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OPTIMIZATION OF DOUBLE LAYER GRID STRUCTURE WITH TEACHING-LEARNING BASED OPTIMIZATION

Harsh Patel[1], Vishal Arekar[2], Atul Desai[3]

[1] *M. Tech Student of Structural Engineering Department, BVM Engineering College, V.V. Nagar, Gujarat*

[2] *Assistant Professor, Structural Engineering Department, BVM Engineering College, V.V. Nagar, Gujarat*

[3] *Associate Professor, Structural Engineering Department, BVM Engineering College, V.V. Nagar, Gujarat*

***Abstract* — An effective optimization algorithm titled as TLBO stands for Teaching-Learning Based Optimization is used for structural optimization. This paper present a meta-heuristic optimization method TLBO and its application using the phenomenon in classes. The TLBO includes two phases: learning from the teacher called 'Teacher phase' and learning by the interface between learners called 'Learner phase'. The validity of the method is established by one benchmark truss problem and the results are compared with the literature and optimization of double layer grid structure is conducted.**

Keywords- Structural optimization, Truss structure, Teaching-learning-based optimization.

I. INTRODUCTION

Structural engineers have always a concern about optimal design in practice. It is responsible for engineers to design structures with high reliability and low cost. For these purposes, many optimal algorithms were investigated to accomplish the tasks including the classical methods and the innovative algorithms. The optimization algorithms used to find minimum weight of the structural system to obtain an optimum set of design variables. Many studies have been conveyed for distinct optimization by using the popular optimization algorithm, such as Genetic Algorithm (GA), Ant Colony Optimization (ACO), etc.

Rao et al. (2011) have established the TLBO for optimization problems. The efficiency of the TLBO algorithm for both constrained and unconstrained problems in the field of structural optimization has not been entirely attempted so far. Some researchers have inspected the TLBO algorithm in certain structural optimization problems such as Togan 2012; Dede 2013; Degertekin and Hayalioglu 2013; Cheng et al. 2013; Camp and Farshchin 2014; Farshchin et al. 2016; Savsani et al. 2016; Tejani et al. 2016. In this study one benchmark problem of truss structure optimization subjected to stress and displacement constraints are presented to validate the effectiveness of the TLBO. And a double layer grid structure is optimized using TLBO algorithm.

II. TEACHING LEARNING BASED OPTIMIZATION

TLBO was used for constrained mechanical design optimization problems first time ever and the researchers obtained better results of their pioneer studies. The general steps in the algorithm are given as:

Step I: State the problem, optimization constraints and termination condition.

Step II: Initialize the population.

Step III: Select the best solution as a teacher, whose contributions in the class is to improve the grades of the learners in 'Teacher Phase'.

Step IV: Learners also improve their grades by mutual interface among themselves in 'Learner Phase'.

Step V: Termination condition: Repeat the procedure from Step III until the termination condition is satisfied.

TLBO considers initial population as randomly generated, similar to the other optimization algorithm. This initial population consists the number of students as design variables (X_i). P_n is size of population, ng is the number of group, X_{min} and X_{max} are the minimum and the maximum value of the design variables of the truss structure.

A result is achieved as a new population in two phases of TLBO algorithm. In the teacher phase, the student having minimum objective function (f) value, which is allocated as a teacher. The other students in the current population are revised as neighborhood of the teacher.

$$student_{new\_i} = student_i + r.*(teacher - TF*mean) \quad (1)$$

Here, r is a randomly generated vector in the range [0,1] and TF stands for the teaching factor.

$$TF = round\ (1 + rand*(2 - 1)) \tag{2}$$

Here, size of r needed to be equivalent to size of the student. If the objective function of revised student is greater than the objective function of old student, the new student is not taken into account. The teaching phase is carried out by the hope that the level of students will be updated to the level of teacher.

In student phase, all revised students are compared with each other to increase their knowledge. As noted in the teacher phase, the new student obtained from student phase is not taken into account if its objective function is not better. At the end of the last iteration, the student whose objective function is minimum in the population is the best solution of optimization problem.

III. FORMATION OF PROBLEM

One of the most important factors in the structural design is the total structural weight. In this study, truss structures are designed to be the minimum weight. For this purpose, the objective function for the truss structures is formulated as:

$$\min \mathrm{W} = \sum_{k=1}^{ng} A_k \sum_{i=1}^{nm} \rho_i L_i \tag{3}$$

Here W is the minimum weight of the structure, which is the objective function, ρ is the density of materials, A stands for the cross-section areas of the each member, nm is the total number of member of the truss structures and ng is the number of group. For this problem, displacement, stress and stability constraints are given as:

$$\delta_i \leq \delta_u, \qquad C_i = \frac{\delta_i}{\delta_u} \rightarrow i = 1,2,\ldots,np \tag{4}$$

$$\sigma_i \leq \sigma_u, \qquad C_j = \frac{\sigma_i}{\sigma_u} \rightarrow j = 1,2,\ldots,nm \tag{5}$$

Where c is the value of each constraints, δ_i and δ_u are the calculated and allowable displacement for point i, respectively. np is the number of points with restricted displacements. σ_j and σ_u are the calculated and allowable stress for member j, respectively. nm is the number of members in truss structure.

The objective function must be changed as independent of constraints. For this aim, a penalty function calculating value of violation of constraints is determined. By means of this function, the objective function is changed to a function including constraints. Penalty function is given as:

$$C = \sum_{i=1}^{m} C_i \tag{6}$$

Where m is the number of the constraints. Objective function is changed to penalized objective function by adding penalty function to it. The penalized objective function, Φ(x), can be formulated as:

$$\Phi(x) = W(x)\ [\ 1 + P.C\ ] \tag{7}$$

Where P is a positive constant which is a variable for each problem. This constant can be determined by the user to take into account of the constraints.

IV. 10-BAR TRUSS STRUCTURE

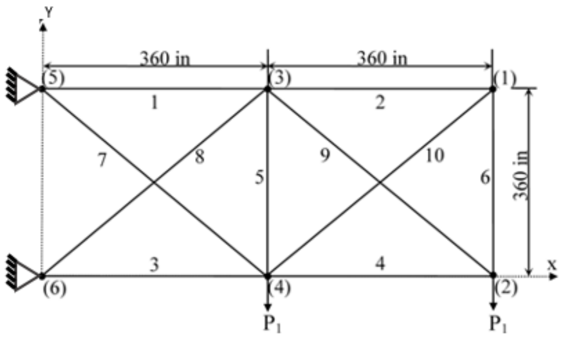

Fig. 1. 10-Bar Truss Structure

Fig. 1 shows the configuration of benchmark problem of 10 bar truss structure. Optimization of 10-bar truss structure using TLBO has earlier been carried out by many scholars, such as Dede (2013); Degertekin and Hayalioglu (2013); Cheng et al. (2013). Different parameters of truss is taken such as the modulus of elasticity of the material is 10000 ksi and the material density is 0.1 lb/in^3. The allowable stress for all the members is set to ±25 ksi, allowable displacement for all free nodes is set to 2 in for the x and y directions, and P_1 is equal to 100 kips. There are 10 design variables and the discrete variables are selected from the set of 30 members.

The best solution vector is [31.51, 1.57, 29.39, 16.97, 1.43, 1.36, 11.39, 18.13, 19.48, 0.1] in^2 and the minimum weight of structure is obtained as 5468.50 lb. Fig. 2 shows the convergence history of the minimum weight for the benchmark problem of 10-bar plane truss.

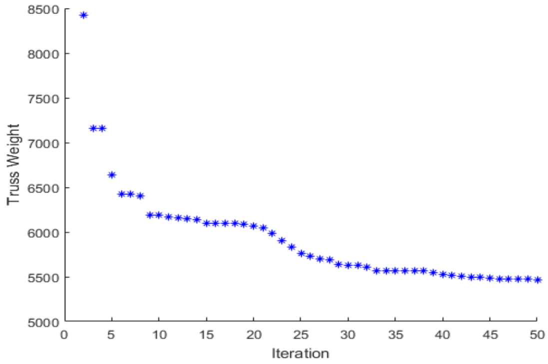

Fig. 2. Convergence History of the Truss Weight vs. Iteration

From this Fig. 2, the average solution is so close to the best solution at the end of the iteration. The results obtained from this study are compared the results given in literature in Table 1.

Table 1. Optimal Design Comparison for 10-Bar Truss Structure

Design Variables (in^2)	**Dede (2013)**	**This Study**
	TLBO	***TLBO***
A1	33.50	31.51
A2	1.62	1.57
A3	22.90	29.39
A4	14.20	16.97
A5	1.62	1.43
A6	1.62	1.36
A7	7.97	11.39
A8	22.90	18.13
A9	22.00	19.48
A10	1.62	0.1
Weight (lb)	**5490.74**	**5468.50**
Maximum Iterations	50	50
Population Size	20	20
Independent Run	20	20

V. DOUBLE LAYER GRID SRTUCTURE

Double layer grids form an important part of the space structures' family and are used to cover large open spaces with few or no internal supports. A double layer grid of size 12 m × 12 m having panel size 2.4 m × 2.4 m (5 panels) supported at four lower corners has been considered for analysis as shown in Fig. 3. The double layer grid is subjected to concentrated load P of 20 kN, applied vertically downward to each node of the top layer.

The stress constraint is 250 MPa and displacement constraint is 33.33 mm for the structure. The grid has total 200 members which are divided in four groups as per stress distribution. The lower limit for member area is 442 mm^2 and upper limit for member area is 884 mm^2. The obtained results for TLBO algorithm is shown in the Table 2 in which the weight is obtained from TLBO algorithm for different generations and different population sizes. The values of max stress and max deflection are compared using STAAD Pro.

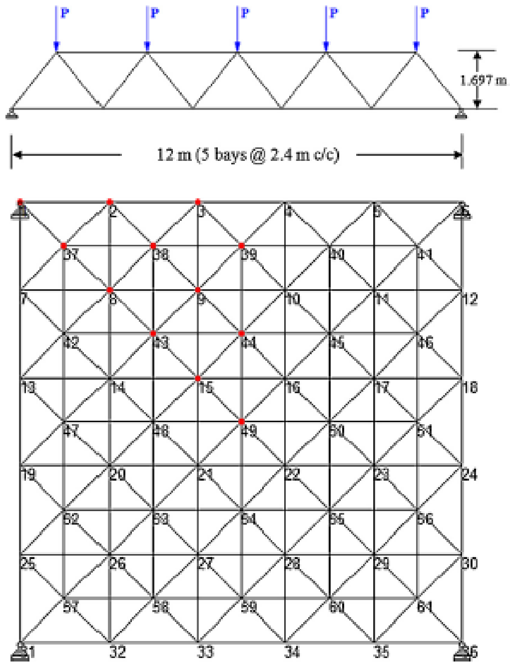

Fig. 3. Double Layer Grid Structure

Table 2. Optimal results for Double Layer Grid Structure

Generations	Population size	Weight (Kg)	Max Stress (MPa)	Max Deflection (mm)
		(using TLBO)	(using TLBO and STAAD Pro.)	
30	5	2103.107	213.801	22.801
	10	1974.462	201.606	26.603
	15	1857.292	247.568	26.714
	20	1930.726	232.138	26.956
	25	1854.922	241.246	25.905
	30	1766.215	249.978	28.613
40	5	1889.351	240.286	27.93
	10	1774.669	240.785	28.094
	15	1874.121	233.794	26.502
	20	1767.196	245.078	28.22
	25	1845.15	248.909	28.075
	30	1774.578	243.084	28.45
50	5	2247.946	235.978	26.93
	10	1799.174	226.947	28.094
	15	1839.082	227.371	26.502
	20	1804.141	240.932	28.22
	25	1774.169	217.174	28.075
	30	1818.231	249.646	28.2

VI. CONCLUSION

The results for validation problem of truss structure are nearly same from the literature. The obtained results for double layer grid structure are converging quickly and requires less numbers of generations for optimization of the problem. In this paper, an efficient and parameter free optimization algorithm titled Teaching-learning-based optimization is debated for optimization of double layer grid structure.

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