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KONSTRUKTERA SRBIJE

14. KONGRES

NOVI SAD
24-26. SEPTEMBAR

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U SARADNJI SA:

GRAĐEVINSKIM FAKULTETOM
UNIVERZITETA U BEOGRADU

MINISTARSTVOM PROSVETE,
NAUKE I TEHNOLOŠKOG RAZVOJA
REPUBLIKE SRBIJE

INŽENJERSKOM KOMOROM
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Ahmed Alalikhan [1], Saad Al-Wazni[2], Zoran Mišković[3], Ratko Salatić[4]

NUMERIČKI EKSPERIMENT DETEKCIJE OŠTEĆENJA PRIMENOM *TABU SEARCH* METODE

Rezime:

U radu je prikazana procedura simulacije detekcije oštećenja slobodno oslonjene čelične grede uz primenu *Tabu search* metode optimizhacije. Numerički proračuni su sprovedeni u ANSYS softveru za analizu primenom metode konačnih elemenata. Detekcija oštaćenja uključila je loakalizaciju i kvantifikaciju oštećenja. Metoda se bazira na detekciji oštećenja na osnovu promene dinamičkih karakteristika konstrukcije. Glavna procedura, primenom *Tabu Search* meode optimizacije, razvijena je u *Matlab* okruženju. Oštećenje je moguće uspešno detektovati, po oba uključena parametra u analizu, tj. lokalitetu i nivou oštećenja.

Ključne reči: detekcija oštećenja, dinamičke karakteristike, tabu search

NUMERICAL TEST OF DAMAGE DETECTION USING *TABU SEARCH* METHOD

Summary:

The study presents the procedure of simulation of damage detection of simply supported steel beam using *Tabu search* optimization method. Numerical computation carried out in ANSYS finite element analysis software. Damage detection assums determination of location and amount of damage. The method uses detection of damage based on changing dynamic properties of structure. The main procedure, using optimization *Tabu Search* method, is developed in *Matlab* package. Damage was successfully detected after performing the procedure for both parameters, location and amount of damage.

Key words: Damage detection, Tabu search, Dynamic properties

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1 INTRODUCTION

The purpose of the present work is to establish a method for predicting the location and amount of damage in a simply supported beam using numerical changes in dynamic properties, structural modal frequencies and shapes. A crack or other type of defect, in a structural member result in local reduction of stiffness, which would affect vibration properties of the structure, [1]. These changes of stiffness could be used to detect existence of a damage, which can be simulated by a crack through the beam depth, characterized with its location and depth of the structural member and structure as a whole. Nahvi and Jabbari, [1], applied in their work this idea, using the intersection of contours with the constant modal natural frequency planes to relate the crack location and depth. Owolabi et al., [2], in their work measured changes in the first three natural frequencies and corresponding amplitudes of measured frequency response functions, in order to detect cracks with a similar technique mentioned before.

Present case study adopts the concept of numerical model updating technique, varying location and amount of damages, and performed using ANSYS Finite Element Analysis software. Numerical model updating technique is an important tool to determine corresponding modal properties of structural model. It has been repeated many times to the numerical model until it reaches close properties of damaged case (measured experimentally or simulated). This concept used several times, as it is reported in many papers referenced in [3]. This procedure requires incorporation of an optimization method for damage detection. In this paper used so-called *Tabu search method* of optimization techniques for this purpose, which could be applied to get target.

2 IDENTIFICATION OF DAMAGE DETECTION

Damage may be detected according mainly to two ways, destructive and non-destructive approach. The last one is adopted in presented study. In addition, non-destructive methods include a wide range of parameters that can be taken into account. Presented study includes the changes of natural frequencies and mode shapes only.

The basic idea could be summarized in few steps. Firstly, has to create the FE structural model (case study) using the FEM modeling software. ANSYS software is used for modal computation and determination structural dynamic properties (frequencies and mode shapes). This operation repeats during simulation of different locations and amount of damage, which results in different values of frequencies and mode shapes for each case. This procedure is so-called numerical updating technique. The second part includes an optimization procedure, *Tabu search* method chosen in this study, which is programmed as routine in *Matlab* software. Optimization process includes comparison of modal parameters of the real damaged structure (measured experimentally or computed for particular scenario of damage) and modal parameters corresponding to the simulated damage case. In the presented numerical test both groups of parameters are computed numerically. When the modal parameters become close, optimization procedure reaches target (minimum difference), and the damage is detected, [4].

The whole process can be summarized in figure 1. In the present study, real modal properties are obtained numerically for particular damage scenario, not by experimental modal analysis of real damage structure.

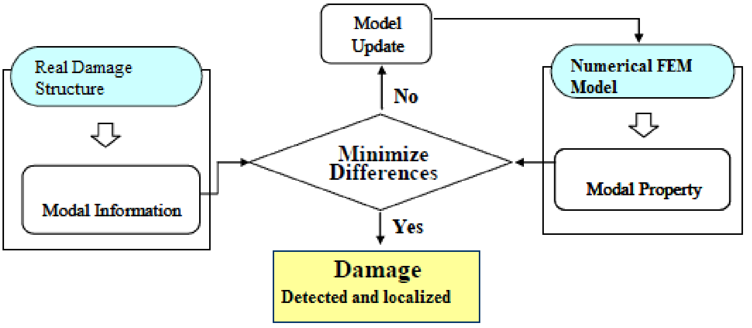

Figure 1 – General structure of damage detection algorithm

3 OPTIMIZATION PROCEDURE

3.1 TABU SEARCH METHOD OF OPTIMIZATION

Tabu Search method (TS) is a meta-heuristic iterative procedure, which starts from some initial feasible solution and attempts to determine a better solution. TS procedure initially starts from several neighborhood hyper-points (position or state of a system), and selects the new point (move) producing the best solution among all candidate points (moves) for current iteration. Points with the best solution may not improve the solution in the current iteration. Selecting the best move (which may or may not improve the current solution) based on the sub-position that good moves are more likely to reach the optimal or near-optimal solutions. The set of admissible solutions attempted at a particular iteration forms a candidate list. *TS* selects the best solution from the candidate list. Candidate list size is a trade-off between quality and performance. The best solution in any heuristic method need an objective function (target function) in order to reach optimal solution, hence, the adequacy of the objective function will be crucial on the results. According to researches [5, 6], algorithm of *TS* method can be summarized in the following steps:

- Choose (construct randomly) an initial solution S_0;
- Set the current solution $S = S_0$;
- Loop over iteration:

  While (the termination criterion not satisfied):

  Select S in $\arg\min[f(S')] < f$, where S is not on *tabu-list*, $S' \in N(S)$ and N is all neighbor solutions.

  if $f(S')$ is less than f^* (the minimum value of objective function)

  make $f^* = f(S')$ and the best solution $S^* = S$;

  Record *tabu-point* for the current move in the *tabu-list*.

  End While (the termination criterion satisfied):

In the algorithm, $\arg\min$ returns the subset of solutions in $N(S)$ that minimizes objective function.

3.2 OBJECTIVE FUNCTION DEFINITION

The value of objective function plays an important role in damage detection technique, from which, the location and percent of damage could be determined. According to [7, 8], an objective function represents the error between the real (measured or computed) and numerically simulated modes and frequencies. The goal from the objective function is to reach to a minimum value, which represents the minimum difference among the modal properties for two, previous defined, cases.

To find out the most efficient objective function, two fundamental objective functions have been considered:

- The difference (errors) in natural frequencies, in the form defined by equation (1),

$$f_2 = \sum_{i=1}^{n} \left(\frac{\omega_e - \omega_m}{\omega_e} \right)^2 \tag{1}$$

where are:

ω_e ……Natural frequencies of real damaged structure

ω_m …...Natural frequencies of numerically simulated damaged structure during optimization process

n ……..Number of mode shapes included into the consideration.

- The difference in mode shapes in the form defined by equation (2),

$$f_2 = \sum_{i=1}^{n} \frac{Norm\ \left|\phi_e - \phi_m\right|}{Norm\ \left|\phi_e\right|} \tag{2}$$

where are:

ϕ_e ………. Mode shapes of real damaged structure

ϕ_m …….. Mode shapes of numerically simulated damaged structure during optimization process

n ……….. Number of mode shapes included into the consideration.

$Norm\ \left|\phi\right|$ .Norm of the vector of relevant displacement components of all structural nodes (in this study used just translational degree of freedom in transverse direction of node vector displacement) and the norm is defined as sum of those components.

Finally, the sum of the functions defined by (1) and (2) assumed as an objective function in this study, (3).

$$F = f_1 + f_2 \tag{3}$$

4 NUMERICAL TEST OF SIMPLE SUPPORTED BEAM

ANSYS software program is used to analyze the case study. A simply supported steel beam, span of $L = 10\ m$, rectangular cross section width of $b = 300\ mm$ and height of $h = 600\ mm$ was adopted. The beam divided to 100 elements and the damage varied within each element during the analytical process. The modal analysis performed and beam properties proposed as (linear elastic homogenous) with mass density of $\rho = 7860\ \ kg/m^3$. The first five modes are considered during the study.

Artificially applied damage of the structure consists of a crack on element No. 15, which was a crack from the bottom beam side towards to top beam side, with a length of $l = 300\ \ mm$, so, it corresponds of the 50%, if is assumed ratio of crack length and total depth of the beam cross section.

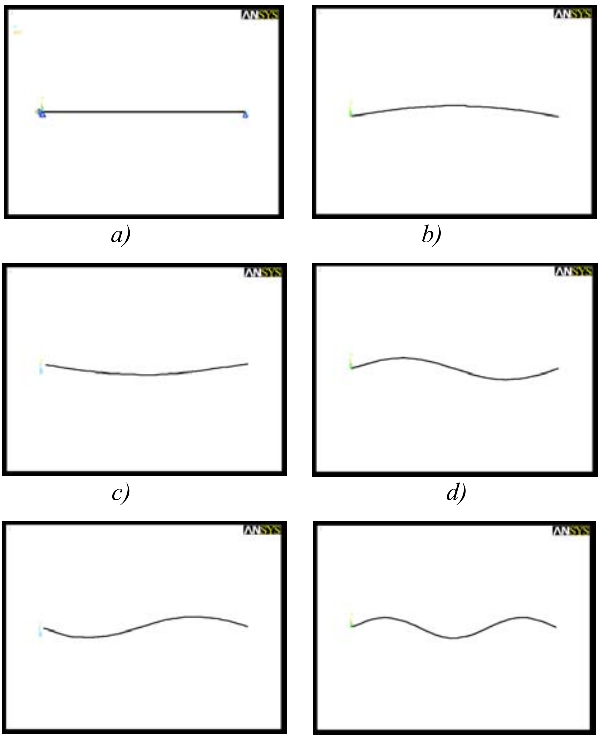

Figure 2: a) FE model of damaged structure with supports; b) 1st mode shape - 1st bending (front view); c) 2nd mode shape - 1st lateral (top view); d) 3rd mode shape - 2nd bending (front view); e) 4th mode shape 2nd lateral (top view); f) 5th mode shape 3rd bending (front view)

Numerical model of the damaged structure, with computed first five mode shapes, using the ANSYS software, are shown in figure 2.

Table 1 – Natural frequencies of real damaged beam – FE computed

Mode No.	1	2	3	4	5
Frequency (Hz)	6.853	13.535	27.327	52.519	61.285

Extracted mode shapes, for the first five extracted mode shapes, are shown in figures 2*b* to 2*f*, while the modal frequencies are listed in the table 1.

5 RESULTS OF PROPOSED DAMAGE DETECTION PROCEDURE

After application the proposed damage detection procedure using *TS* method, during the iteration process with various damage location and percent of damage, so-called numerical model updating, the optimal solution is obtained. It closely corresponds to the applied damage, which means that location and amount of damage is detected. The process performed automatically using the routine created in *MATLAB* package. Improvement of the applied objective function, defined by equation (3), during iterations is shown in figure 3.

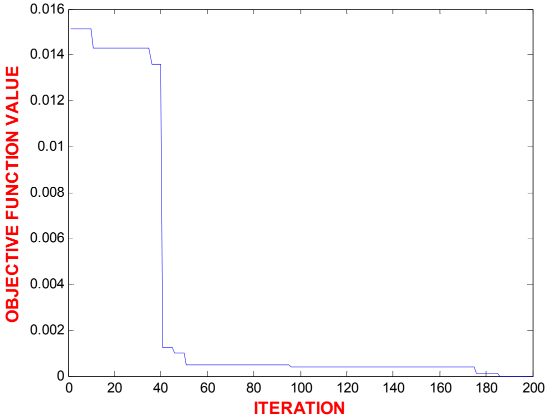

Figure 3. Improvement of the objective function during iterations

Decreasing behavior of the objective function value during the iterations indicates effectiveness of applied optimization method, *TS* method, which means that the process is getting, step by step, closer to exact value during the iterations. Procedure find out exactly that the element no. 15 is damaged with a damage percent of 50% . Therefore, after 185 iterations, the objective function (error function) reached the target zero-value, as a global *minimum* value. Mentioned behavior can be recognized in figure 4 as well. Figure shows local minimum values of the objective function computed during iteration in the searching space. Due to the efficiency of applied searching method, *TS* method, there is evident that it was able to avoid all existing local minimum values and didn't stuck with any of them during the searching process. This phenomena (i.e., avoiding trapping in some local minimum) governs the optimization method in terms of being either a successful method or not.

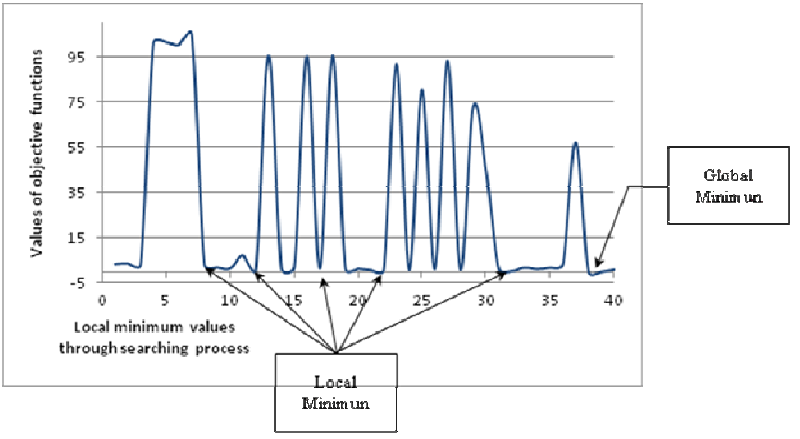

Figure 4. Minimum values of objective function computed in searching space

6 CONCLUSIONS

The results from the presented research show important advantages of the proposed damage identification procedure. Structural modal properties are very sensitive to existence of damage, and give significant indication of structural damage. So, these properties have strong influence on objective function, if they are included in adequate form. Any tiny change, which may occur, can be recognized during optimization process. In order to capture a location and amount of damage within a short time, an adequate optimization method and well constructed objective function, are required. Possibility to avoid local minimums, during searching process, have to be checked for every heuristic method before being used in order to insure that the best solution can be reached. *Tabu Search* method exhibits a very good performance to locate the global minimum value throughout the searching domain. Inspection of 100 finite elements of the structural model, in order to find the damaged one, within a short time proves the advantage of selected *Tabu Search* optimization method for damage detection.

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