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NUMERICAL VERIFICATION OF DAMAGE LOCALIZATION METHOD BASED ON MOVING MASS IN TRUSS STRUCTURES

The article presents examples of damage localization in numerical models of trusses based on changes in natural frequency. The changes were caused by an additional mass moving on the truss nodes. The results of the localization in several truss bars (top chord, bottom chord, diagonal bars, posts) are presented. The influence of damage size on the localization effectiveness is shown. The differential operator was used in the analyses.

Keywords: civil engineering, truss, damage, modal analysis

1. Introduction

Damage detection using modal analysis has been used in civil engineering since the 1970s [1]. Modal diagnostics is based on changes of dynamic parameters: the natural frequency, the form of natural vibrations and the damping coefficient. Most of the methods are based on the reference model, for which the values of the dynamic parameters of the structure in undamaged state are known. In [2] the comparison of vibration curves using a differential operator was applied to the damage location. In [3] an additional parameter (mass, support) was introduced to the system which allows indicating the location of the damage by analysing changes in the natural frequency relative to their position. Methods without a reference model are also being developed. Examples of the use of an additional, changing position of the mass along with the analysis of the resonant frequency derivatives allow locating the damage

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in beams [4, 5] and plates [6]. A similar approach to distinguishing the magnitude of damage was adopted in [7]. The application of modal analysis to the localization of damage in trusses can be found in [8, 9]. The following paper presents the preliminary results of damage localization in truss models with the use of modal analysis in combination with a central differential operator without a reference model.

2. Description of numerical analyses

2.1. Numerical models

During the analyses, two numerical models of trusses with parallel chords were used. Both models have a span $L = 2{,}0\ m$ and a height $H = 0{,}2\ m$. A square cross-section with side dimensions equal to $h = 10\ mm$ has been adopted in all steel truss bars. The supports were placed in the extreme nodes of the upper chord. The finite element method models were built in the Matlab environment FEM libraries from the Calfem package.

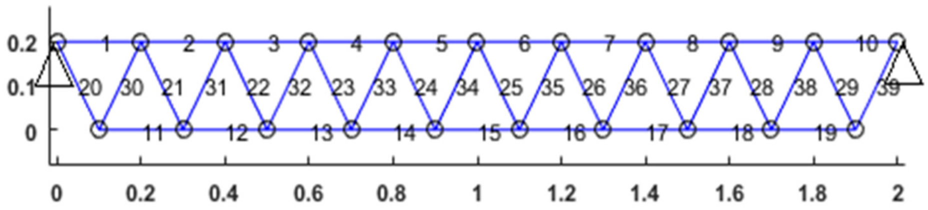

Fig. 1. Warren truss

The model of the first truss (Fig. 1) was constructed of $n_e = 39$ elements and contained $n_d = 21$ nodes. The model's geometry is Warren type "V" truss with tensioned and compressed diagonal bars without posts.

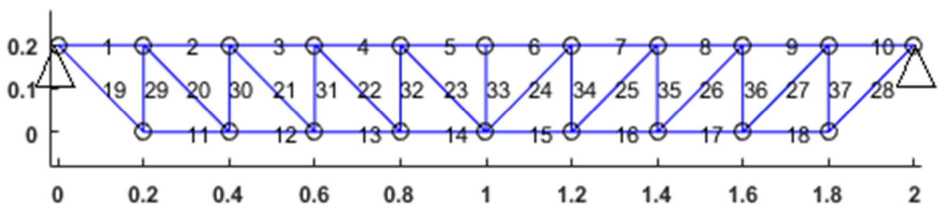

Fig. 2. Pratt truss

The second model of the truss (Fig. 2) was constructed of $n_e = 37$ elements and contained $n_d = 20$ nodes. The model's geometry is Pratt type "N" truss with tensioned diagonal bars and compressed posts.

2.2. Damage localization method

The damage was modeled by reducing the cross-section area of one of the truss bars without changing the mass of the truss. The natural frequencies $\omega_q\,\{l_m,\ l_c,\ h_c\}$ were calculated with the mass added successively in $l_m=1..n_d$ truss nodes, assuming the location of damage $l_c=1..n_e$ with different size of damage h_c (*1 mm-8 mm*). The eigenvalue problem was solved in the Matlab environment. The results show of changes in the first frequency ω_1 performed using the second-order differential operator

$$\omega''_{l_m,1} = \frac{\omega_{l_m+1,1} - 2\omega_{l_m,1} + \omega_{l_m-1,1}}{d^2} \tag{1}$$

assuming for the trusses $d=1$. All simulation included a mass of 5% of the trusses weight. The nodes of the top chord $l_m=1, 2...11$ were taken into account.

3. Simulation results

The simulation results for the first truss were compiled for damage by 50% reduction in the cross-section area of the truss bars ($h_c = 5\ mm$). Figs. 3–5 show the changes with respect to the position of the mass on the top chord of the first frequency ω_1 and the differential operator ω_1'' for the Warren truss. Figs. 3–5 present changes for different groups of truss bars: Fig. 3: top chord (el. 1–10), Fig. 4: bottom chord (el. 11–19), Fig. 5: diagonal bars (el. 20–29). In the figures with the operator, an increased value near the damaged element was shown. The most significant changes for this truss were observed for the bottom chord (Fig. 4b). For chords bars near the supports and for diagonal bars in the middle of the span, the changes were hardly visible.

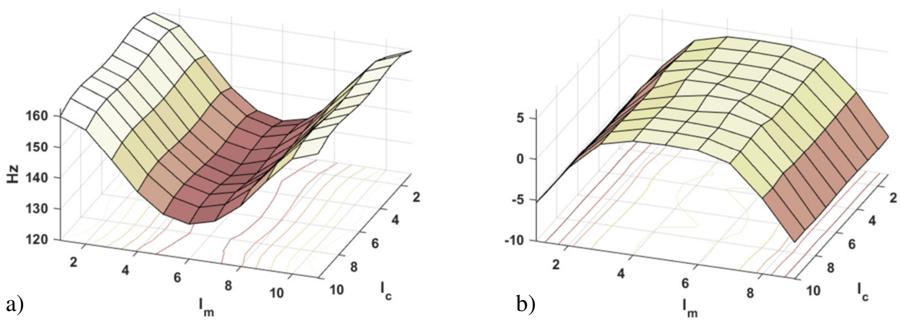

Fig. 3. The mass in the nodes of the top chord, damage in the bars of the top chord (el. 1–10) of the Warren truss: a) change ω_1 b) change ω_1''

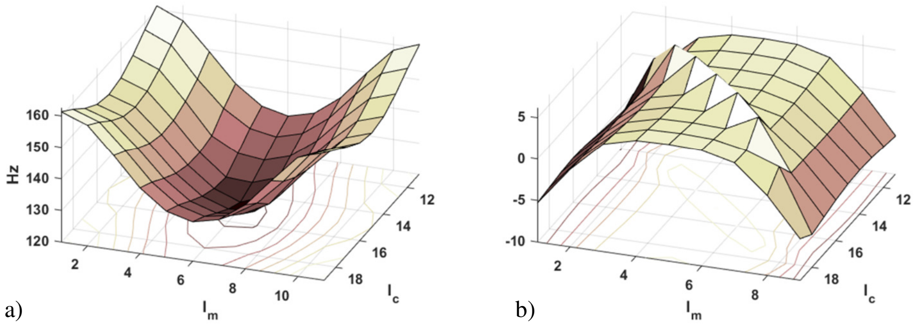

Fig. 4. The mass in the nodes of the top chord, damage in the bars of the bottom chord (el. 11–19) of the Warren truss: a) change ω_I b) change ω_I''

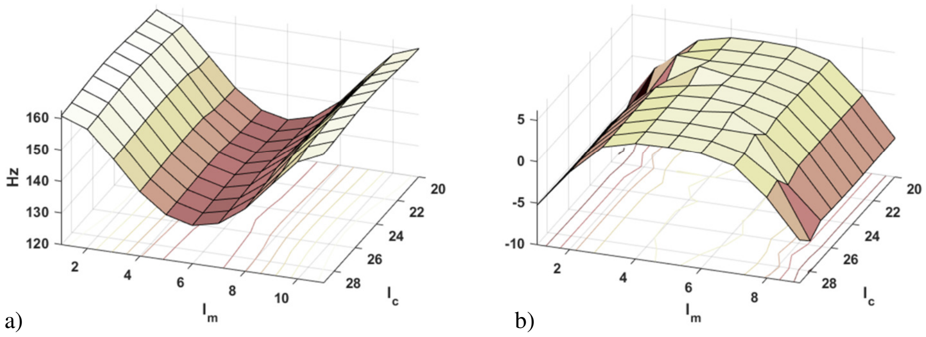

Fig. 5. The mass in the nodes of the top chord, damage in the diagonal bars (el. 20–29) of the Warren truss: a) change ω_I b) change ω_I''

The simulation results for the second truss were compiled for damage by 50% reduction in the cross-section area of the truss bars (h_c =5 *mm*). Figs. 6–9 show the changes of the first frequency ω_I with the mass position on the top chord and the change of the differential operator ω_I'' for the Pratt truss. The figures show the changes for different groups of truss bars: Fig. 6: top chord (el. 1–10), Fig. 7: bottom chord (el. 11–18), Fig. 8: diagonal bars (el. 19–28), Fig. 9: posts (el. 29–37). In the figures with the operator, an increased value near the damaged element was shown. The most significant changes for this truss were observed for the bottom chord (Fig. 7b). For all bars near the supports and the centre of the truss, the changes were hardly visible.

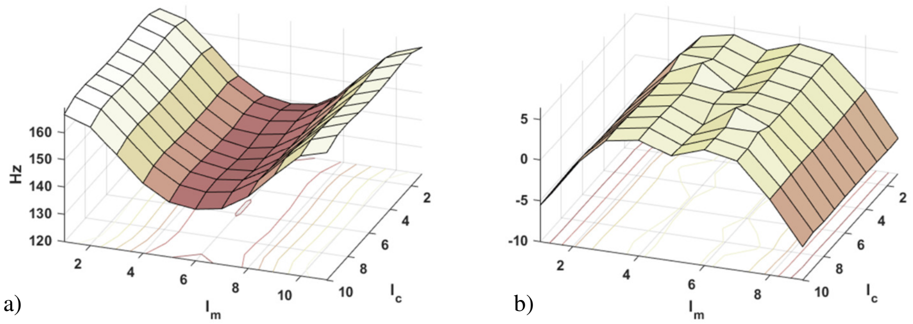

Fig. 6. The mass in the nodes of the top chord, damage in the bars of the top chord (el. 1–10) of the Pratt truss: a) change ω_l b) change ω_l''

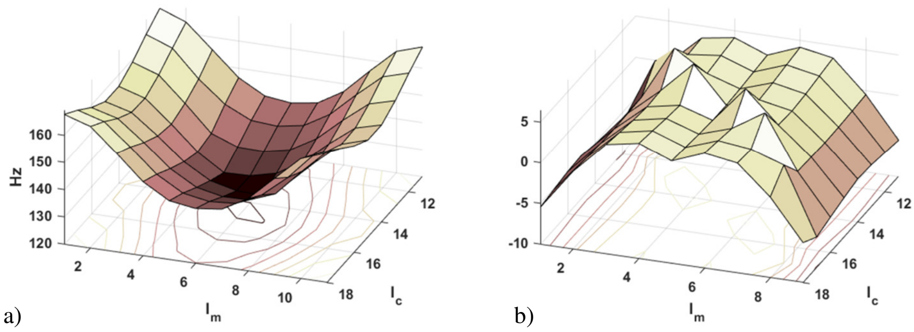

Fig. 7. The mass in the nodes of the top chord, damage in the bars of the bottom chord (el. 11–18) of the Pratt truss: a) change ω_l b) change ω_l''

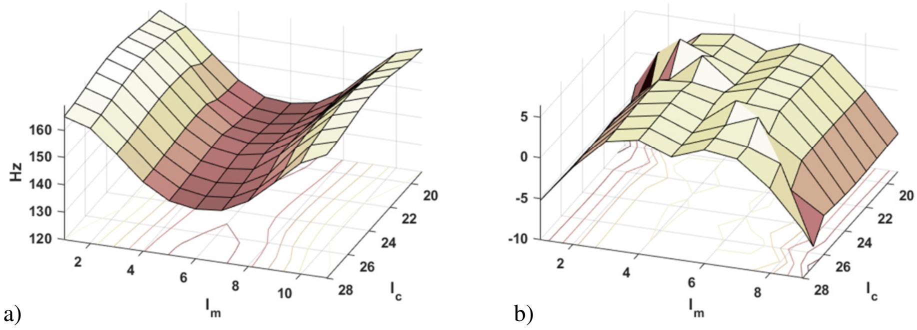

Fig. 8. The mass in the nodes of the top chord, damage in the diagonal bars (el. 19–28) of the Pratt truss: a) change ω_l b) change ω_l''

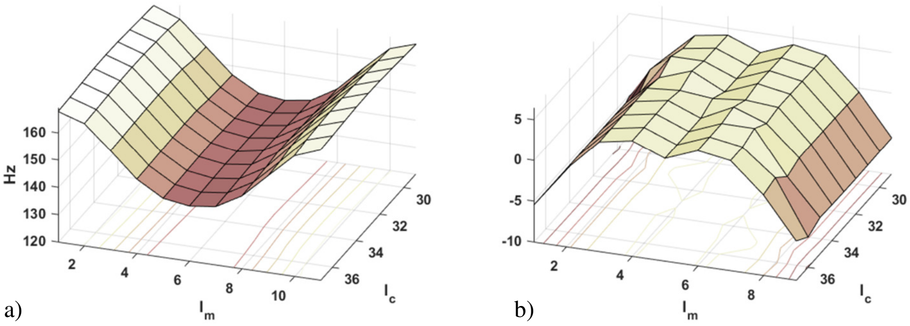

Fig. 9. The mass in the nodes of the top chord, damage in the posts (el. 29–37) of the Pratt truss: a) change ω_l b) change ω_l''

Fig. 10 shows the impact of the damage h_c (*1 mm - 8 mm*) for both trusses in element no. 14 in the bottom chord on the value of the operator ω_l''. The figures show significant changes in the damage area as the damage increases.

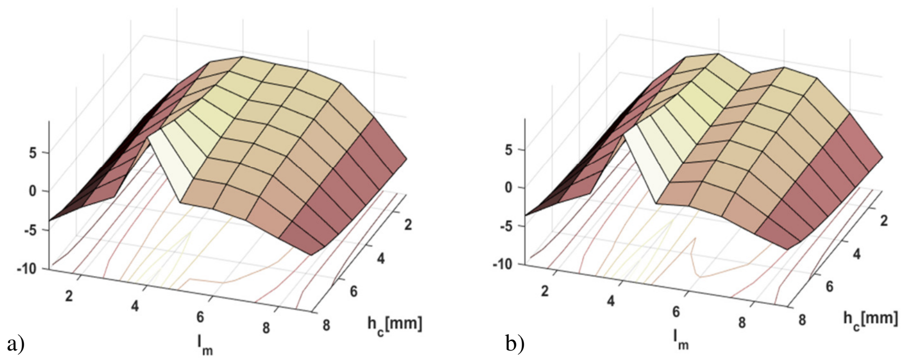

Fig. 10. The mass in the nodes of the top chord, damage in the bottom chord element no. 14, change ω_l'': a) Warren truss b) Pratt truss

Next Fig. 11 shows the impact of the damage h_c (*1 mm - 8 mm*) for both trusses in element no. 4 in the top chord on the value of the operator ω_l''. The figures show, as previously, significant changes in the damage area as the damage increases. For Warren truss (Fig. 11a) the changes were hardly visible.

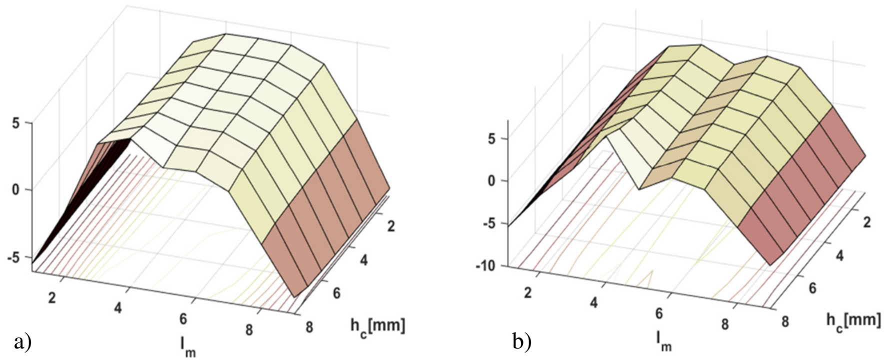

Fig. 11. The mass in the nodes of the top chord, damage in the top chord element no. 4, change ω_1'': a) Warren truss b) Pratt truss

4. Summary

The presented preliminary results of the application of the method based on the change of the natural frequency caused by moving mass allow damage localization in most truss bars. The main advantage of the presented approach is the possibility of damage localization without a reference model. A second-order differential operator was used in the work to analyse changes in natural frequencies. Hovewer, the damage was not detected in all truss elements and not for all damage sizes. In order to improve the presented method, a damage index independent of the reference model is expected in further research.

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