorithm being applied in the minimization process. The analyses are performed on two numerical examples that are usually used as test examples for validating a method. The total potential energy results are compared with other documented methods. According to results, the presented TPO/MA method for basic cable structural system (example 1) gives equal energy value and for more complex structures (example 2) better energy values are obtained. The results show the robustness and effectiveness of the technique used. It can also be concluded the technique can be applied to more complicated structures like tensegrities.

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