Teaching learning based optimization algorithm for analyses of trusses considering elastoplastic behavior

YUSUF CENGİZ TOKLU
Department of Civil Engineering, Faculty of Engineering,
Bilecik Şeyh Edebali University, Bilecik, Turkey
cengiztoklu@gmail.com

RASİM TEMÜR
Department of Civil Engineering, Faculty of Engineering,
Istanbul University, Istanbul, Turkey
temur@istanbul.edu.tr

GEBRAİL BEKDAŞ
Department of Civil Engineering, Faculty of Engineering,
Istanbul University, Istanbul, Turkey
bekdas@istanbul.edu.tr

Abstract: - Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) is an analyses technique developed by implementation of metaheuristic algorithms for finding an equilibrium state of a structural system according to the well-known principle of minimum total potential energy. According to this theory, a system is in equilibrium state only if total potential energy of it which means sum of the strain energy and work done by external loads is minimum. This paper presents a methodology for TPO/MA analyses of truss structures considering elastoplastic behavior of material and geometrical nonlinear behavior of system. Methodology is developed based on one of the recently proposed metaheuristic algorithm called teaching learning based optimization (TLBO) method. In order to put for the effectiveness or ineffectiveness of presented method for problem, results are compared with existing ones from the literature. According to results, TLBO is more effective in computational cost than others.

Key-Words: - meta-heuristics; teaching learning based optimization; total potential optimization method; TPO/MA; truss structures; elastoplastic.

1 Introduction

Formulations used in analyses of structural systems are derived from the well-known principle of mechanics named minimum potential energy. Total potential energy of a system is the sum of the strain energy caused by the deformation of the structure and the negative of the work done by the external loads during that deformation. If this energy value is minimum, the system is in an equilibrium state.

Conventional methods, i.e. finite element method, use mathematical operations to obtain minimum energy of a system. From these operations, a basic equation $\Delta = K^{-1}P$ is obtained and analyses is performed based on this equality. In this equality, P is the external load vector, K is the stiffness matrix, and Δ is displacement vector. For linear structures K can be determined by simple vectorial operations and Δ can be obtained by well-known solution techniques. In the case of nonlinear structures displacement vector contains unknown values, and thus an iterative approach must be conducted in order to solve the system.

Alternatively, analyses can be conducted by TPO/MA method. In TPO/MA, instead of mathematical operations of traditional methods, metaheuristic algorithms are employed to obtain minimum energy value of the system. This approach uses last geometry (deformed shape) for calculation of strain energy and external load work. Thus, geometrical nonlinearity becomes already taken into consideration without any additional process and exact solution can be obtained. But, analyses time of the system can be long for very complicated structures. Thus, selection of suitable metaheuristic

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algorithm is very important to provide acceptable computational time.

Until recently, some metaheuristic algorithm such as local search (LS), harmony search (HS), particle swarm algorithm, etc. has been used in TPO/MA approach [1-7]. In this paper, teaching learning based optimization (TLBO) is applied as metaheuristic algorithm and the results are compared with the ones existing in the literature to observe the effectiveness or ineffectiveness of method.

2 Methodology

Methodology of teaching learning based optimization (TLBO) algorithm has been proposed by Rao et al. [8] in 2011 from the inspiration of teaching and learning interaction in a class. Since then, TLBO algorithm has been implemented wide variety of optimization problems with different engineering department, especially mechanical, civil and electrical engineering [9-14]. Unlike the other metaheuristic algorithms, TLBO does not have special algorithm parameters. This innovate part of the algorithm provided numerous applications in a very short time.

The methodology of TLBO algorithm developed for potential energy minimization can be divided two main part.

Part 1- First calculations: This part of the methodology consist from two sub steps. In the first one, data of the problem including elasticity modulus of material, cross-section dimensions of members, coordinates and boundary conditions of joints, start and end joint numbers for each member, external loads, range for design variables is entered. As stated in previous section, design variables of TPO/MA technique are joint displacements. Additionally, population size (ps) and stopping criteria or criterion must also defined for optimization process. Although, according to optimization problem various condition may be identify as stopping criteria, general trend is to determine a maximum number for iteration.

The second step is generated initial solution matrix (class). Each column of this matrix a candidate solution (leraner) that contains randomly generated joint displacements of system. By using these displacements, the strain energy (StE) for each member and energy done by external loads (WEL) which is calculated by multiplying intensity of loads and displacements in direction of related loads are determined. Sum of these energies give total potential of system (TPs). These TPs values are also stored in solution matrix for future comparisons. For further information about calculations see Ref [1, 4-7]

Part 2- Iterations: This part is also contains three sub steps. First one is teacher phase. As teacher is person with the best knowledge in a class, a solution vector with the minimum TPs is assigned as teacher of the solution matrix ($X_{teacher}$).

$$X_{teacher} = X_{min\, f(X)} \quad (1)$$

After determining the $X_{teacher}$, other solution vectors are updated as

$$X_{new,i} = X_{old,i} + rnd\left(0,1\right)\cdot\left(X_{teacher} - T_F\cdot X_{mean}\right) \quad (2)$$

where X_{mean} is mean value of all related joint, each $X_{old,i}$ is stored vector, $X_{new,i}$ is updated vector, *rnd* is a random number within the range [0, 1] and T_F is teaching factor determined as

$$T_F = round\left[1 + rnd\left(0.1\right)\right] \rightarrow \left\{1-2\right\} \quad (3)$$

If TPs of the new vector is better than the old one, the old one is replaced with the new vector. This updating and replacing process is done for each solution vector (from i=1 to ps).

Then, leaner phase is applied to the solution matrix. Learners have also an important role in learning process by interaction each other. In TLBO algorithm, this procedure is formulated as

$$X_{new,i} = \begin{cases} X_{old,i} + r_i\cdot\left(X_i - X_j\right); & f\left(X_i\right) > f\left(X_j\right) \\ X_{old,i} + r_i\cdot\left(X_j - X_i\right); & f\left(X_i\right) < f\left(X_j\right) \end{cases} \quad (4)$$

where X_i and X_j are the randomly selected learners. By applying the same process that used in teacher phase for selection of new and old solutions, learner phase is ended.

In the third step of part 2, the stopping criteria is checked. If it is not satisfied the iterative process (Part 2) is stopped.

3 Numerical Examples

The presented method is applied on a 6-bar truss system given in Fig. 1. Cross section of all member are taken as 100 mm^2 and concentrated load with P= 150 kN intensity were applied as external load (see Fig. 1).

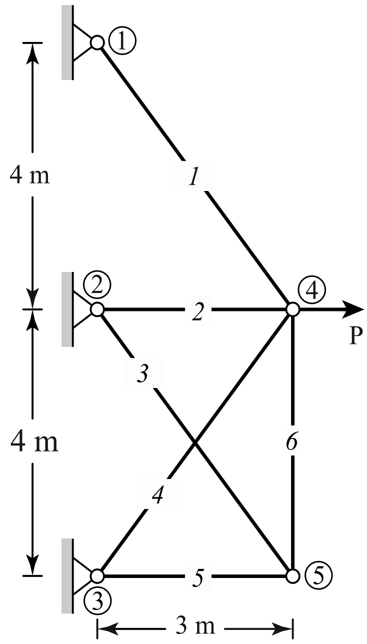

Figure 1. 6-Member truss system.

There different material properties are used in the analyses. As seen in Fig. 2, MAT1, MAT2 and MAT3 are represent, linear, bilinear and nonlinear materials. Thus, presented method is performed for mostly used material types.

The same analyses are also done with other documented method to show strengthens or weaknesses of presented method. Results are also compared a well-known technique called finite element method (FEM) that gain general acceptance as analyses methods. In order to show important difference between linear and nonlinear analyses results and prove effectiveness of the proposed method for nonlinear solutions, both linear and nonlinear analyses are done.

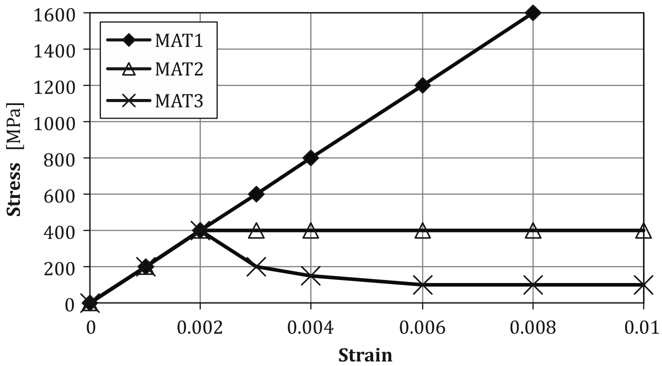

Figure 2. Material properties of system

Analyses result including minimum potential energy value, joint displacements and member forces are given in Table 1. As seen in Table 1, expect the FEM linear analyses, same results are obtained with all methods. In the Figs. 3 and 4, convergence speed (computational cost) of HS and TLBO approach can be seen. Although the same minimum energy value are obtained for both approach, important difference in computational cost is observed. The effectiveness on convergence speed for joint displacements and member forces are also seen from the Figs. 5-8.

Table 1. Analyses result for different solution techniques

Material	Energy [kNm]	Joint Displacements [mm]				Member Forces [kN]					
	U	*u*(4)	*v*(4)	*u*(5)	*v*(5)	*f*(1)	*f*(2)	*f*(3)	*f*(4)	*f*(5)	*f*(6)
MAT1[a]	-1.059727	14.15	2.84	0.30	2.31	49.725	94.331	-6.669	43.056	4.001	5.335
MAT1[b]	-1.059735	14.12	2.83	0.30	2.32	49.810	94.14	-6.688	42.973	4.034	5.351
MAT1[c]	-1.059735	14.12	2.83	0.30	2.32	49.811	94.142	-6.688	42.974	4.035	5.352
MAT1[d]	-1.059735	14.12	2.82	0.30	2.31	49.863	94.143	-6.671	42.949	4.013	5.339
MAT1[e]	-1.059735	14.12	2.83	0.30	2.32	49.799	94.142	-6.703	42.981	4.012	5.339
MAT2[c]	-36.75831	1931.60	-403.79	1.89	88.17	80.000	40.000	-40.000	40.000	42.512	37.642
MAT2[d]	-36.75835	1931.00	-402.64	1.84	89.00	80.000	40.000	-40.000	40.000	42.122	37.793
MAT2[e]	-36.75831	1931.60	-403.75	1.89	88.21	80.000	40.000	-40.000	40.000	42.477	37.639
MAT3[c]	-52.09811	2235.51	387.11	-283.55	1277.18	80.000	40.000	-10.000	40.000	22.839	21.616
MAT3[d]	-52.09777	2234.42	383.46	-280.13	1269.86	80.000	40.000	-10.000	40.000	22.744	21.826
MAT3[e]	-52.09811	2235.52	387.11	-283.56	1277.2	80.000	40.000	-10.000	40.000	22.852	21.624

[a] Linear solution obtained using FEM
[b] Geometrically nonlinear solution obtained using FEM
[c] Toklu (2004)
[d] Bekdas et al. (2014)
[e] Present Method

4 Conclusion

In this paper, TPO/MA truss analyses considered geometrical and material nonlinear behaviour are investigated. Optimization process is developed based on TLBO algorithm. In order to show accuracy of effectiveness the proposed method, analyses results are compared with finite element method and other methods that used different metaheuristic algorithms.

According to results, the same minimum potential energy, joint displacement and member forces are obtained for all methods. However, better convergence speed are observed in computational cost which is very important parameter of selection of metaheuristic algorithm of TLBO approach. Consequently, TLBO algorithm is an effective, robust and powerful method for this kind of problem.

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