EFFECT OF THE ORIENTATION OF AN OBLIQUE CRACK BRANCHES ON THE BEAM EIGENFREQUENCIES

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Abstract: *The paper presents a numerical study on how the orientation of the oblique components of Y-shaped cracks influences the structures' eigenfrequencies. For this analysis, models are created in which the two branches of the crack propagate at various angles. The cross-sectional component is placed in characteristic locations of the structure in out of plane vibration. The simulation results demonstrated that the crack propagation direction had a significant effect on the eigenfrequency values.*
Keywords: *damage detection, branched crack, eigenfrequency, vibration mode*

1. INTRODUCTION

The properties of materials used in the construction of different aggregates or engineering structures like bridges and buildings may lose partial or complete functionality if they are affected by the presence of damages, leading to structural failure. The present concern for engineers is to be able to detect the early occurrence of damages in structures by using global detecting methods that are economical and easy to implement. Structural health monitoring methods are necessary for ensuring the safety of structures [1-4]. They can be applied in the case of multiple damages [5], on composite materials beams [6] and plate-like structures [7]. Depending on the size, location and geometry of the damage, the physical properties of a material as well as its dynamic properties, like eigenfrequencies are affected [8]-[9]. These changes in modal parameters can be used to detect the presence, size and location of cracks in structures.
Because the eigenfrequency shift in some cases is very small, the need for exact detecting methods is implied [10]. In our previous research, we have studied the effect of several scenarios of cracks, such as transversal [11], T, L and Y shaped cracks [12-15]. In the present research, we have approached a more complex geometry of a Y-shaped crack positioned at key locations in the structure, which resembles a real-life scenario of a crack that propagates through the material with different ramification angles.
This paper presents a numerical study destined to find the dynamic response of cantilever beams with Y-shaped cracks, in particular, the effect of the orientation of the oblique components.

2. MATERIALS AND METHODS

2.1. The test beam

The current paper focuses on finding the changes in modal parameters due to the presence of a two-branched crack with different angles of penetration at different locations in a cantilever beam. The assigned material for the beam is Structural Steel, with its physical-mechanical properties (defined in the ANSYS library) and main dimensions presented in table 1.

Table 1: Cantilever beam properties and dimensions

Physical-mechanical properties						Main dimensions		
Mass density [kg/m^3]	Young modulus [N/m^2]	Poisson ratio [-]	Tensile strength [MPa]	Yield strength [MPa]	Min. elongation [%]	Length [mm]	Width [mm]	Thickness [mm]
7850	$2 \cdot 10^{11}$	0.3	470-630	355	20	1000	20	5

The damage geometry is described as a Y-shaped crack resulted from a transverse component followed by two oblique ramifications, with its general dimensions presented in figure 1.

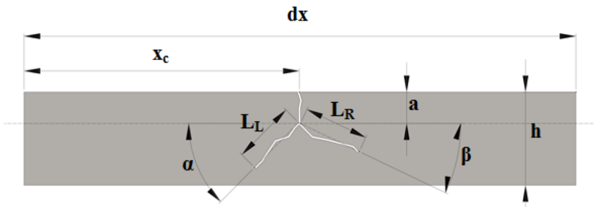

Figure 1: The geometry of the Y-shaped crack

The transverse crack component extends 1 mm in depth from the upper surface and it is further penetrating the material by two ramifications of 3 mm length at angles α and β between 0 and 90˚ iterated by a step of 30˚. For this study we positioned the crack at key locations, firstly next to the fixed end, second, we moved the crack at an inflection point for the third vibration mode and for the last scenario we placed the crack in a point where the third modal form shape achieves maximal displacement. The angle values chosen for all particular cases are indicated in table 2, along with the other main dimensions of the damage.

Table 2: Dimensions of the Y-shaped crack

x_c [mm]	a [mm]	L_L [mm]	L_R [mm]	α [˚]	β [˚]
10; 300; 480	1	3	3	0	0
					30
					60
					90
				30	0
					30
					60
					90
				60	0
					30
					60
					90
				90	0
					30
					60
					90

2.2. Test procedure

The modal analysis was carried out by means of the ANSYS simulation software, by applying a fixed boundary condition on the left beam end. The Y-shaped crack model was implemented in concordance with that presented in [16]. The oblique branches have different angles, as presented in figure 2. Hexahedral elements with the maximum edge size of 2 mm are used, resulting in a fine mesh. In the cracked region the mesh is even finer.

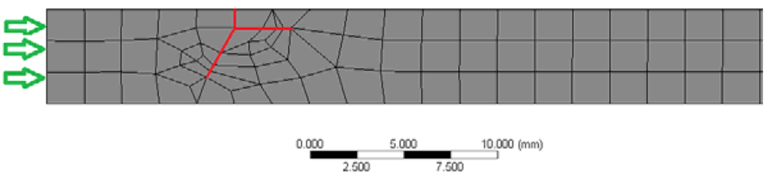

Figure 2: Zoom on the left fixed beam end highlighting the created damaged

The acquired results for the beam in healthy and damaged state are the values of the eigenfrequencies for the first 6 modes of out-of-plane vibration. The first evaluation focused on the influence of the different propagation angles of the crack, while the second one was on the influence of the crack position for the third vibration mode. In figure 3 we illustrate the stress distribution for the 3 key positions of the crack for the third vibration mode, where x_c=10 mm represents the crack positioned near the fixed end, x_c=300 mm the position of the crack where the beam deflection is maximal and x_c=480 mm at an inflection point.

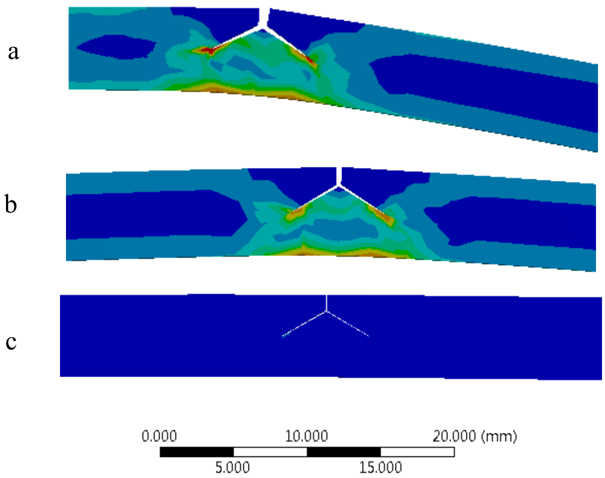

Figure 3: Zoom on the three characteristic locations: (a) maximum curvature at x_c = 10 mm; (b) local maximum of the curvature x_c = 300 mm; (c) curvature's inflection point x_c = 480 mm

3. RESULTS AND DISCUSSIONS

In order to understand the phenomena of frequency shift due to the different types of cracks in a cantilever beam, we plotted the frequency shift curves for all damage cases for the first six vibration modes. In figures 4 and 5 we present the plotted frequency shift curves for the vibration modes one to three.

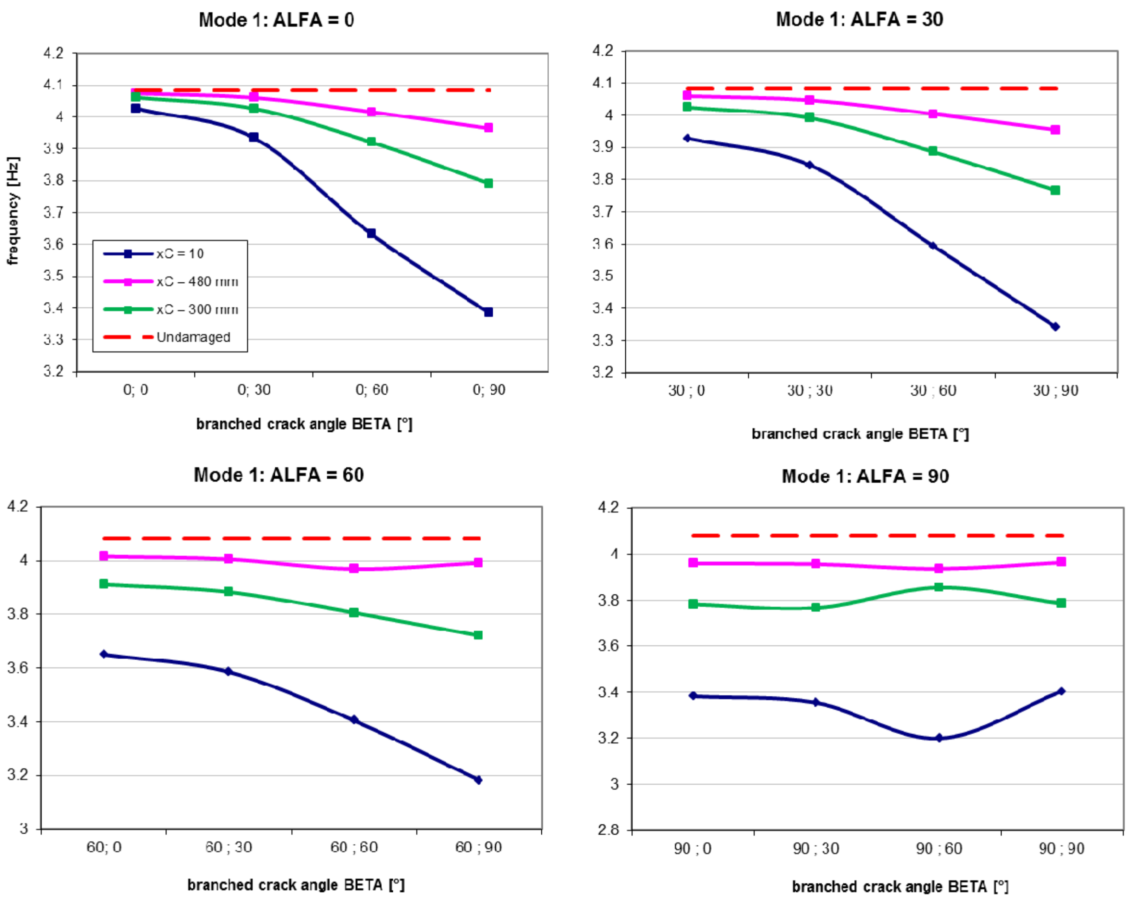

Figure 4: Plotted frequency shift curves for the first mode of vibration for the three damage positions

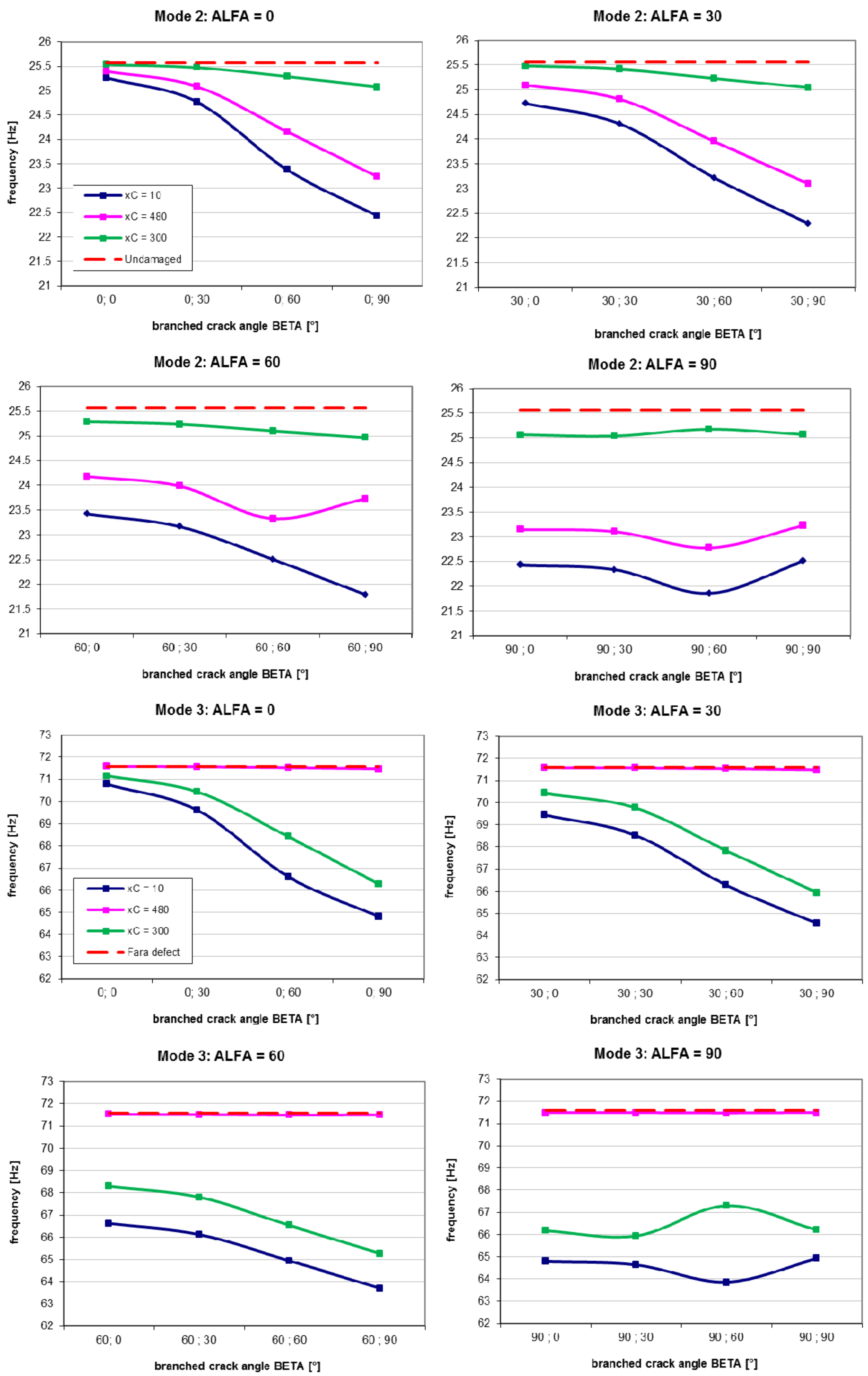

Figure 5: Plotted frequency shift curves for the second and third vibration mode for the three damage positions

The way how a Y-shaped crack diminishes the eigenfrequencies of the beam is shown by comparing the evolution of the frequency shift on different locations and geometry of the crack. One can observe that, in comparison, the position of the crack with the most influence on the modal parameters is located near the fixed end, which demonstrates that for a cantilever the location with the highest bending moment is at the fixed end.
After comparing the values obtained for all damage scenarios we can assume that the presence of a Y-shaped crack with branches at 60˚ and 90˚ has the largest effect on the frequency drop irrespective to the crack location.
Since the frequency shifts are in direct relation with the mode shape curvatures or bending moments from the plotted values one can observe that the beam achieves different frequency shifts at different locations. For the damaged case with the crack located at an inflection point, as expected, the obtained values indicated a low-frequency diminishing. This happens because no stress is present in the crack region, as shown in figure 3c. The results of the damaged beam, as well as the results on the healthy beam obtained by FEM analysis, are presented in table 3 for conformity. It can be easily observed that the shift is less 1%.

Table 3: Comparison between the frequencies of the undamaged beam f_{iU} and the frequency f_{iC} of the beam with a crack positioned at a beam's inflection point (x_c= 480 mm for mode 3)

f_{iU} [Hz]	α [˚]	β [˚]	f_{iC} [Hz]	difference [%]
71.597	0	0	71.588	0.01
		30	71.577	0.03
		60	71.538	0.08
		90	71.484	0.16
	30	0	71.569	0.04
		30	71.559	0.05
		60	71.524	0.10
		90	71.474	0.17
	60	0	71.52	0.11
		30	71.514	0.12
		60	71.488	0.15
		90	71.503	0.13
	90	0	71.481	0.16
		30	71.482	0.16
		60	71.469	0.18
		90	71.484	0.16

Table 4: Comparison between the frequencies of the undamaged beam f_{iU} and the frequency f_{iC} of the beam with a crack positioned at a point where the curvature achieves a local maximum (x_c= 300 mm for mode 3)

f_{iU} [Hz]	α [˚]	β [˚]	f_{iC} [Hz]	difference [%]
71.597	0	0	71.157	0.61
		30	70.439	1.62
		60	68.42	4.44
		90	66.285	7.42
	30	0	70.436	1.62
		30	69.763	2.56
		60	67.833	5.26
		90	65.93	7.92
	60	0	68.292	4.62
		30	67.802	5.30
		60	66.524	7.09
		90	65.263	8.85
	90	0	66.17	7.58
		30	65.932	7.91
		60	67.305	5.99
		90	66.21	7.52

In contrary, for cracks located at points where the curvature (or the bending moment) achieves a local maximum, thus high stress is present in the crack region, significant frequency drop is remarked – see figure 3a and b and table 4.

4. CONCLUSION

The frequency changes were determined and compared by means of simulation for a cantilever beam having a Y-shaped crack with different dimensions and positioned at different locations.
It was found that the branch penetration angle of the crack produces different frequency shifts.
It was also observed that the greatest shift and stress is found at the fixed end, for all six modes of vibration.
The smallest frequency changes, as expected were found at inflection points where the beam faces less stress, thus crack has a low effect.
After comparison of the eigenfrequencies values for the different penetration angles of the damage, it was found that the geometry formed by a transverse crack with one branch propagating in the same transverse direction and the other at 60˚ degrees presents the largest frequency drop, no matter of the crack position on the beam.
The damage patterns are different for every location, geometry and dimensions of a crack, so it is possible to develop reliable methods based on modal parameter changes for damage detection.

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