Damage Detection on Steel Plane Trusses via Harmony Search Algorithm

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Abstract- A damage detection study is presented on steel plane truss structures via harmony search algorithm which is one of the basic metaheuristic methods. This algorithm method mimics better musical harmony procedures. Optimum solutions are carried out by a harmony memory matrix consisting of a predetermined number of solution vectors. Scenario damages are considered on truss models. The locations of the damages are tried to determine by using the dynamic parameters. To obtain damage locations, a program based on the finite element method is coded in MATLAB programming. The dynamic parameters of damaged models are obtained by SAP2000 software. By using MATLAB programming, the scenario damage locations considered in SAP2000 programs are tried to determine by approaching the dynamic values of the damaged model as a result of a series of iterations. The results are presented by tables and figures. The results show that scenario damages on truss models are successfully detected by using dynamic parameters in MATLAB programming.

Keywords Optimum design, harmony search algorithm, damage detection, steel truss.

1. Introduction

Metaheuristic algorithm methods are commonly selected for solutions of various optimization problems. Some of them are listed as genetic algorithm method, particle swarm optimization method, ant colony algorithm method, artificial bee algorithm method, harmony search method, bat inspired algorithm method, and teaching learning based optimization method and the other methods.

Harmony search (HS) algorithm method is selected in this study to obtain optimum solutions. HS mimics musical harmony procedures, and has been used for various structural problems in last years by many researchers. Lee and Geem [1] developed harmony search algorithm on structural optimization in 2004. Saka [2] researched optimum design of steel sway frames to BS5950 using harmony search algorithm in 2009. Değertekin et al. [3] used harmony search algorithm method for optimum design of geometrically non-linear steel frames with semi-rigid connections in 2009. Değertekin and Hayalioglu [4] studied harmony search algorithm for minimum cost design of steel frames with semi-rigid connections and column bases in 2010. Değertekin et al. [5] focused on optimum design of geometrically nonlinear steel frames with semi-rigid connections using improved harmony search method in 2011. Toğan et al. [6] studied optimization of trusses under uncertainties with harmony search in 2011. Artar [7] used harmony search algorithm method for comparative study on optimum design of multi-element truss structures in 2016. Daloğlu et al. [8] studied optimum design of steel space frames including soil-structure interaction using harmony search algorithm method in 2016. Artar and Daloğlu [9] researched optimum weight design of steel space frames with semi-rigid connections using harmony search and genetic algorithms in 2016. Artar [10] applied harmony search algorithm on optimum design of steel space frames under earthquake effect in 2016.

In this study, scenario damages on steel plane truss structures are investigated by using Harmony Search Algorithm method. To detect damages, a program based on finite element method was coded in MATLAB programming. Harmony search algorithm method applied the procedures for better musical harmony. The locations of the damages are tried to determine by using the dynamic parameters. The presence of damages in structural elements is identified by stiffness reduction as a reduction in modulus of elasticity. In this study, two different examples having various damage scenarios are modeled in SAP2000 software to obtain the experimental dynamic parameters. The scenario damage locations considered in SAP2000 programs are tried to detect by approaching the dynamic values of the damaged model as a result of a series of iterations by using the program developed in MATLAB programming. Thus, the locations of simulated damages are determined by updated numerical model. The results obtained from solutions prove that scenario damages on plane truss structures are successfully determined by using dynamic parameters. Moreover, solutions show that robustness and acceptability of harmony search algorithm method.

2. Harmony Search Algorithm

Harmony Search (HS) Algorithm, a basic metaheuristic algorithm method, is developed in 2004 by Lee and Geem [1]. This algorithm method includes some procedures which mimics better musical harmony processes. Analyses in HS are conducted by harmony memory matrix (HM). Each row in the matrix represents a structural model. Harmony memory matrix is determined as

$$H = \begin{bmatrix} x_1^1 & x_2^1 & .. & x_{n-1}^1 & x_n^1 \\ x_1^2 & x_2^2 & .. & x_{n-1}^2 & x_n^2 \\ .. & .. & .. & .. & .. \\ x_1^{HMS-1} & x_2^{HMS-1} & .. & x_{n-1}^{HMS-1} & x_n^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & .. & x_{n-1}^{HMS} & x_n^{HMS} \end{bmatrix} \quad (1)$$

Harmony Memory Size (HMS) shows a specified number of solution vectors. Values in harmony matrix are updated by harmony memory consideration rate (HMCR) and pitch adjustment ratio (PAR). The operators (HMCR and PAR) provides a stronger harmony memory matrix for better optimum solution vectors. HMCR and PAR are calculated as below,

$$\begin{cases} x_i^{nh} \in \left\{ x_i^1, x_i^2, ..., x_i^{HMS} \right\} with\ probability\ of\ HMCR \\ x_i^{nh} \in X_{sl}\ with\ probability\ of\ (1-HMCR) \end{cases} \quad (2)$$

$$\begin{cases} Yes,\ with\ probability\ of\ PAR \\ No,\ with\ probability\ of\ 1-PAR \end{cases} \quad (3)$$

3. Theoretical Background

Detection of scenario damages is researched by using reduction factor for modulus of elasticity of each member in structural model. In this study, four different reduction factors such as 1.00, 0.75, 0.50 and 0.25 are applied in the analyses. While the reduction factors equal to 1.00, the element has not damaged. On the other hand, if the reduction factor of member is 0.75, the member in the structure model has 25% of damage. Natural frequencies of simulated damaged model are predefined by using SAP2000 and entered as input data. The program developed in MATLAB programming tries to determine the locations of damages using Harmony search algorithm. Local stiffness (k), mass (m) and transformation (T) matrices of each element are calculated. Thus, global stiffness (K) and mass (M) of structural system are calculated and natural frequencies of numerical model are determined as below,

$$\left(K - \lambda_i M \right) \phi_i = 0 \qquad i=1\ldots\ldots\ldots n \quad (4)$$

$$\sqrt{\lambda_i} = w_i \qquad f_i = \frac{w_i}{2\pi} \quad (5)$$

where K and M are the global stiffness and mass matrices, respectively. w_i is angular vibration frequency of structure (rad/s), φ_i is eigenvector (mode shape), λ_i is eigenvalue and n is total number of mode shapes. f_i is vibration per second (Hz). Then, the objective function value of each row in HS for each mode is determined as below [11],

$$F_{frequencies,i} = \left| \frac{f_i^E - f_i^N}{f_i^E} \right| \qquad i=1\ldots\ldots m \quad (6)$$

$$F_{t,i} = \sum F_{frequnecies,i} \quad (7)$$

f_i^E and f_i^N stand for experimental and numerical natural frequencies, respectively. $F_{frequencies,i}$ and $F_{t,i}$ show objective function value for i[th] mode and total objective function value of all modes, respectively. When the total objective function value is equal to zero, the difference between updated numerical model and simulated damaged model is same.

A flowchart of Harmony Search Algorithms is shown in Fig.1.

4. Numerical Examples

4.1. 20-Element steel plane truss model

A 20-element steel plane truss example is presented in Fig. 2. All members are pipe section of 10x1 as seen Fig.2. The modulus of elasticity is E=2.00 x108 kN /m2 and material density is ρ = 7.85 ton/m3. The same example is studied for two different damage scenarios. In case 1, member no. 15 has 50% of damage and in case 2, member no. 11 has 75% of damage. Table 1 presents the values of the first three natural frequencies obtained from MATLAB and SAP2000 software for undamaged and damaged cases. While Fig 3 presents results for case 1, Fig 4 shows results of case 2. Fig. 5 shows first three mode shape of undamaged model.

As presented in Table 1, the results of natural frequencies in MATLAB and SAP2000 programs are very close for first three modes in undamaged and damaged cases. In case 1, member no.15 has 50 % damage and the program using MATLAB is carried out around the 30th iterations as seen in Fig.3a. Fig. 3b proves that member 15 has 50% reduction in modulus of elasticity. Similarly, in case 2, member no.11 has 75% damage and the program coded in MATLAB is carried out at about the 30th iterations as shown in Fig.4b. Also, Fig. 4b presents that the member no.11 has 75% reduction in modulus of elasticity.

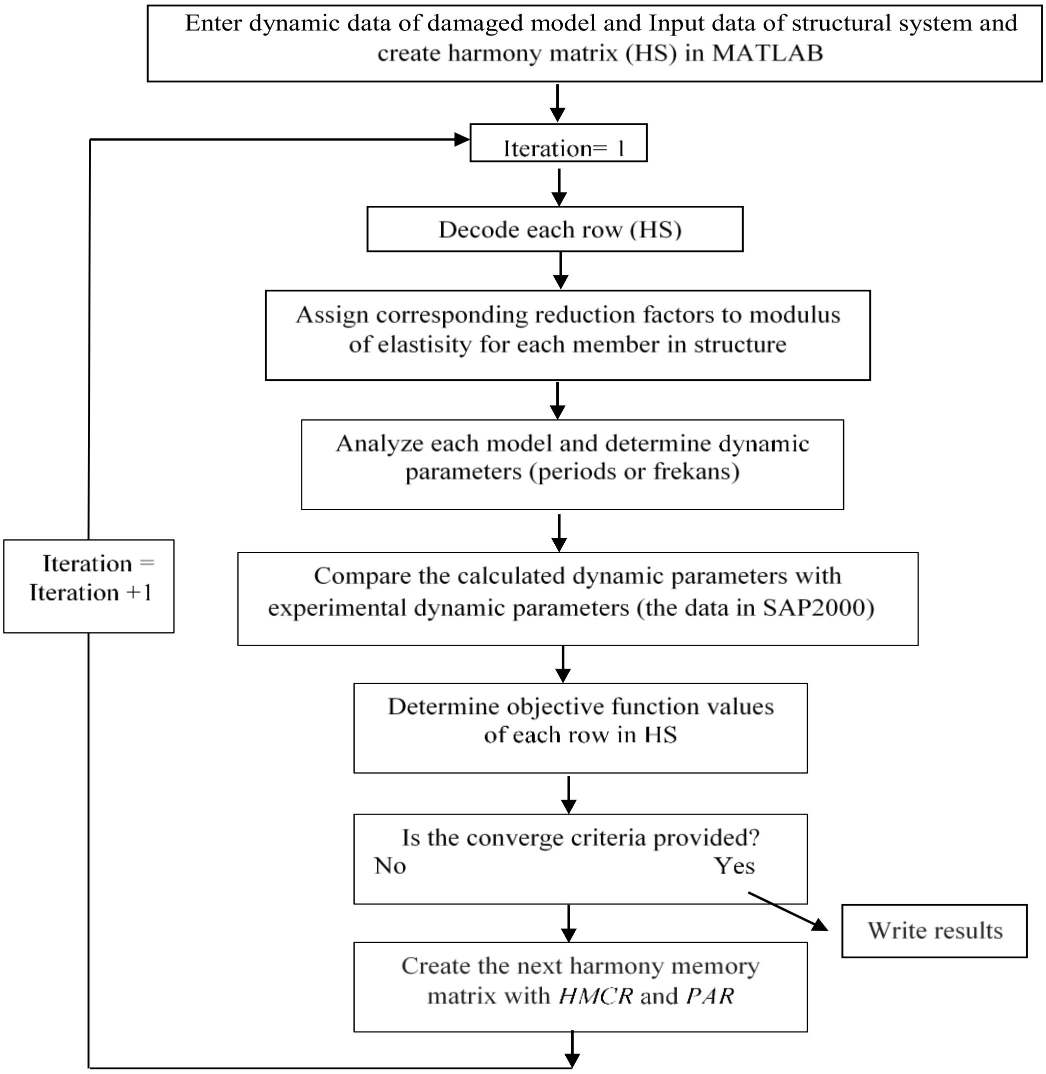


Fig. 1. Flowchart for the optimum solution procedures for damage detection in HS algorithm.

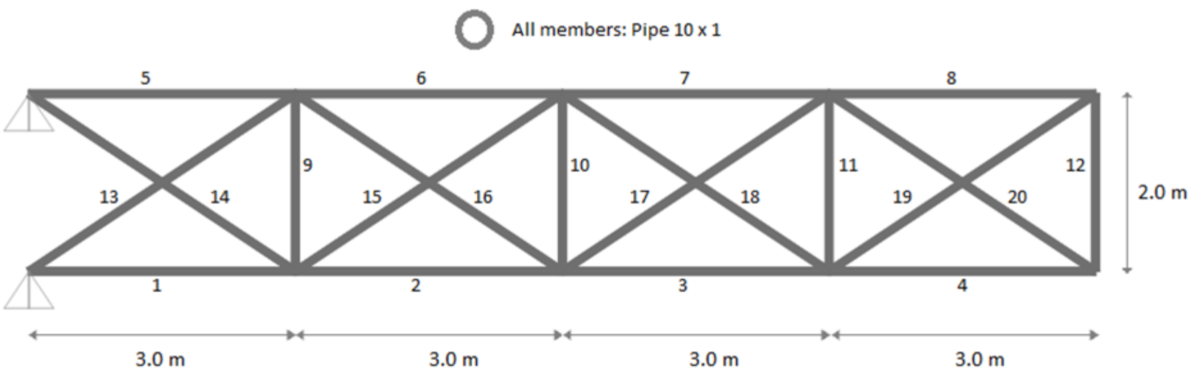
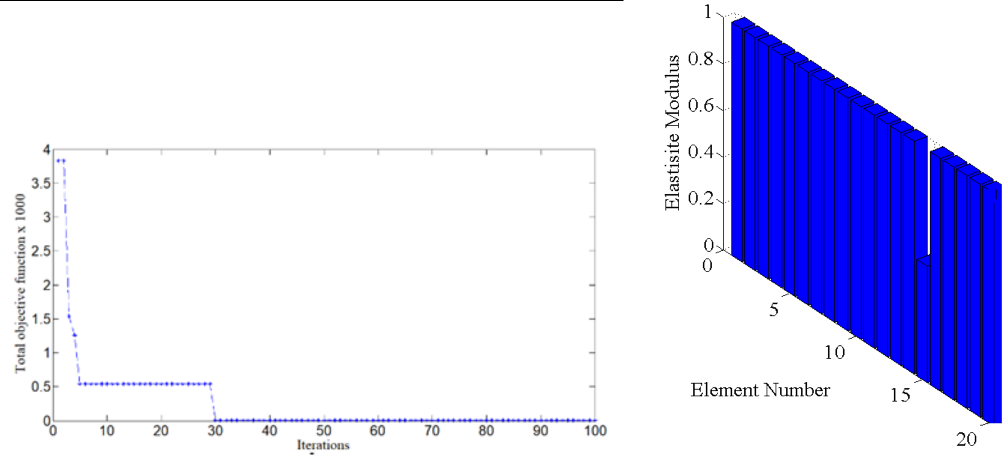


Fig. 2. 20-element steel plane truss.

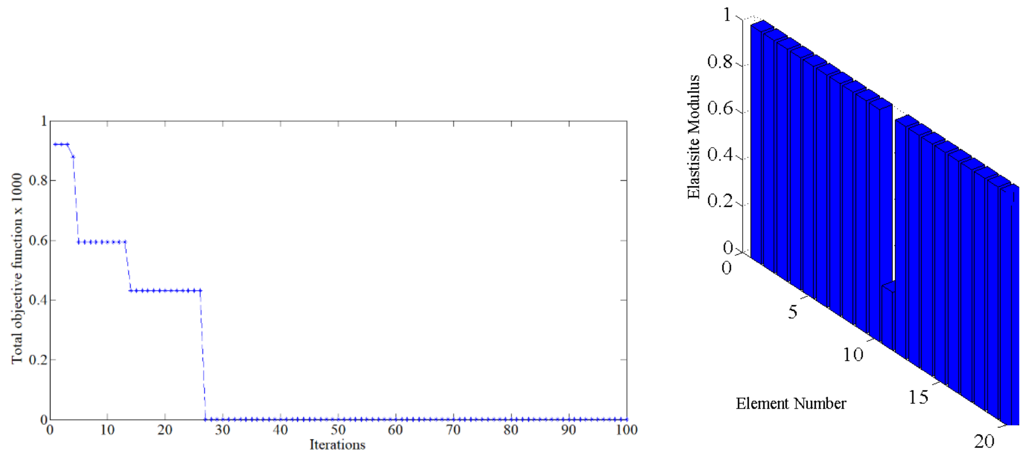
Table 1. Natural frequencies (Hz)

Mode	Undamaged Case (Hz)		Case 1 member no.15: 50% damaged		Case 2 member no.11: 75% damaged	
	SAP2000	MATLAB	SAP2000	MATLAB	SAP2000	MATLAB
1	10.96797	10.9679	10.89275	10.8927	10.96797	10.9679
2	50.95267	50.9525	50.13671	50.1365	50.95267	50.9525
3	77.89691	77.8966	76.73378	76.7335	77.18673	77.1864



a) Solution with iteration steps b) damaged member

Fig. 3. Results for case 1



a) Solution with iteration steps b) damaged member

Fig. 4. Results for case 2

As presented in Table 1, the results of natural frequencies in MATLAB and SAP2000 programs are very close for first three modes in undamaged and damaged cases. In case 1, member no.15 has 50 % damage and the program using MATLAB is carried out around the 30th iterations as seen in Fig.3a. Fig. 3b proves that member 15 has 50% reduction in modulus of elasticity. Similarly, in case 2, member no.11 has 75% damage and the program coded in MATLAB is carried out at about the 30th iterations as shown in Fig.4b. Also, Fig. 4b presents that the member no.11 has 75% reduction in modulus of elasticity.

4.2. 33-Element steel plane truss bridge

Fig. 6 presents a 33-element steel plane truss bridge along with all the distances and sizes. The modulus of elasticity E=2.00 x108 kN/m2 and material density ρ = 7.85 ton/m3. Two different damage scenarios with one and two damages are carried out. In case 1, member no.3 has 50% damage. In case 2, member no.3 has 50% and member no.14 has 25% damages. Table 2 presents the values of the first three natural frequencies obtained from MATLAB and SAP2000 software for undamaged and damaged cases. Fig 7 and 8 show solution figures for case 1 and case 2, respectively. Fig. 9 presents first three mode shape of undamaged model.

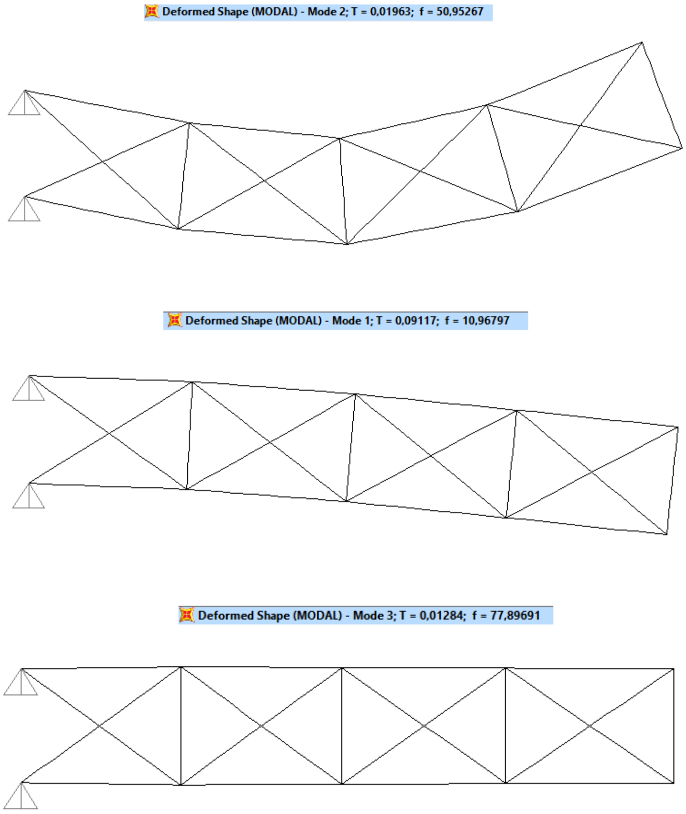


Fig. 5. First three mode shape of undamaged model

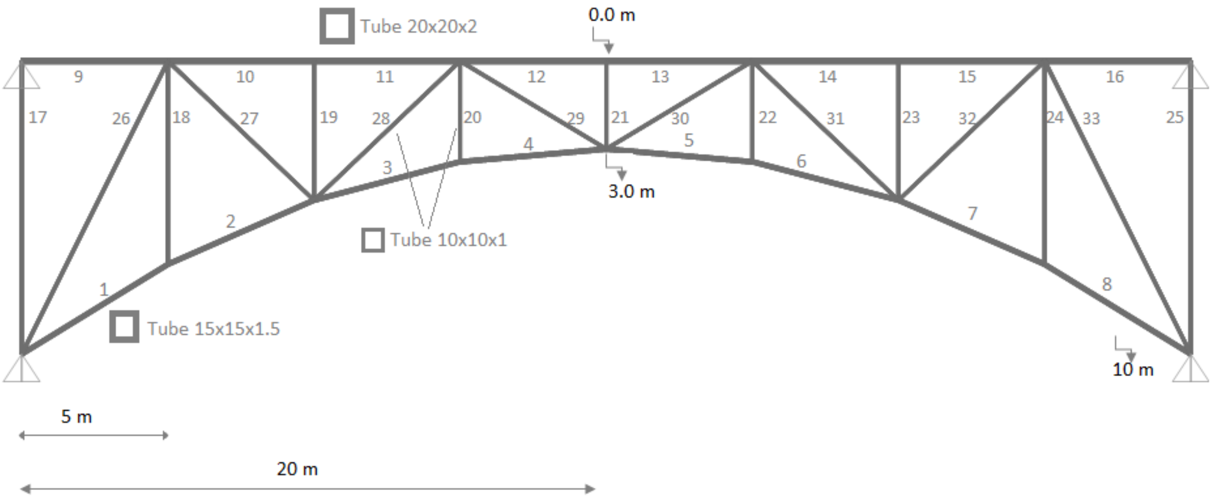
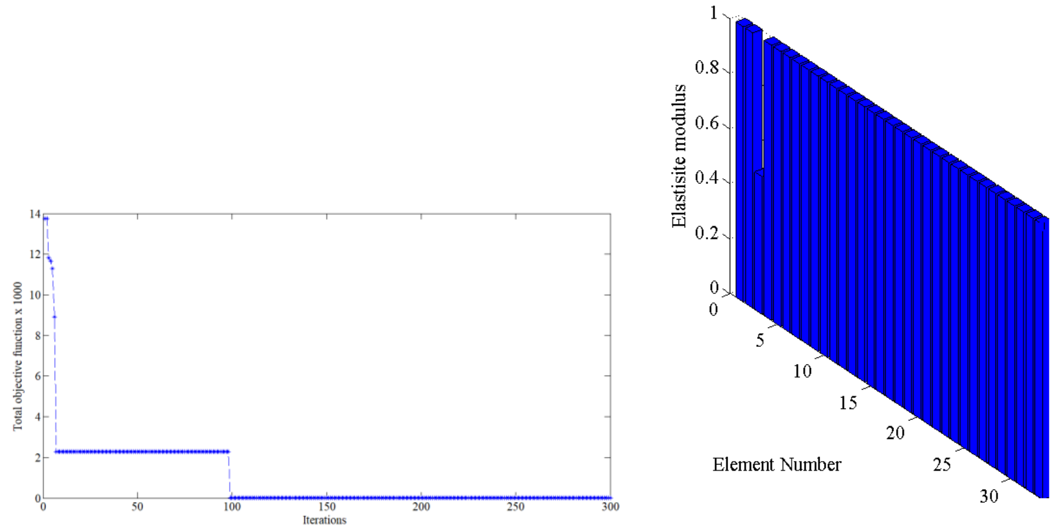


Fig. 6. 33-element steel plane truss bridge

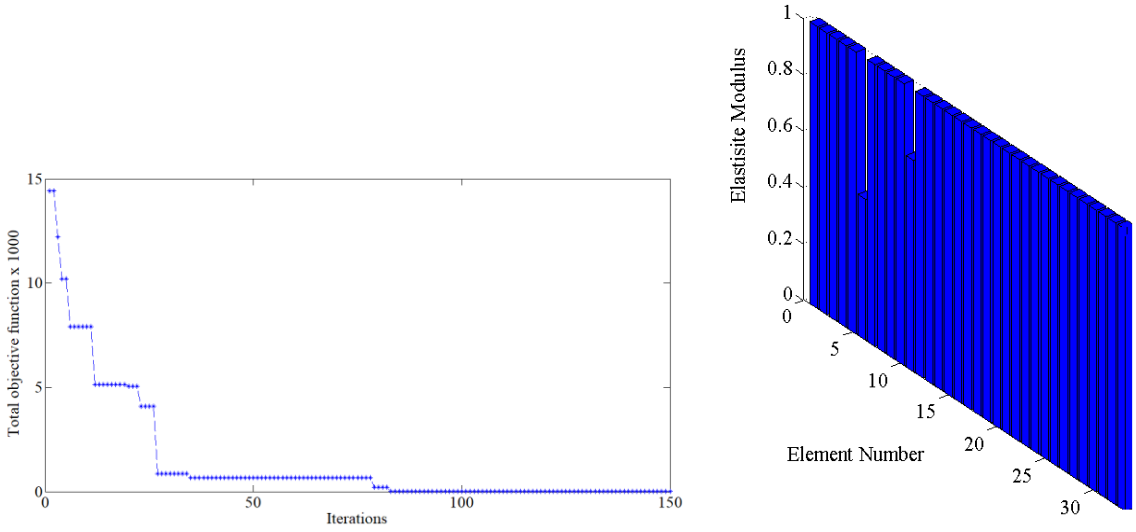
Table 12. Natural frequencies (Hz)

Mode	Undamaged Case (Hz)		Case 1:One damaged member no.3 : 50% damaged		Case 2: Two damaged Case element no.3 : 50% and element no.14: 25% damaged	
	SAP2000	MATLAB	SAP2000	MATLAB	SAP2000	MATLAB
1	16.14925	16.1492	16.12883	16.1288	16.12673	16.1267
2	20.75732	20.7572	20.68065	20.6806	20.67982	20.6797
3	25.76528	25.7652	25.54086	25.5408	25.52803	25.5279



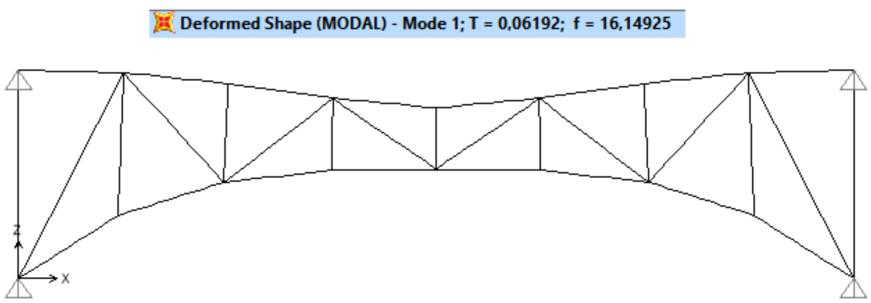
a) Solution with iteration steps b) damaged member

Fig. 7. Results for case 1



a) Solution with iteration steps b) damaged member

Fig. 8. Results for case 2



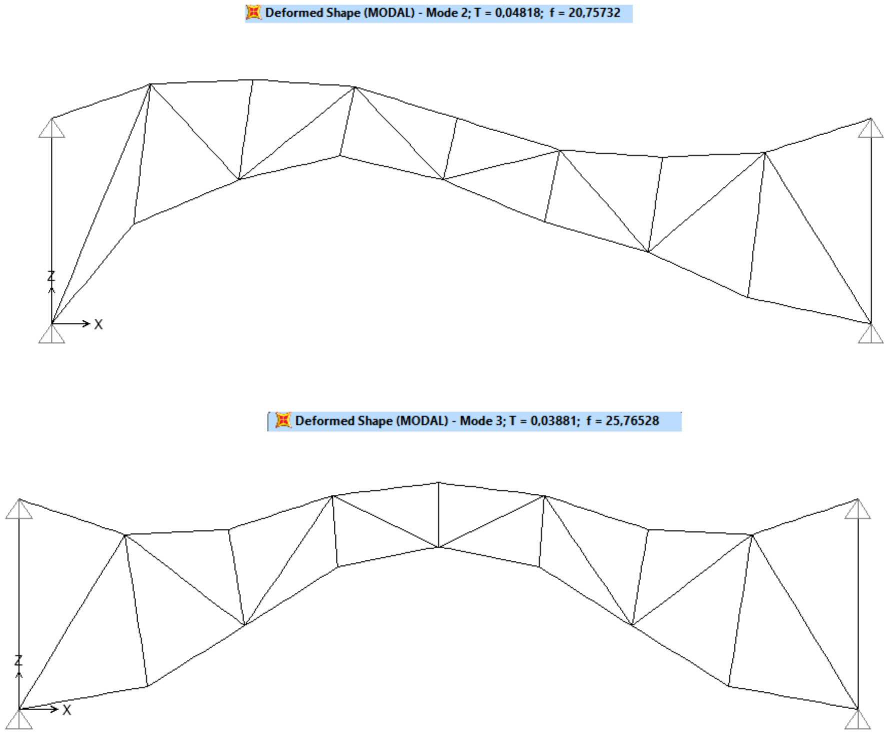


Fig. 9. First three mode shape of undamaged model

As it is observed from Table 2, the results of natural frequencies in MATLAB and SAP2000 programs are very similar for first three modes in undamaged and damaged cases. In case1, only member no 3 has 50% damage. Fig. 7a presents that solution of case 1 is carried out after 100 iterations and Fig. 7b proves that member no 3 has 50% reduction in modulus of elasticity in case 1. On the other hand, in case 2, member no.3 has 50% damage and member no.14 has 25% damage. Fig. 8a shows that solution of case 1 is obtained at about 85th Iterations. Also, Fig. 8b presents that member no.3 and member no. 14 has 50% and 25% reduction in their modulus of elasticity.

5. Conclusions

This paper presents a damage detection study on steel plane truss structures using harmony search algorithm. Two different examples having various damage scenarios are studied in SAP2000 software to obtain the experimental dynamic parameters. To determine the location and severity of damages, a program based on finite element method was coded in MATLAB programming. The scenario damages are tried to determine by approaching the dynamic values of the damaged model as a result of a series of iterations by using the program developed in MATLAB programming. Thus, the locations of simulated damages are determined by updated numerical model. In this study, a 20-element steel plane truss and a 33-element steel plane truss bridge are investigated for different damage cases. The results obtained from solutions prove that scenario damages on simulated plane truss structures are successfully determined by using dynamic parameters. Also, the solutions indicate the robustness and applicability of harmony search algorithm method.

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