Investigating the Behavior of the Truss Structures with Unilateral Boundary Conditions

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Abstract: - During the design process of a structure, an important matter is to determine boundary condition of the joint. Incorrectly specified boundary conditions can decrease the analyses time and can also cause incorrect results. According to displacement capability of the joint the most appropriate condition within the existing onesi.e. hinged, sliding, fixed etc., is selected and assigned to joint. Except the existing conditions; some special conditions, such as unilateral boundaries can also identify for a joint. The unilateral boundary condition can be observed at soil-structure interaction where both tensile and compressive stresses are occurred under the foundation because of axial force eccentricity.

In this paper, behavior of the truss structures with unilateral boundary conditions is presented. The analyses are conducted by using Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) technique, that developed methodology based on improved In order to apply to the problem

The methodology of the paper was developed based on an improved Particle Swarm Optimization(PSO) algorithm. The analyses results have proved that the applied technique is efferent and suitable for solving this kind of problem.

Key-Words: -Unilateral Boundary Conditions, truss structures, energy methods, particle swarm optimization, TPO/MA.

1 Introduction

Boundary condition used in the structural analysis is formed by idealization of various assumptions. For example; when the rotational and linear displacements of a joint very small (nearly equal to the zero), the boundary condition of the joint is idealized as fixed.

This idealization has two benefits. First one is to reduce mathematical operations and time of the analyses. Although the methods developed for structural analyses such as finite element (FEM), finite difference uses different approach for solving, the main aim of them is to solve the expression of equilibrium condition of the structure $P=K\Delta$. In this expression, P represent the vector of external loads; K is the stiffness matrix involves material and geometrical properties of the structural member and Δ represents displacement vector of joints which is usually unknown values. By the idealization of boundary condition, some terms of the displacement vector is eliminated. Thus, analyses time and mathematical operations reduces. The second benefit is to solve systems with less information. The exact situation of the supports can be only known by conducting several experiments and calculations. Generally, the findings have a minor effect on the solutions.

Some of the mostly used boundary condition types can be seen in Fig. 1.

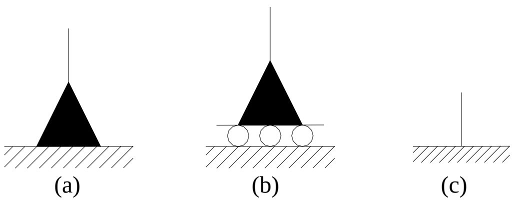

Fig 1. Boundary conditions (a) hinged (b) sliding (c) fixed.

Except these boundary conditions; there are some special condition types such as unilateral boundary conditions. As an example for unilateral boundary condition, the systems that observed soil-structure interaction, i.e. retaining walls or foundations can be given. A retaining wall under various loading can be seen in the Fig. 2.

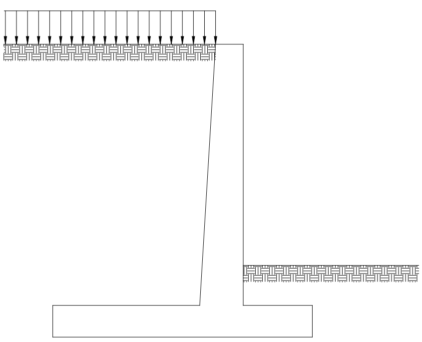

Fig 2. Retaining wall

Retaining walls usually use for providing stability of soil between two different ground level. Thus, while a side of retaining wall has a rigid soil body, the other side is empty. Because of this reason, unilateral boundary conditions are occurred on the retaining wall.

Another example for unilateral boundary condition, behavior of the can be given. In the structural design, the soil behavior usually can be defined by modelling soil as springs. The mathematical model of the retaining wall foundation can be seen in Fig. 3. N axial force and M moment forces caused both tensile (between A and B point) and compressive (between B and C point) stresses at the foundation of the wall. Although springs serve under compressive and tensile forces, the soil can only react for compressive forces.

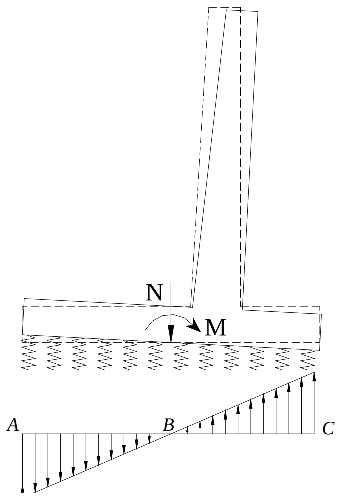

Fig 3. Mathematical model and base reaction of retaining wall foundation

In the traditional analyses, when the tensile force is obtained on springs, the structural model must be updated by delating springs that have tensile force and then, analyses must be repeated. Updated mathematical model of the retaining wall foundation can be seen in Fig. 4. As seen in figure the springs that has tensile forces (between A and B point) is eliminated. This iterative procedure continues until eliminating all springs with tensile forces.

In this paper, the behavior of the unilateral boundary condition is investigated. Total Potential Optimization using Meta-heuristic Algorithms (TPO/MA) [1-3] technique is used for the analyses. The methodology is constructed by applying the Particle Swarm Optimization (PSO) algorithm rules for the metaheuristic method.

According to minimum potential energy (MPE) principle a system is at equilibrium state if the total potential energy of the system, which is sum of stain

$$V_{ij}^{t+1} = w.V_{ij}^{t} + c_1 \cdot r_1^t \cdot \left(X_{lbest} - x_{ij}^{t}\right) \\ +c_2 \cdot r_2^t \cdot (G_{gbest} - x_{ij}^{t}) \quad (1)$$

New position of the particle "X_{ij}^{t+1}" is obtained by summation of current position of the particle "X_{ij}^{t}" and particle velocity "V_{ij}^{t+1}" (Equation 2). [4].

$$X_{ij}^{t+1} = X_{ij}^{t} + V_{ij}^{t+1} \quad (2)$$

The best solution of the objective function (fitness value) is recorded and updated in each iteration. This loop continues until a predetermined condition is met. In solutions to the some problems belong to particle swarm optimization, velocity vector may take undesired values and converge to infinity by growing up excessively. To be able to prevent this situation; specifying minimum and maximum limits for velocity vectors is a method which is frequently applied in the searches.

$$If \quad V_{ij}^{t+1} > V_{max}, V_{ij}^{t+1} = V_{max} \quad (3)$$
$$If \quad V_{ij}^{t+1} < V_{min}, V_{ij}^{t+1} = V_{min} \quad (4)$$

The values that velocity vector may take are shown in Equation 3 and 4 in case of the velocity vector exceeds maximum and minimum limits. The values that velocity vector may take in case of it exceeds the defined values are denoted as "V_{min}" and "V_{max}".

3 Numerical Examples

Two numerical examples are conducted by using the proposed method. First example is a 21-bar truss system. The geometry of the system can be in Fig. 6. Cross sectional areas of the all members are 100 mm^2 and elasticity modulus of the material is 200000 N/mm^2.Except the support named with D which is hinged support, all support is unilateral. The unilateral support is defined as free at upper direction and fixed at down. The PSO parameters are taken as for velocity V_{min}=0.01 and V_{max}=10, for inertia weight w_{min}=0.001 and w_{max}=0.7 (by changing linearly) and for the acceleration coefficient c_1= c_2=2.

The system is analysed under 10 different load case. In all these cases, P and R loads are constant intensity 10 MN.However the load Q is changed between -5000 kN to -500 kN (Table 1) in order to see the unilateral behaviour of the supports.

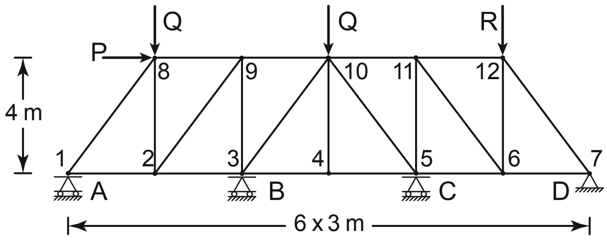

Fig.6. Geometry of the truss system of Example 1

Table 1. Load cases of Example 1

Case	Q [N]	Case	Q [N]
1	-5000	6	-2500
2	-4500	7	-2000
3	-4000	8	-1500
4	-3500	9	-1000
5	-3000	10	-500

The total potential energy values obtained fromharmony search (HS) and particle swarm optimization (PSO) approaches analyses can be seen in Fig. 7. In order to show reliability of these approaches the finite element method (FEM) results are also shown in the figure. As seen in figure, the analyses results of all three methods are the same.

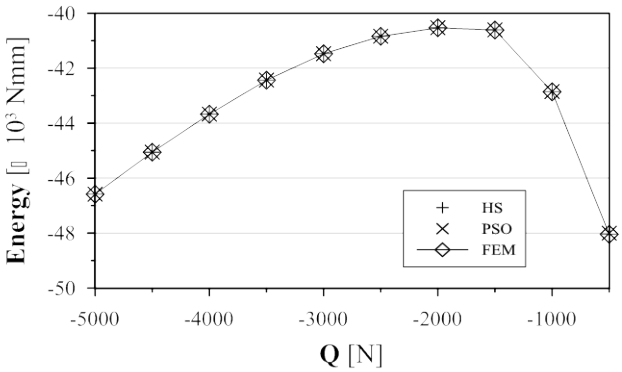

Fig. 7. Total potential energy of the system for different loads

In the Fig. 8, the energy values obtained during the optimization process for harmony search (HS) and particle swarm optimization (PSO) approaches are compared each other. As seen in the Fig. 8, the PSO approach founds the minimum energy more quickly than the HS approach. In the Fig. 9, it is shown that how to approach the proposed method to the final displacements of the joint. Although in the first iterations the results are change in wide range, by the increase of the iterations converges of the optimum result is succeed.

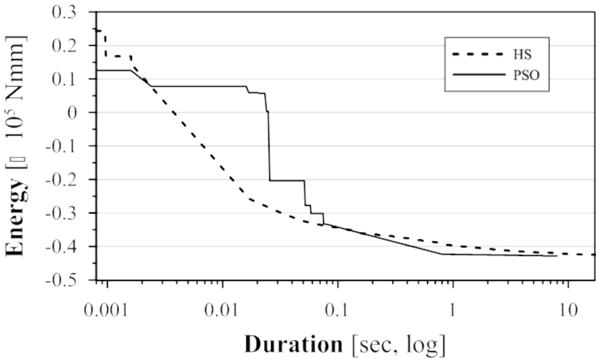

Fig. 8. Energy vs duration for HS and PSO solutions

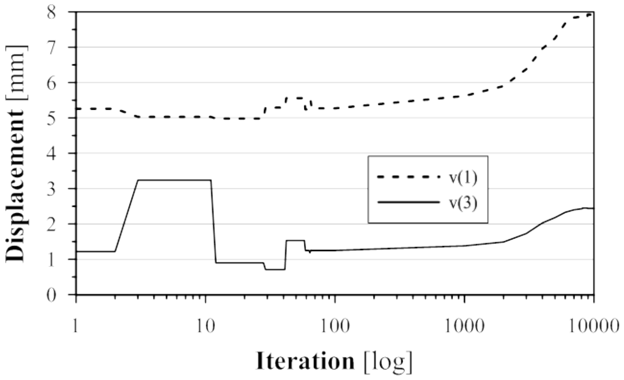

Fig. 9. The y direction displacement vs iteration number of joints 1 (A support) and 3 (B support)

Second example is a 26-bar truss system (Fig. 10). Cross sectional areas outer and inner are 200 mm^2 and 100 mm^2, respectively. Elasticity modulus of the material is 200000 N/mm^2. In the example, supports 5 and 6 are unilateral.

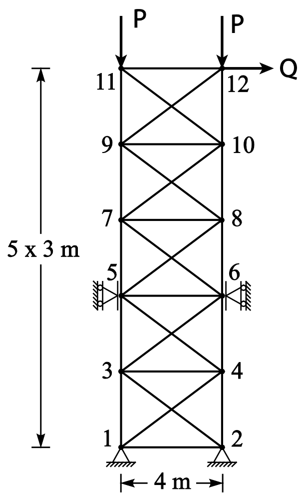

Fig. 10. Geometry of the truss system of Example 2

In order to investigate unilateral behaviour of the supports, the system is solved under 5 different load cases (Table 2). The deformed shape of the system for each load case can be seen in Fig. 11. As it is expected for the load cases 1 and 2, the support named as 5 is free and support 6 is free for cases 4 and 5. For the case 3, both supports are fixed because of the very small displacement at their joints.

Table 2. Load cases of Example 2

Case	P [N]	Q [N]
1	-20000	40000
2	-20000	20000
3	-20000	0
4	-20000	-20000
5	-20000	-40000

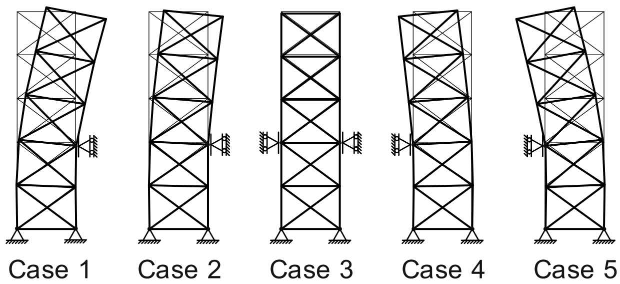

Fig. 11. Geometry of the truss system of Example 2

4 Conclusion

The accuracy of the proposed method was checked by comparing the result finite element method and the similar results are found. The analyses process was repeated for the same example. The results of several analyses (100 runs) are given in Table 3. According to the results difference between the results are very low (Max. 2%).

Table 3. Load cases of Example 2

	Case 1	Case 2	Case 3	Case 4	Case 5
Min	-2191828	-650215	-140585	-647711	-2192852
Max	-2111672	-634673	-140524	-632233	-2112806
Avg.	-2155754	-642595	-140560	-640736	-2163221
St. Dev.	39855.35	7746.35	18.09	7674.92	38623.03
Nrm. Std. Dev.	0.01818	0.01191	0.00013	0.01185	0.01761

This situation can also observed in Figs. 12 and 13 in which joint displacement and member forces are given. For that reason the proposed method is robust and reliable.

According to the analyses results the method is feasible for unilateral boundary condition problems. For future studies it can be applied more complicated problems such as frames, plates and solids.

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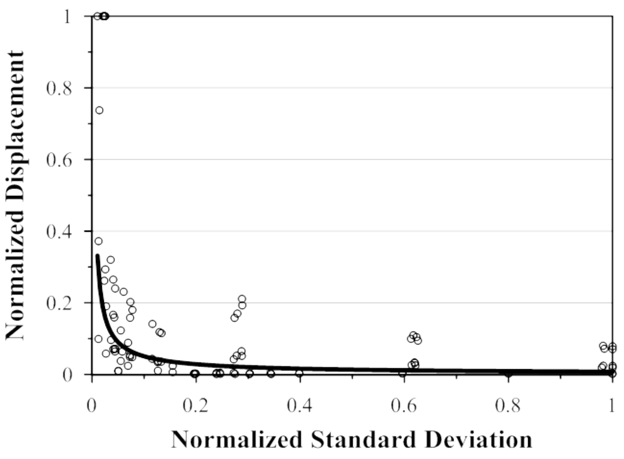

Fig. 12. Normalized standard deviations of joint displacements in 100 independent runs for Example 2

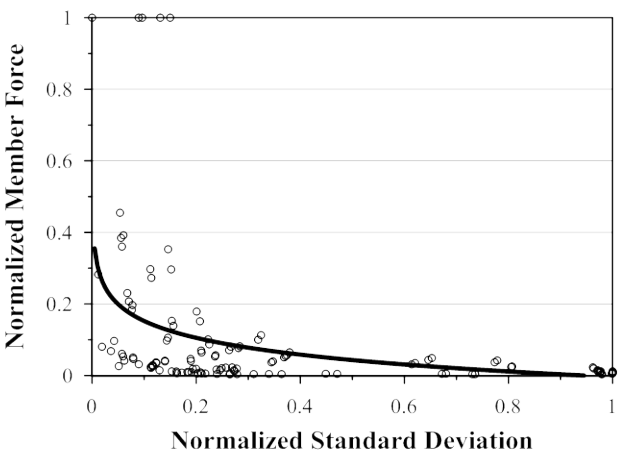

Fig. 13. Normalized standard deviations of member forces in 100 independent runs for Example 2

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