Analyses of Truss Structures under Thermal Effects

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Abstract: - In the analyses of truss structures, thermal loadings may to be critical effects in term of displacement and additional stress in members, particularly for long spans. This paper present nonlinear analysis of truss structures subjected to thermal loading effects by Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) technique which is developed from the idea of using the optimization algorithm for obtaining the deformed shape of system with minimum potential energy instead of using matrix operations in conventional methods. This technique has been employed for solving problems such as linear /nonlinear behavior of plane and space truss structures, elasto-plastic behavior of truss systems, unilateral boundary condition, cable nets and tensegrity structures. Studies on application of beams, plates and shells studies are also continuing. In his study, besides describing the methodology of the TPO/MA in general terms, the application of truss structures under thermal effect is investigated to shown accuracy, robustness and reliability of the method.

Key-Words: -meta-heuristics; harmony search; total potential optimization method; nonlinearity; thermal effect.

1 Introduction

There are several loading conditions that engineers are taken into consideration during structural design. These loads can be classified under two heading, general and regional loads. General loads, i.e. dead and live loads are the universal loading conditions that must be obligatory used in the design all over the world and regional loads, i.e. earthquake, wind, thermal loads are changeable loads that are used according to area that build the structures or properties of the structures such as height, maximum length of spans inter alia.

In this paper, the effect of the thermal forces on the analyses of truss structures is investigated. The analyses were performed by Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) technique, which is successfully applied several analyses problems including nonlinear truss, cable net and tensegrity structures [1-3]. Actually the proposed technique and conventional analyses techniques are developed from the same well known theory of the mechanic called minimum potential energy that describes as a structure is in equilibrium state where the total potential energy is minimum. Difference between conventional and proposed method is to use metaheuristic method instead of mathematical operations for finding deformed shape of the structural system that makes potential energy of the minimum. While conventional method used iterative approach for considering nonlinear behavior of the structure, nonlinearity of the system can be automatically taken into condition at the TPO/MA technique due to calculating strain and external load energy on the last deformed shape of the structure. This point is one the main advantage of the technique. In the study, the Harmony Search (HS) algorithm is employed as metaheuristic algorithm [4]. According to analyses results, the proposed method is feasible and effective for solving truss systems subjected to thermal loadings.

2 Methodology

In the proposed TPO/MA techniques, the harmony search algorithm is applied for finding deformed shape of structure that gives minimum potential energy. The HS algorithm is a metaheuristic algorithm inspired from the musical performance of a musician. This algorithm searches optimum solution in fourth main steps.

Step 1- Data entering: In this stage, constraints the problem is defined. These constraints are material properties, member cross-sectional dimensions, nodal coordinates, boundary conditions, joint loads and temperatures changing for each member. Beside of these diameter of the solution domain and special parameters of the optimization algorithm are also determined in this step.

Solution domain is a circular area that is defined around each joint and the coordinates of origin is the same as the related joint. During the optimization process new coordinates for each joint is randomly generated within the range of this area.

The HS algorithm parameters are Harmony Memory Size (HMS), Harmony Memory Considering Rate (HMCR) and Pitch Adjacent Rate (PAR).

Step 2- Generation of initial harmony memory (HM) matrix: The HM matrix contains Harmony Vectors (HVs) and the numbers of these vectors are equal to HMS. Each harmony vector contains randomly generated nodal coordinates of structure. All these coordinates stored in each HV are constituted a possible deformed shape of the system. By using coordinates generated in second step, the strain energy (SE), the energy of done by external loads (EEL) and total potential energy (TP) of the systems are calculated. The TP value of the system is also stored in corresponding HV. The objective function of the optimization is to minimize the TP value of the system.

Step 3- Construction of new HVs: After generation of initial HM matrix, an additional HV is constructed. This vector can be generated in two ways; from whole solution domain or by using one of the HV stored in HM matrix. In the first way procedure is same one described in initial HVs (Step 2). In the second way, the properties of the new vector is generated by using a small area around one of the randomly selected from HM matrix. Diameter of this area defines a multiplication of diameter of solution domain and PAR value. The generation of the new vector is doneaccording to HMCR value. After generation a new vector, the energy value of it is calculated.

Step 4- Comparison: If the TP energy of new vector is better (having lesser energy) than worst existing vector in HM matrix, the new vector is replaced with the worst vector. Then process continues from the Step 3. This iterative procedure is repeated until the stopping criterion is satisfied. The stopping criterion of process is iteration number defined by user.

3 Numerical Examples

In this section, analyses for three numerical examples results considering thermal effects were presented. In the analyses Eurocode 3 (EC3) [5] rules is applied for thermal effects. According to EC3, the thermal effecthas been taken into account by using a reduction factor for effective yield strength and slope of elastic range. For different temperatures, the reduction factor can be seen in Fig. 1.For temperatures smaller than 100°C, the reduction factor is equal to 1.

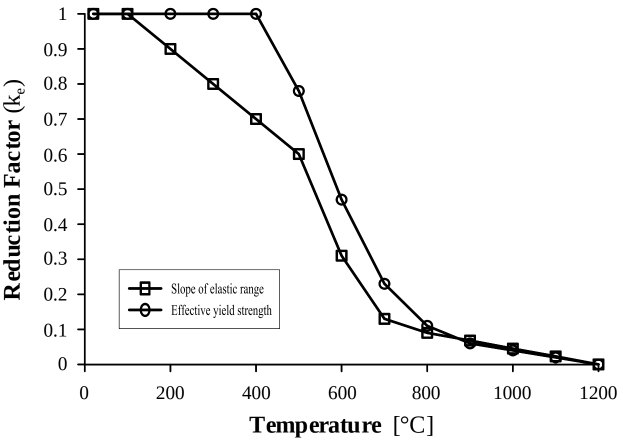

Fig. 1.Reduction factors for effective yield strength and slope of elastic range atelevated temperature

A typical stress-straindiagram for a range of temperature between 100°C-1100°C is given in Fig. 2. As seen Fig.2, temperature has significant effect on yield strength, i.e. for 1100°C, it becomes approximately 2% of the 100°C.

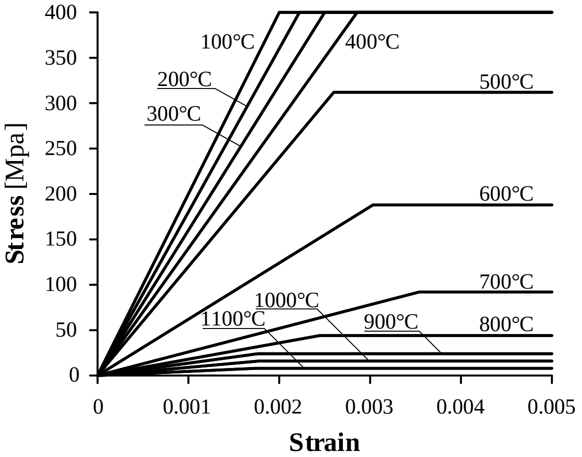

Fig. 2. Typical stress-strain diagram for different temperatures

First example is a 2-bar truss system (Fig. 3). The area of cross-sections of each bar is 100 mm^2 and yield strength of the material is 400 MPa correspond 0.002 strain value. Load is defined with 1000 N density as seen Fig. 3. The analyses is done for temperature range (between 100°C-1100°C) that given in Fig. 2.

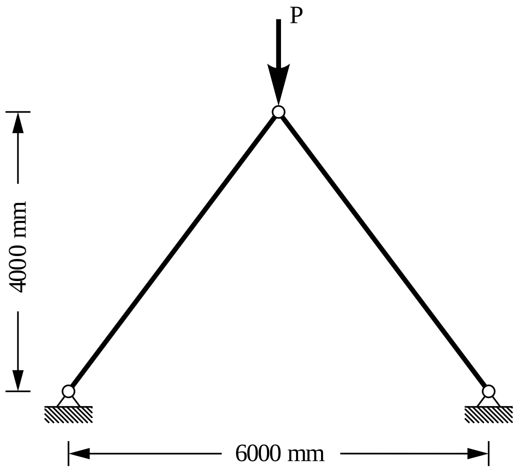

Fig. 3. 2-bar plane truss system (Example 1)

In order to show reliability of the presented method, the same analyses are also done with finite element method (FEM).The exact results are obtained for both methods (Fig. 4). As it is illustrated in the Fig. 4, by increasing the temperature the displacements is also increasing (for example the displacement for 1100°C is approximately 45 times bigger than 100°C). The total potential energy of the system for related temperature range is also given in Fig. 5.

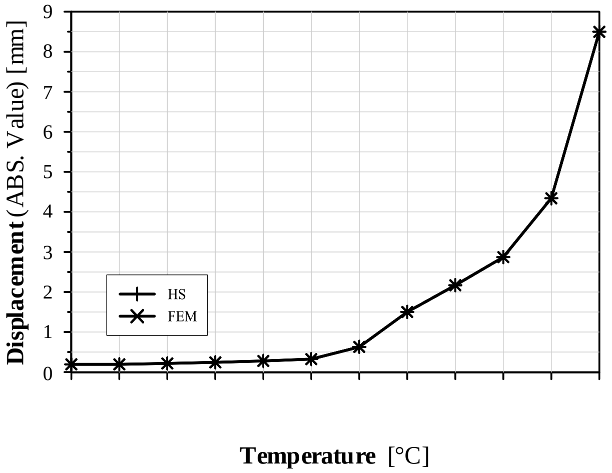

Fig. 4. Nodal displacements for different temperatures

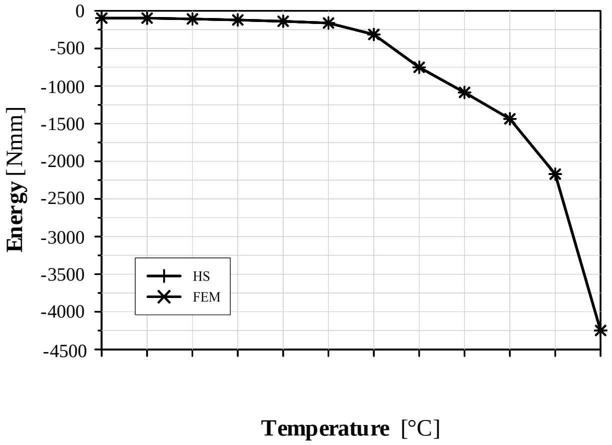

Fig. 5.Total potential energies of the system for different temperatures

For the second example, the method is performed on a 6-bar plane truss system (Fig. 6). Cross-sectional area for members 2-4 are defined as 100 mm^2 and for the other member area is 200 mm^2. As load, a single concentrated load with 5000 N density at node 4 is applied to the system (for direction see Fig. 6).The material properties are taken same as example 1.

The nodal displacements of 4and 5 in x (u_4, u_5) and y (v_4, v_5) directions under different temperature are illustrated in Figs. 7 and 8. Despite having constant up to 500°C, displacements are increasing rapidly after this temperature. This result indicates compliance with the stress-strain diagram given in Fig. 2. Deformed shape of the system between 900°C-1100°C can be seen in Fig. 9. As seen from the Fig. 9, at the 900°C yielding is not obtained for any truss members. Members 1, 2 and 4 are yielded at 1000°C and member 5 is also yielded at 1100°C.

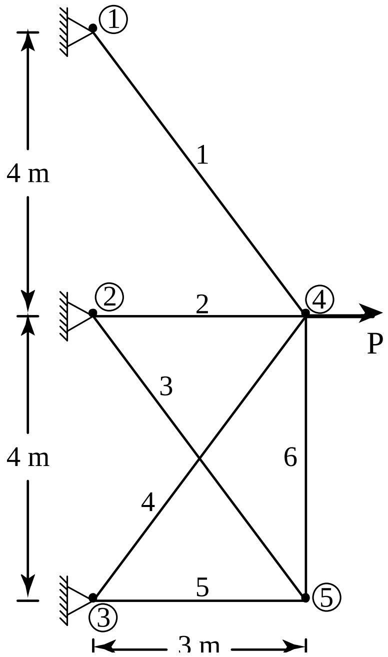

Fig. 6. 6-bar plane truss system (Example 2)

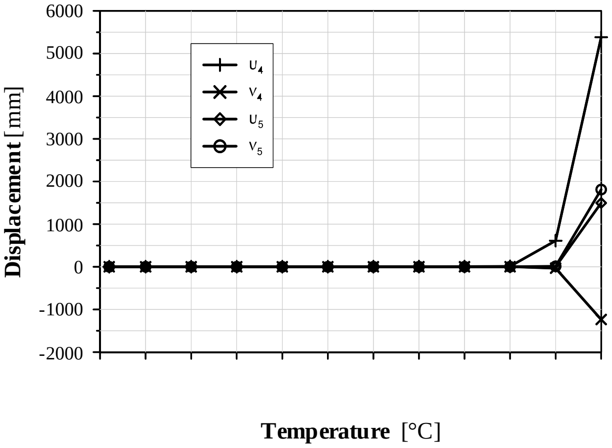

Fig. 7.Displacements of node 4 and 5 for 20°C-1100°C temperatures

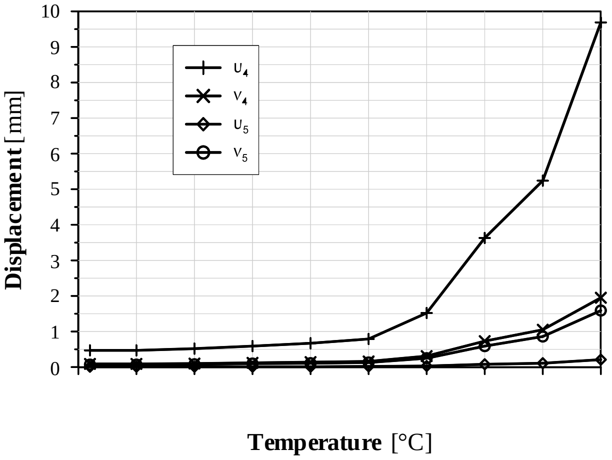

Fig. 8.Displacements of node 4 and 5 for 20°C-900°C temperatures

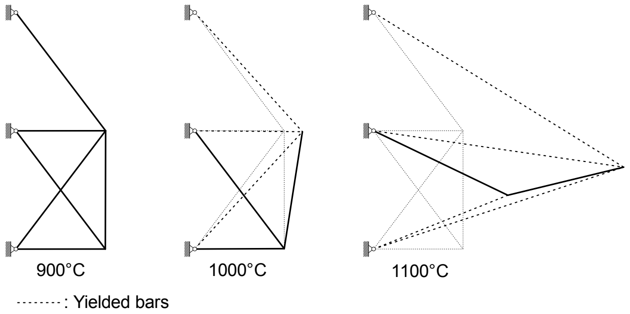

Fig. 9.Deformed shape of the systembetween900°C-1100°C temperatures

The last example is 3-bar truss system that given in Fig. 10.Area of cross-sections of each bar is 15500 mm^2. Elasticity modulus of the material is 200000 MPa and yield strength value is 250 MPa. In the Fig. 11, load-displacement variation for 100°C-1100°C temperatures is given. In the point of change of the inclination of the figure, the bar with number 2 is exceeded the yield strain.

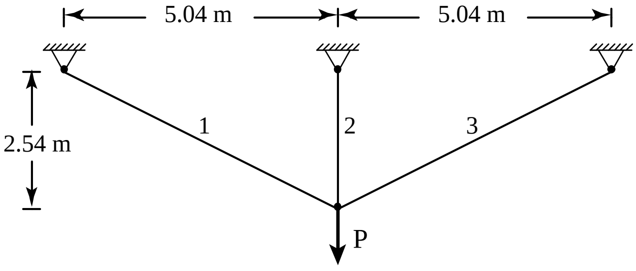

Fig. 10. 3-bar plane truss system (Example 3)[6]

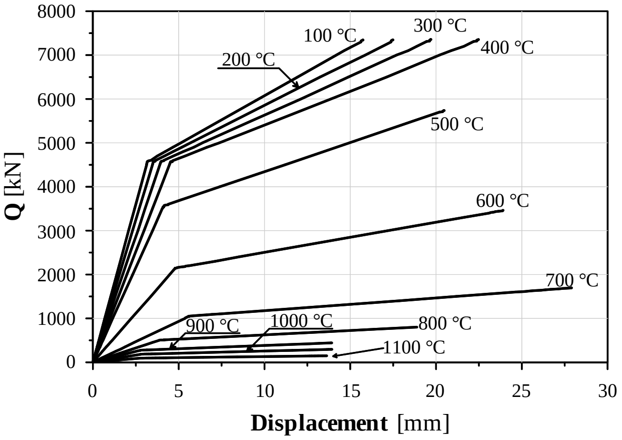

Fig. 11.Load vs. displacement for 100°C-1100°C temperatures

4 Conclusion

The main idea of the paper is to show thermal effect on analyses using TPO/MA. The thermal effect on analyses was considered according to rules described in EC3. In order to show reliability of the method the analyses were also repeated by well-known method called FEM. The conclusion obtained from the analyses results can be summarised as follows.

For temperaturesup to 500°C, the impact of the thermal effect on the analyses results is limited.In the range of 500°C-1100°C temperatures, because of big decrease of yield strength, the analyses results have significantly changed. For example, the nodal displacement for 1100°Cis increased 45 times of 100°C (see example 1).

Until recently, the proposed method has been successfully applied wide range of problems including material and geometric nonlinearity of trusses, unilateral boundary conditions, cables and tensegrity structures. The analyses results of presented paper have shown that the proposed method is also reliable for analyses with thermal effect.

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