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The Influence of the Weight Loss upon Natural Frequency Changes in Case of Severe Defects

The paper presents a research regarding the use of a "virtual" material in order to compensate the loss of mass in the case of the damaged beam. Because of the loss of mass, the frequency of the beam suffer an increase over the natural frequency of the undamaged beam and so we have proposed the use of this material, having the same density with the density of the beam, in the gap left by damage.

Keywords*: cantilever beam, damage, weight loss compensation, frequencies*

1. Introduction

In order to monitor the health of structures, local nondestructive methods and global damage detection methods are used. The nondestructive methods have certain advantages and disadvantages. They allow detecting, locating and sometimes characterizing the damage quite precisely, but these methods need access to the damaged area and the inspection of a large structure can be costly and time consuming [1]. Global methods are capable to evaluate the state of the whole structure and these dynamic techniques do not request access to the damaged area.

Damage detection methods using natural frequency shift, damping, changes of mode shapes and flexibility of the structure are presented in the specialized literature [2-4]. Some methods based on frequency change permit the detection of the damages while some others allow the detection, localization and quantification of the damage [5,6,7].

In this paper we want to show that, in the case of the damaged beam, because of the loss of mass, the natural frequency of the beam increase, for certain positions of the defect, over the natural frequency of the undamaged beam. In order to compensate this loss of material, we used a "virtual" material in the gap left by damage and thus we achieved a more real simulation of cracks in beams. Analyses were performed using the finite element method to confirm that the use of this "virtual" material is suitable for our purpose.

2. Analysis with FEM of damaged beams

We used a steel cantilever beam (Figure 1) having the following geometrical characteristics: length $l = 1000$ mm , wide $b = 5$ mm , height $h = 5$ mm and consequently, for the undamaged state the cross-section $A = 25 \cdot 10^{-6}$ m^2 and the moment of inertia $I = 52.0833 \cdot 10^{-12}$ m^4.

The chosen material parameters for the FEM simulations are in concordance to that of the real beam, being: mass density $\rho = 7850$ kg/m^3 , Young's modulus $E_1 = 2 \cdot 10^{11}\ N/m^2$, Poisson's ratio $\mu = 0.3$.

The analysis is performed on the steel beam and the mesh was created with finite elements of two different dimensions 2 mm and 0.5 mm respectively (fig. 1).

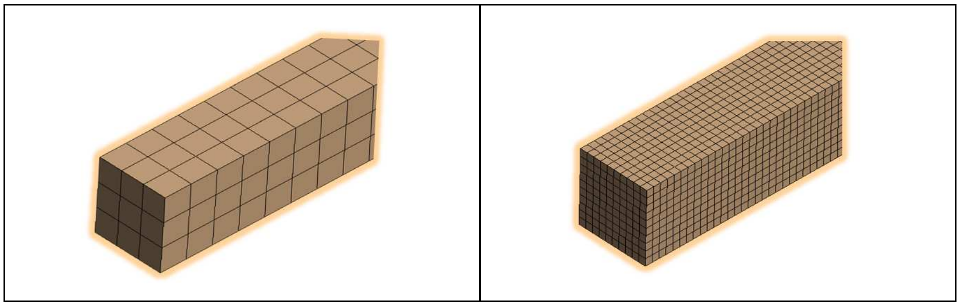

Figure 1. The undamaged cantilever beam meshed with 2 mm and 0.5 mm elements respectively

We consider a damage with the width $d = 2$ which reduces the cross-section to 60% (as we can see in fig. 2).

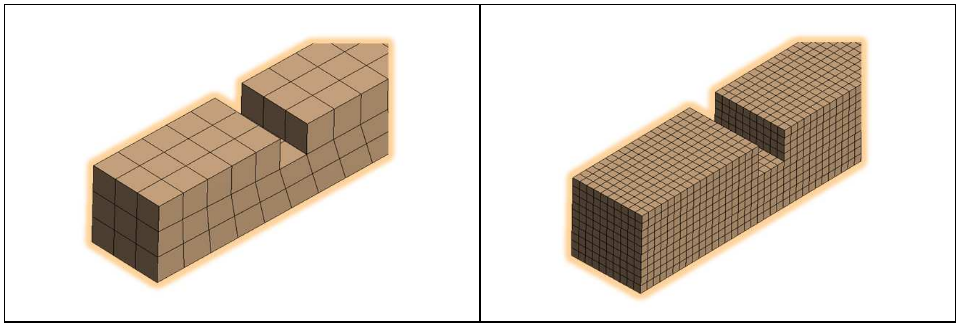

Figure 2. The damaged cantilever beam meshed with 2 mm and 0.5 mm elements respectively

For a mesh with 2 mm elements and from numerical simulations using the finite element method we obtained the natural frequencies, for the first two modes, both for the undamaged and for the damaged beam (as presented in table 1).

Table 1 The frequencies for the undamaged and for the damaged beam for the first two modes and the 2 mm mesh

Mode	Distance from the clamped end	Frequencies for the undamaged beam	Frequencies for the damaged beam
1	10	4.0789	3.9675
	500	4.0789	4.0664
	990	4.0789	4.0853
2	10	25.552	24.926
	500	25.552	25.201
	990	25.552	25.589

Next, for a mesh with 0.5 mm elements and we obtained the natural frequencies both for the undamaged and for the damaged beam (as presented in table 2).

Table 2 The frequencies for the undamaged and for the damaged beam for the first two modes and the 0.5 mm mesh

Mode	Distance from the clamped end	Frequencies for the undamaged beam	Frequencies for the damaged beam
1	10	4.0768	3.9578
	500	4.0768	4.063
	990	4.0768	4.0832
2	10	25.537	24.872
	500	25.537	25.163
	990	25.537	25.574

As can be seen from de results given in Tables 1 and 2, the mass loss determines the increase of natural frequencies for the damaged beam, over the natural frequencies of the undamaged beam. In order to eliminate this deficiency, in the gap left by the damage, we have introduced a material with the mass equal with the mass displaced, but with much lower Young's modulus $E_2 = 200\,N/m^2$ (see fig. 3). In the same conditions as before, taking first a 2 mm mesh, then a 0.5 mm mesh we have performed a numerical simulation to obtain the natural frequencies of the damaged beam with the „virtual material" into the gap.

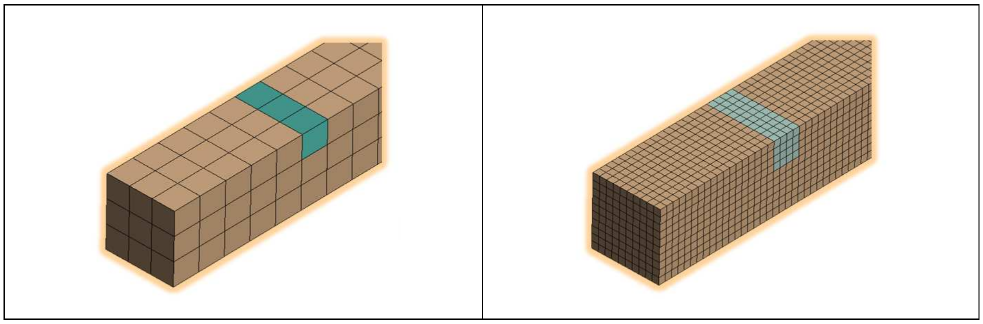
Figure 3. The damaged cantilever beam meshed with 2 mm and 0.5 mm elements respectively with the „virtual material" into the gap

Table 3 The frequencies for the undamaged and for the damaged beam with mass compensation, for the first two modes and the 2 mm mesh

Mode	Distance from the clamped end	Frequencies for the undamaged beam	Frequencies for the damaged beam with mass compensation
1	10	4.0789	3.9714
	500	4.0789	4.0672
	990	4.0789	4.08
2	10	25.552	24.931
	500	25.552	25.166
	990	25.552	25.159

Table 4 The frequencies for the undamaged and for the damaged beam with mass compensation, for the first two modes and the 0.5 mm mesh

Mode	Distance from the clamped end	Frequencies for the undamaged beam	Frequencies for the damaged beam with mass compensation
1	10	4.0768	3.9578
	500	4.0768	4.0624
	990	4.0768	4.0773
2	10	25.537	24.872
	500	25.537	25.134
	990	25.537	25.46

The results obtained with FEM analysis allow us to plot figures 4 and 5, which show that the use of this "virtual material" help us to simulate, more accurately the real cracks.

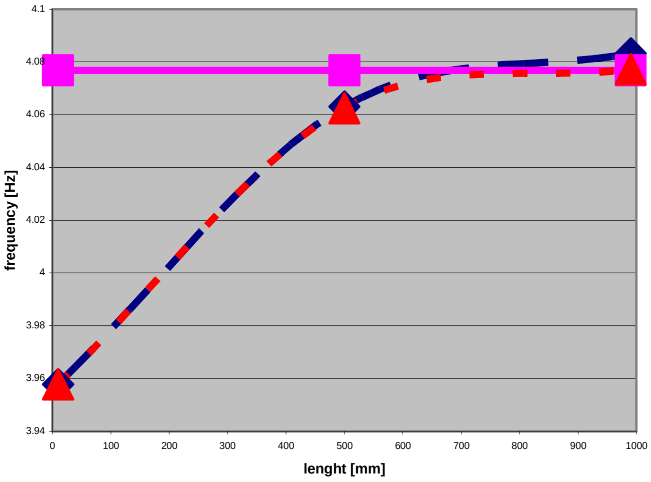

Figure 4. Graphical representation of the frequencies obtained from the analysis with 0,5 mm mesh

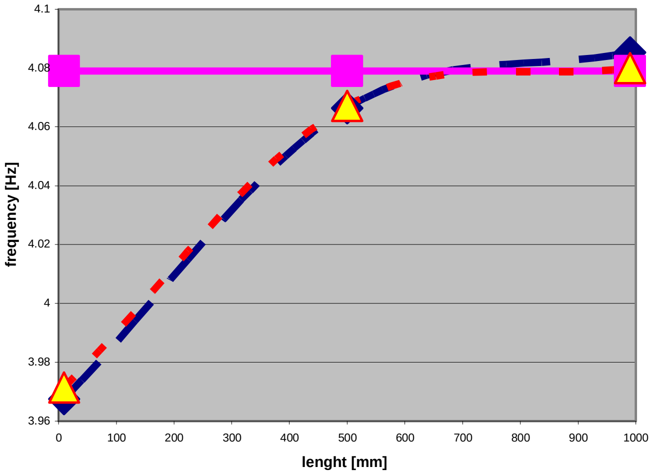

Figure 5 Graphical representation of the frequencies obtained from the analysis with 2 mm mesh

In figure 4 we have the graphical representation of the frequencies obtained from the FEM analysis with 0.5 mm mesh, the natural frequency of the undamaged beam is with continuous line, the frequencies for the damaged beam with dashed line and the frequencies for the damaged beam with mass compensation, with dotted line. In figure 5 we have the graphical representation of the frequencies obtained from the FEM analysis with 2 mm mesh, the natural frequency of the undamaged beam is with continuous line, the frequencies for the damaged beam with dashed line and the frequencies for the damaged beam with mass compensation, with dotted line.

3. Conclusion

As we observed from the FEM analysis performed, the mass loss, in the case of the damaged beam, increases the frequency compared with the natural frequency of the undamaged beam.

By compensating the loss of mass with an element with the density equal to the density of the beam, but super elastic, we can eliminate these errors presented earlier and simulate, more accurately the real cracks.

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