Truss Structure Optimal Parameter Selection using Hybrid GWO-CS Optimization Algorithm

Vipul Prajapat[1], Dr. I.C Sharma[2], Myanak Mehniratta[3]

[1]M. tech Scholar, [2]Professor, [3]Assistant professor, [123]Arya collage of Engineering and Research Centre

Abstract- The buildings and structure are the very important terms for the research point of view. In the civil research field the Truss structure is the main idea to develop a full strength building structure. In this work we use Truss structure which having 10 Bar model means 10 coordinates are available in the structure. The coordinates plays a important role to design the Truss structure or any structure related to the civil engineering filed. Our main aim to optimize the weight of the structure with the help of coordinates available in the structure. We use a hybrid approach of optimization which is combination of Grey Wolf Optimization and Cuckoo search algorithm for the minimization of the weight of the coordinates. The formulation of the Truss structure provided with the help of the model. The GWO-CS algorithm is work in two stages. Firstly the position of the coordinates is identified by the GWO and finds the three best positions as per the requirement. After the best position of the coordinates update the position with the help of Cuckoo search algorithm. Using the GWO-CS algorithm the weight of the Truss structure minimized. The strength of the structure increase with minimizes the weight of the coordinates. In last the comparatively study provide with the GWO and TLBO algorithm. Truss structure perfect design obtained after the optimization of GWO-CS algorithm. The GWO-CS algorithm minimizes the weight of the truss structure more than the GWO and TLBO method.

Keywords- GWO-CS Optimization, Truss Structure, Hybrid Optimization etc.

I. INTRODUCTION

In the present day scenario the civil engineer structures like buildings and bridges provide many advantages in our daily life. The traditional and optimum design process is used for the construction of these. Like traditional approaches the design firstly introduced after that the analyze all the parameters are accurate or not. The design process can be terminated. But in optimum case design approach is not terminated after finding an adequate design. The basic feature of optimum design technique criteria to be minimized or maximized (objective function) depends on the designer's needs. Modal analysis is applied to find the various periods that the structure will naturally resonate at, by using the structure's overall mass and stiffness. The main advantage of modal analysis is in earthquake engineering. The vibration period can be checked it helps to improve the natural frequency of the structure which not be matched with earthquake frequency. When the models are subjected to cyclic or vibration loads, the dynamic response of structures due to these external loads acting, which include resonance frequencies (natural frequencies), mode ,shape and damping, are estimated.

1.1 Objectives

Recently a work using Teacher learning based optimization (TLBO) was used to optimise the truss structure using multiclass approach. The TLBO provided good results but also left the option to use proposed multiclass approach for other algorithms. In our thesis, we continue this work and our objectives will be:

- To simulate and design different truss structure in MATLAB
- To apply grey wolf optimization (GWO-CS) algorithm in place of TLBO as TLBO is local optimization technique and generally falls into local optima which may not give optimized results.
- To compare the results in terms of coefficient of variation, and damage probability index (DPI).

II. STRUCTURAL OPTIMIZATION

In structural optimization inequality constraints are frequently imposed to control the behaviour of the structure such as by limiting the allowable displacements and the allowable stresses while avoiding instabilities such as those associated with buckling Structural optimization problems are generally divided into three classes.

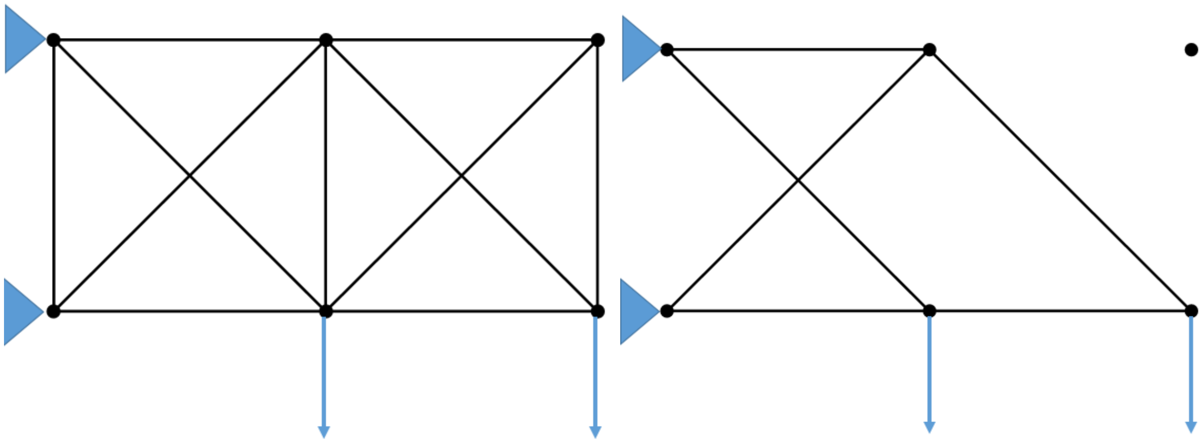
1. Size optimization problems:
2. Shape optimization problems:
3. Topology optimization problems:

Size optimization- In size optimization, or optimization of discrete parameter systems as it is often called, the sizes of already defined structural members are varied to find the optimal design. This implies that before such an optimization can be done, the structure to be analyzed must be defined.

Shape optimization- A shape optimization can be used when no change in topology is needed or wanted, e.g. to refine the solution from a topology optimization. It is especially good at eliminating high stress concentrations . the position of the nodes as design variables to explicitly move the border.

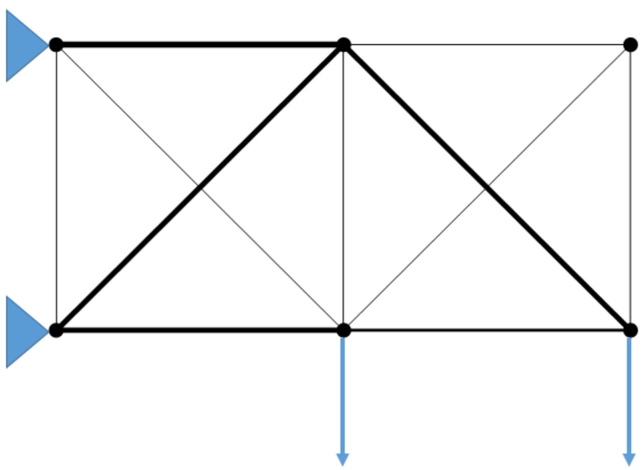
Topology optimization- Topology optimization is the most general type of structural optimization, widening the problem to the study of the structures topology, i.e. not only to the size and shape of the members but also how the members are connected to each other.

The commonly used optimization is Topology Optimization because it is ideally shaped optimization. A large number of node can be eliminated by using the topology optimization. The figure shown below initial design ,topology design and size optimized design for a cantilever Truss.



(a) (b)

Fig.1: a) Initial truss design; b) topology optimized truss[7],



(c)

Fig.1: c)A design where the cross sectional areas of the members have been optimized and line weight are proportional to cross sectional areas [4].

III. OPTIMIZATION

a. GWO optimization

We followed the hierarchy nature of the wolves while developing the GWO. The alpha, beta, delta, and omega $(\alpha, \beta, \delta \text{ and } \omega)$ consider as the parameters. Where the best fittest solution consider as the alpha (α). The second and third best solutions are $(\beta, and\ \delta)$ respectively. The rest of the solution consider as the omega (ω). The optimization process guided by the three wolves and omega follow these three wolves.

The mathematical expression of wolves **encircle prey** in the hunting process shown in the equations

$$E = \vec{F}.\overrightarrow{G_p}(k) - \vec{G}\ (k)| \quad (1)$$

$$\vec{G}(k+1) = \overrightarrow{G_p}(k) - \vec{P}.\vec{E} \quad (2)$$

The P and $\vec{Q}$ are a coefficient vector, $\vec{G}$ reflects the position vector the grey wolf, k represents the current iteration, $\overrightarrow{G_p}$ is the position vector of prey. The formulation of the coefficient vector showed in the equation 3 and 4.

$$\vec{P} = 2\,\vec{p}\,.\overrightarrow{b_1} - \vec{p} \quad (3)$$

$$\vec{Q} = 2.\overrightarrow{b_2} \quad (4)$$

The range of the component p is from 2 to 0 and b_1, b_2 both are random vectors in [0, 1].

The alpha usually guides hunting, but beta and delta also play a vital role in obtaining the best position of the prey. We consider the alpha is the best solution and bêta; delta provides the location of prey. We save three best solution obtained so far and omega values update as per the best position of the search agent.

$$\overrightarrow{E_\alpha} = |\overrightarrow{Q_1}.\overrightarrow{G_\alpha} - \vec{G}| \quad (5)$$

$$\overrightarrow{E_\beta} = |\overrightarrow{Q_2}.\overrightarrow{G_\beta} - \vec{G}| \quad (6)$$

$$\overrightarrow{E_\delta} = |\overrightarrow{Q_3}.\overrightarrow{G_\delta} - \vec{G}| \quad (7)$$

$$\overrightarrow{G_1} = \overrightarrow{G_\alpha} - \overrightarrow{P_1}.(\overrightarrow{E_\alpha}) \quad (8)$$

$$\overrightarrow{G_2} = \overrightarrow{G_\beta} - \overrightarrow{P_2}.(\vec{E}) \quad (9)$$

$$\overrightarrow{G_3} = \overrightarrow{G_\delta} - \overrightarrow{P_3}.(\overrightarrow{E_\delta}) \quad (10)$$

$$\vec{G}(K+1) = \frac{\overrightarrow{G_1}+\overrightarrow{G_2}+\overrightarrow{G_3}}{3} \quad (11)$$

The vector $\vec{a}$ use to control the trade off between exploration and exploitation phase, the range of this vector between 0 to 2.

$$\vec{a} = 2 - t.\frac{2}{Max_{iter}} \quad (12)$$

3.2 Cuckoo search Algorithm

Applied Cuckoo search algorithm to the updated positions which are obtained by WOA algorithm. Set the same bound limits. Equations 2 or 5 again update after the implementation of CS. The levy flight evolution and again update the position of local search through CS algorithm. The L´evy flight essentially provides a random walk while the random step length is drawn from a L´evy distribution. The new solution is written as

$$X_i^{(t+1)} = X_i^t + a \oplus Levy(\lambda) \quad (12)$$

Where α > 0 is the step size which should be related to the scales of the problem of interests. In most cases, we can use α = 1. The above equation is essentially the stochastic equation for random walk. The product ⊕ means entry wise multiplications.

Where levy flight is describe by equation

$$Levy \oplus u = t^{-\lambda} \quad (1 < \lambda \leq 3) \quad (13)$$

IV. PROPOSED WORK

4.1 Hybrid GWO-CS optimization

Once all wolves are initialized with some random feed then fitness function is calculated for each wolf. In a group 10-20 wolves are considered. Out of them the one with minimum fitness function (as GWO works to reduce the distance between prey and wolf and optimal position is the prey position whereas CS works for maximization of profit) is considered as leader of the group and α_wolf, followed by two more wolf with corresponding decreasing fitness function as β_wolf and γ_wolf . The mean of these positions is considered as optimal position of wolf in that iteration.

$$GWO\ optimal\ position = \frac{\alpha_{wolf}+\beta_{wolf}+\gamma\_wolf}{3} \quad (14)$$

Top three wolf positions are updated by equation 1 and 2 and new position is the mean of these three. In GWO, to move towards the prey, the distance between prey and golf is minimized and changed over time. The step size by which wolf moves is randomly weighted by a constant which leads to fall it into local optima. This problem is solved by cuckoo search algorithm which update the current position based on the best position so far. CS optimality is more relied on other habitat groups rather than only time. To make it hybrid we updated the best three locations of wolves in the group by CS method which update it by a step of λ with angle ω. The step size is updated as:

stepsize=w*step.*(s-best); (15)

where 's' is the position of alpha_wolf, beta_wolf and gamma_golf

'step' is the previous step size of cuckoo movement

'stepsize' is the updated step size

'w' is the weighting factor = 0.001

The position of cuckoo is now updated as:

$$s = s + stepsize \times \omega \quad (16)$$

whereω is the deviation of cuckoo and a random quantity.

Using equation 16 the $\alpha_{wolf}, \beta_{wolf}, \gamma_{wolf}$ are updated to new positions and handle will get back to GWO form CS. Now GWO takes mean of all three best positions again and tradeoff the local optima error in this hybrid.

Steps of proposed work

Step1. randomly place the coordinate X in an area of $100 \times 100\ m^2$

Step2. Fix the few nodal coordinate as reference coordinate with respect to frequency range.

Step3. Start a loop for each coordinate and call the optimization module. Inside this module, initiate the wolf position randomly within the truss area.

Step4. For each wolf, optimization module (objective function) is called coordinate in the truss structure. Measure the weight of the structure.

Step5. Weight is calculated and passed back to GWO-CS optimization. This step is repeated for every grey wolf in the group.

Step6. Top three best wolves are selected for which weights comes out to be minimum in present iteration and these wolf's position are updated by cuckoo search optimization by equation:

$$s = s + stepsize \times \omega$$

Step7. Updated positions for three best wolves are used to calculate the overall best position for present iteration and step5 is called again to calculate the weights.

Step8. This process continues till whole iterations for each coordinates are not finished.

Step9. Results are evaluated on the basis of minimum of weights.

Step10. A comparison is done with the GWO results for all these three parameters.

V. RESULTS AND DISCUSSION

The proposed work of minimize the weight of the Truss structure using the GWO-CS optimization algorithm. This method is implemented in the MATLAB. A lot of inbuilt functions in it makes the use easier and saves our time to build our code from scratch, so we can use that time in problem solution of research. We have developed our code in modules and are named as per their functions. These designed functions are called in main script, and user doesn't need to use them or call them separately. The truss structure formulation obtained from the model of truss as in [7]. We also compared the results with previously used Gray Wolf Optimization (GWO). The tuned parameters are the weight and area of the truss structure which minimize the weights of the structure. We tested the 10 Bar Truss structure using proposed method and improved the results.

The 10 bar Truss structure shown in the figure 5.1. This type of truss structure has 10 independent variables

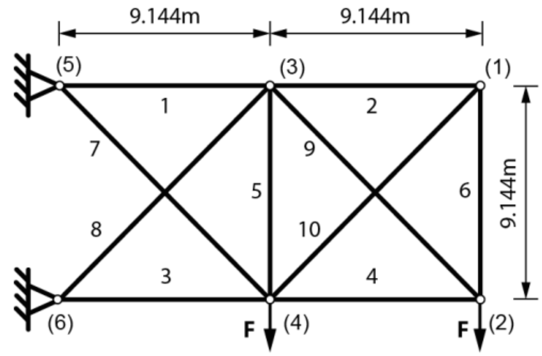


Fig.2: bar truss structure problem [22]

The material which used for the truss formation is Aluminium 6063- T5. This material has some characteristics like Young modulus 68947 MPa and the density of 2.7 g/. Point load is F=444.82 kN, as shown in Figure 5.1. The model is limited to a maximal displacement of ±0.0508 m of all nodes in all directions, axial stress of ±172.3689 MPa for all bars, and minimum area of all members is limited to 0.6426 cm^2 [22].

The initial cross section area for the 10 bar truss structure is 452.3893 cm^2. This is also the cross section area for examples which do not consider sizing, as this is the minimal rounded up diameter (240 mm) of elements which meets buckling constraints. The initial model with these bars has a weight of 13019.482 kg. In order to allow for shape optimization coordinates of nodes 1 and 3 are variables in examples which optimize this aspect of the truss. Node 5, as it is a support is not set as a variable.

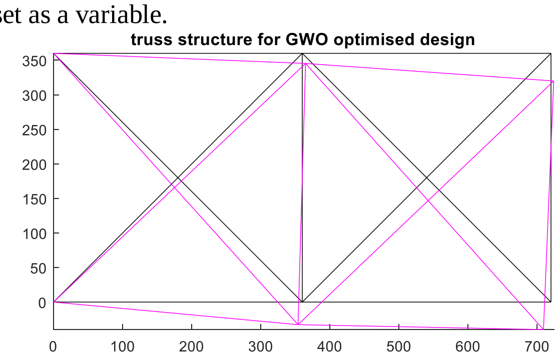


Fig.3: 10 bar truss structure obtained by GWO optimization

In figure 3 the 10 bar truss structure obtained by the GWO optimization. It provides the weight minimization improvement then the TLBO algorithm. The black shade lines are actual 10 bar truss structure and pink colour line is the 10 bar truss structure after the weight optimization by the GWO algorithm. The net weight of the truss is 5063.90 unit of the coordinate structure.

Figure 4 shows the 10 bar truss structure using TLBO method. The weight minimization of the structure is less than the weight minimization through the GWO. So the results are not very improved in this case.

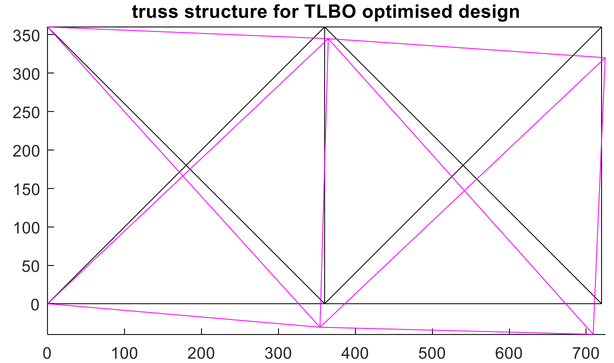


Fig.4: 10 bar truss structure obtained by the TLBO method.

Figure 5 shows the convergence curve for the 10 bar truss structure using three different methods. In this curve the GWO-CS method is provided the better result in terms of the weight minimization of the structure. Basically the coordinates and the area tuned by the algorithm. On the basis of these tuned variables we obtained the final result which is weight minimization. The comparison shown in the curve provides that GWO-CS is better than the GWO and TLBO methods of the weight minimization of truss structure.

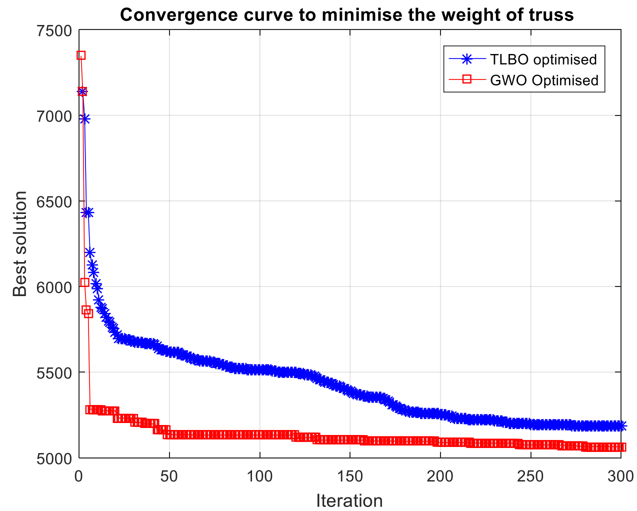
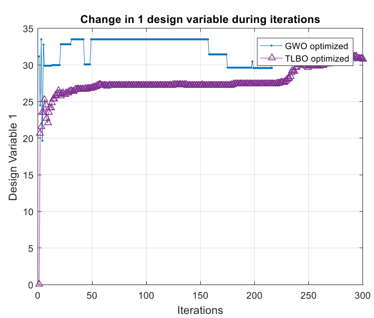
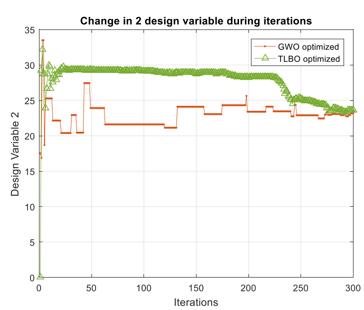
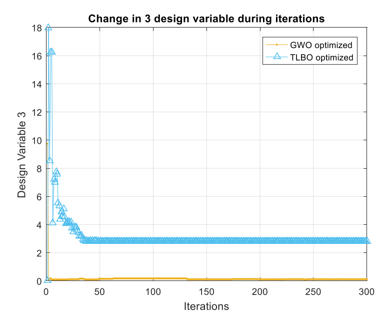
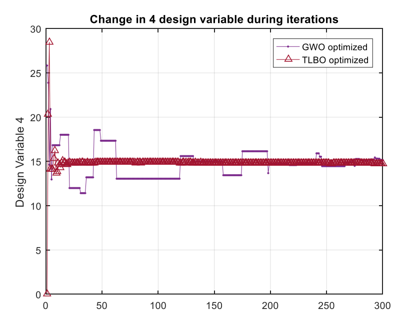
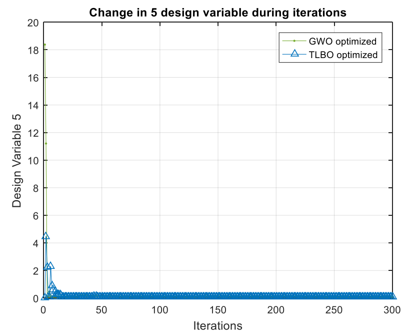
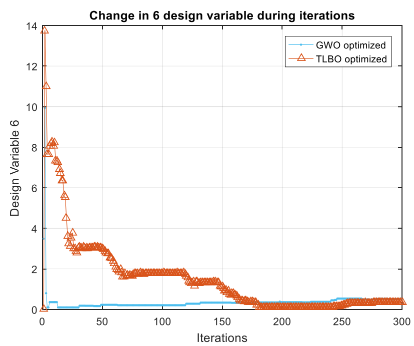
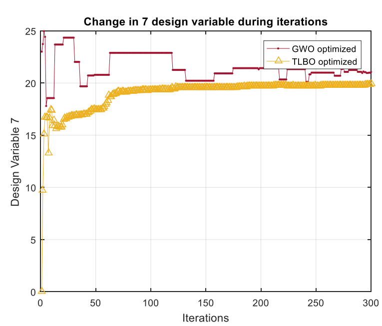
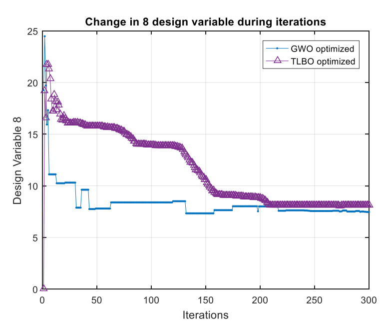
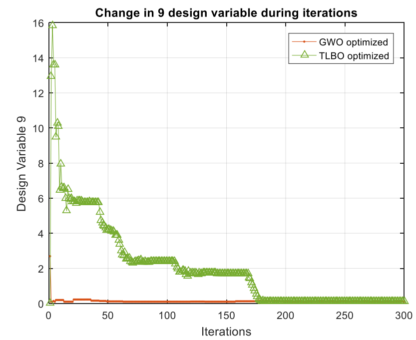
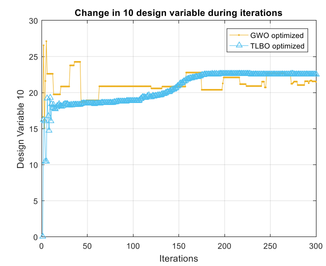


Fig.5: 10 bar truss structure convergence curve comparison between GWO-CS , GWO and TLBO method

Table 2 Fitness function curve for different bar coordinate

Coordinate number	Optimization Curve
1	
2	
3	
4	

5	Change in 5 design variable during iterations Design Variable 5 Iterations GWO optimized TLBO optimized
6	Change in 6 design variable during iterations Design Variable 6 Iterations GWO optimized TLBO optimized
7	Change in 7 design variable during iterations Design Variable 7 Iterations GWO optimized TLBO optimized
8	Change in 8 design variable during iterations Design Variable 8 Iterations GWO optimized TLBO optimized
9	Change in 9 design variable during iterations Design Variable 9 Iterations GWO optimized TLBO optimized
10	Change in 10 design variable during iterations Design Variable 10 Iterations GWO optimized TLBO optimized

In table 2 all the methods performance analysed. The weight of the 10 coordinates shown by the three algorithms separately. The GWO-CS provides the better weight minimization in the 10 bar truss structure.

Table 2 Comparison of 10 bar truss structure weight optimization using GWO-CS, GWO and TLBO

No. Of bar variables	GWO-CS	GWO	TLBO
1	29.65	30.74	30.79
2	22.79	23.18	23.59
3	0.011	0.121	2.82
4	14.89	15.13	14.77
5	0.002	0.1004	0.100
6	0.432	0.51	0.35
7	20.90	21.05	19.90
8	7.23	7.46	8.09
9	0.012	0.103	0.100
10	20.98	21.48	22.55
Function Minimize	4963.56	5063.90	5187.03

IV. CONCLUSION

In this work a 10 bar structure analyzed with the help of optimization algorithm. Firstly the 10 Bar Truss structure formulated with the help of frequency constraints. Then calculate the objective function which is basically the weight minimization function. The truss structure having the coordinates in different position of the structure. We use GWO-CS optimization algorithm for minimize the function of the truss structure. The coordinates weights and area are minimized by the optimization. The total weight or net weight of the truss structure is very low in case of GWO-CS optimization. Reduced the weight of the truss structure minimize the risk of earthquake on the truss structure. The comparison also provided in this work. The GWO-CS optimization of truss structure weight compares with the GWO optimized weight and TLBO optimized weight. The results of GWO-CS more improved than the other two methods.

V. REFERENCES

[1]. S. M. Seyedpoor & M. Montazer (2016) A damage identification method for truss structures using a flexibility-based damage probability index and differential evolution algorithm, Inverse Problems in Science and Engineering, 24:8, 1303-1322

[2]. Lei, Ying, Jiang, Yongqiang, Xu, Zhiqian, 'Structural damage detection with limited input and output measurement signals' . Mechanical Systems and Signal Processing, v.28, 2012 April, p.229(15) (ISSN: 0888-3270) Elsevier B.V., 2012 April

[3]. Camilo Manrique Escobar, Octavio Andr_es Gonz_alez-Estrada, Heller Guillermo S_anchez Acevedo. Damage detection in a one-dimensional truss using the _rey optimization algorithm and finite elements . 2017.

[4]. Bo Zhao, Zili Xu, Xuanen Kan, Jize Zhong, and Tian Guo, "Structural Damage Detection by Using Single Natural Frequency and the Corresponding Mode Shape," Shock and Vibration, vol. 2016, Article ID 8194549, 8 pages, 2016

[5]. Muthuraman, U & M. Sai Hashita, M & Sakthieswaran, N & Suresh, P & Raj Kumar, M & Sivashanmugam, P. (2016). An Approach for Damage Identification and Optimal Sensor Placement in Structural Health Monitoring by Genetic Algorithm Technique. Circuits and Systems. 07. 814-823. 10.4236/cs.2016.76070.

[6]. Hosein Ghaffarzadeh and Farzad Raeisi , 'Damage Identification in Truss Structures Using Finite Element Model Updating and Imperialist Competitive Algorithm' Jordan Journal of Civil Engineering, Volume 10, No. 2, 2016

[7]. Farshchin, Mohammad & Camp, Charles & Maniat, Mohsen. (2016). Multi-class teaching–learning-based optimization for truss design with frequency constraints. Engineering Structures. 106. 355-369. 10.1016/j.engstruct.2015.10.039.

[8]. Xu, H., Liu, J., & Lu, Z. (2016). Structural damage identification based on cuckoo search algorithm. Advances in Structural Engineering, 19(5), 849–859.

[9]. M. Nobahari, S.M. Seyedpoor, Structural damage detection using an efficient correlation-based index and a modified genetic algorithm, Mathematical and Computer Modelling, Volume 53, Issues 9–10, 2011,

[10]. Kim, Y.-W., Kim, N.-I., & Lee, J. (2016). Damage identification of truss structures based on force method and free vibration analysis. Advances in Structural Engineering, 19(1), 3–13

[11]. U. K. DEWANGAN, 'STRUCTURAL DAMAGE EXISTENCE PREDICTION WITH FEW MEASUREMENTS' U. K. Dewangan et al. / International Journal of Engineering Science and Technology (IJEST), ISSN : 0975-5462 Vol. 3 No.10 October 2011

[12]. Moradipour, Parviz, Chan, Tommy H.T., & Gallage, Chaminda (2013) Health monitoring of short-and medium-spen bridges using an improved modal strain energy method. In Miyamoto, Ayaho, Hakola, Ilkka, Yabe, Akito, & Emoto, Hisao (Eds.) Proceedings of the 5th International Workshop on Civil Structural Health Monitoring (CSHM-5), International Society for Structural Health Monitoring of Intelligent Infrastructure, Ube, Yamaguchi, Japan, pp. 166-181.

[13]. P. Sangeetha, P. Naveen Kumar and R.Senthil,'FINITE ELEMENT ANALYSIS OF SPACE TRUSS USING

MATLAB' ARPN Journal of Engineering and Applied Sciences, VOL. 10, NO. 8, MAY 2015.

[14]. Seyedali Mirjalili a,⇑, Seyed Mohammad Mirjalili b, Andrew Lewis a, 'Grey Wolf Optimizer, Advances in Engineering Software 69 (2014) 46–61

[15]. Henri P. Gavin, 'The Matrix Stiffness Method for 2D Trusses' Matrix Structural Analysis Department of Civil a Environmental Engineering Duke University, 2014

[16]. Seyedpoor, S. (2012). A two stage method for structural damage detection using a modal strain energy based index and particle swarm optimization. International Journal of Non-Linear Mechanics. 47. 1-8. 10.1016/j.ijnonlinmec.2011.07.011.

[17]. Nguyen, Khac-Duy, Chan, Tommy H.T., & Thambiratnam, David P. (2016) Structural damage identification based on change in geometric modal strain energy–eigenvalue ratio. *Smart Materials and Structures*, *25*(7), Article number: 075032.

[18]. D. Wang, W. H. Zhang, and J. S. Jiang, 'Truss Optimization on Shape and Sizingwith Frequency Constraints' AIAA JOURNAL Vol. 42, No. 3, March 2004

[19]. R. V. Grandhi and V. B. Venkayyaf, 'Structural Optimization with Frequency Constraints' AIAA JOURNAL VOL. 26, NO. 7 2013

[20]. R. Sedaghati , A. Suleman and B. Tabarrok, 'Structural Optimization with Frequency Constraints Using the Finite Element Force Method' AIAA JOURNAL Vol. 40, No. 2, February 2002

[21]. M. Mashinchi Joubari1, M. H. Pashaei2, A. Fathi3, ' Sizing optimization of truss structures under Frequency Constraints with Artificial Bee Colony Algorithm' Journal of mathematics and computer Science 9 (2014), 77 – 88.

[22]. A. MESSINA, E. J. WILLIAMS and T[.CONTURSI, 'STRUCTURAL DAMAGE DETECTION BY A SENSITIVITY AND STATISTICAL-BASED METHOD' Journal of Sound and Vibration "0887# 105"4#\ 680_797 Article No[sv870617