DOI: 10.5604/01.3001.0015.5854
Volume 109 • Issue 1 • November 2021
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Instructions for the preparation of a numerical investigation on crack parameters of cantilever beam using FEA

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ABSTRACT

Purpose: The operation of engineering structures may cause various type of damages like cracks, alterations. Such kind of defects can lead to change in vibration characteristics of cantilever beam. The superposition of frequency causes resonance leading to amplitude built up and failure of beam. The current research investigates the effect of crack dimensional parameters on vibrational characteristics of cantilever beam.

Design/methodology/approach: The CAD design and FE simulation studies are conducted in ANSYS 20 simulation package. The natural frequencies, mode shapes and response surface plots are generated, and comparative studies are performed. The effect of crack dimensional parameters is then investigated using Taguchi Design of Experiments. The statistical method of central composite design (CCD) scheme in Response Surface Optimization is used to generated various design points based on variation of crack width and crack depth.

Findings: The research findings have shown that crack depth or crack height have significant effect on magnitude of deformation and natural frequency. The deformation is minimum at 0.009 m crack height and reaches maximum value at 0.011 m crack height.

Research limitations/implications: The crack induced in the cantilever beam needs to be repaired properly in order to avoid crack propagation due to resonance. The present study enabled to determine frequencies of external excitation which should be avoided. The limitation of current research is the type of crack studied which is transverse type. The effect of longitudinal cracks on vibration characteristics is not investigated.

Practical implications: The study on mass participation factor has shown maximum value for torsional frequency which signifies that any external excitation along this direction should be avoided which could cause resonance and lead to amplitude build up.

Originality/value: The beams are used in bridge girders and other civil structures which are continuously exposed to moist climate. The moisture present in the air causes corrosion which initiates crack. This crack propagates and alters the natural frequency of beam.

Keywords: ANSYS, Vibration, Cantilever beam

Reference to this paper should be given in the following way:
M.A. Ansari, V.K. Tiwari, Instructions for the preparation of a numerical investigation on crack parameters of cantilever beam using FEA, Journal of Achievements in Materials and Manufacturing Engineering 109/1 (2021) 5-10. DOI: https://doi.org/10.5604/01.3001.0015.5854

METHODOLOGY OF RESEARCH

1. Introduction

A pillar is for the most part viewed as any part exposed to essentially to cross over gravity or vertical stacking as displayed in Figure 1 underneath. There are numerous kinds of shafts that are arranged by their size, way in which they are upheld, and their area in some random underlying framework.

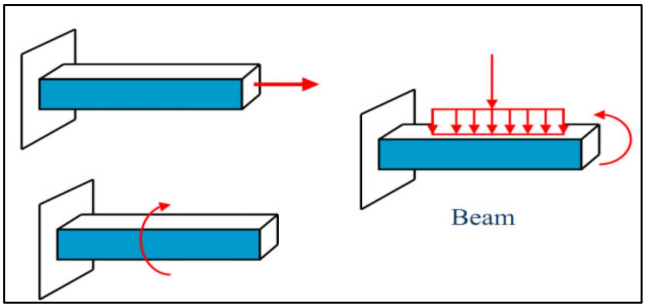

Fig. 1. Loading on beams

Beams are used to support the roof and floors in buildings as shown in Figure 2. A major cause of failures in beams is due to cracks. The presence of cracks in beams results in resonance and amplitude build up. The vibration characteristic of beam is significantly affected by presence of cracks. The vibration on beams can be classified as free vibration or forced vibration type. Basically, in free vibration, there is no force acting on the vibrating system externally [1].

Fig. 2. Beams to support the roof and floors in buildings

The vibration in a tuning fork in the wake of giving its some underlying aggravation by striking it, the vibration in a swing after some underlying back pull, and straightforward pendulum movement all are the case of free vibrations [2-13]. The condition of movement for a different level of opportunity undamped underlying framework is addressed as follows [14]

$$[M]\,\{\ddot{y}\} + [K]\{y\}=\{F(t)\} \tag{1}$$

where $\{\ddot{y}\}$ and y are the separate speed increase and uprooting vectors for the entire design and {F (t)} is the outer power vector. Under free vibration, the normal frequencies, and the mode states of a numerous level of opportunity framework are the arrangements of the Eigen value issue.

$$[[K]-\omega 2\ [M]]\{\ \phi\}=0 \tag{2}$$

where ω is the rakish normal recurrence and ϕ? What is the mode state of the design for comparing regular recurrence? The impacts of vibration are unreasonable anxieties, unwanted commotion, detachment of parts, and halfway or complete disappointment of parts [15].

2. Objective

The current research is intended to determine the effect of crack parameters on vibration characteristics of cantilever beam using techniques of Finite Element Analysis. The Taguchi Design of Experiments is used to determine the natural frequencies and deformation for different design points.

3. Methodology

The CAD model of cantilever beam is modelled in ANSYS design modeler as shown in Figure 3 below. The mechanical properties of the low carbon steel beam studied, [16], are for low carbon steel beam: E=207 GPa, G=80 GPa, ρ=7800 kg/m^3, ν=0.3.

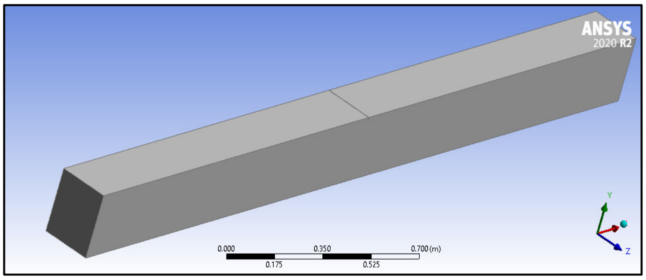

Fig. 3. CAD model of cantilever beam

The dimensions of cantilever beam are 3 m*2 m*25 m. The dimensions are taken from literature [17]. The model of cantilever beam is meshed using tetrahedral elements with transition ratio of 272 and number of layers is 5. The meshed model of cantilever beam is shown in Figure 4 below.

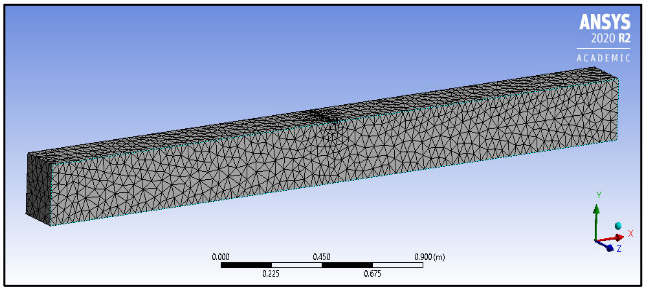

Fig. 4. Meshed model of cantilever beam

The modal analysis is conducted on cantilever beam by applying fixed support on left face as shown in Figure 5 above. The natural frequencies and mode shapes are determined by calculating these values at nodes and interpolating it for entire element edge length.

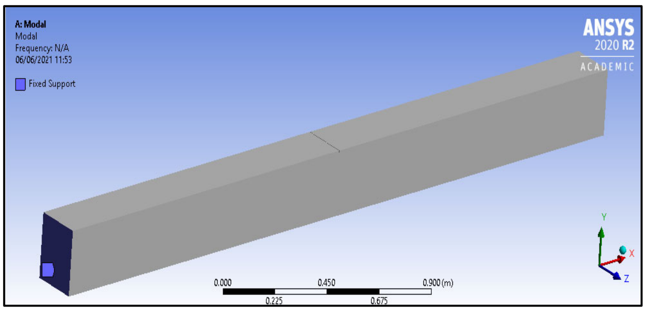

Fig. 5. Loads and boundary condition

Lower modes are associated with lower energy state. Higher modes require higher energy input which a structure or member may not face in its entire life. Therefore, lower modes are normally considered for analysis.

The design of cantilever beam is then optimized using Taguchi Response Surface Method. The response surface method (RSM) is a set of mathematical and statistical techniques that are useful for analysing problems in which several independent variables affect a dependent variable or responses. The relationship between the dependent variable and the independent variable can be represented as

$$y = f(X_1, X_2, X_3, X4 \ldots\ldots X_n) + \varepsilon \qquad (3)$$

where ε represents the noise or error observed in the "y" response. The two dimensions which are optimized using response surface method is crack depth and crack width.

4. Results and discussion

The modal analysis is conducted on cantilever beam with crack to determine natural frequency and deformation. The five natural frequencies are determined.

As it is observed from Figure 6 and Figure 7, the mode shape of 1st natural frequency is along *z* direction and mode shape of 2nd natural frequency is along *y* direction respectively. The mode shape of 3rd natural frequency and mode shape 4th natural frequency is transverse shown in Figure 8 and Figure 9 respectively but mode shape of 5th natural frequency is torsional as shown in Figure 10.

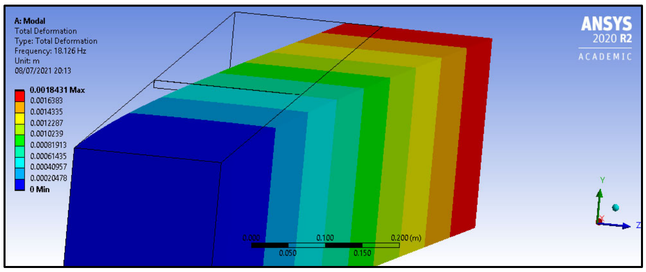

Fig. 6. Mode shape of 1st natural frequency of cantilever beam

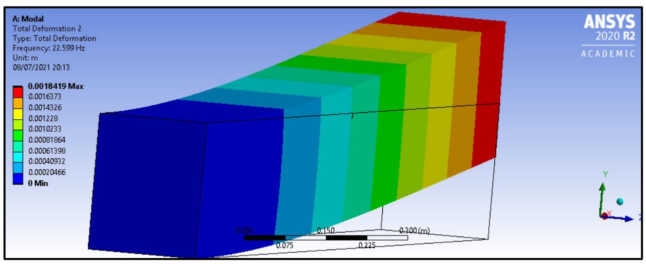

Fig. 7. Mode shape of 2nd natural frequency of cantilever beam

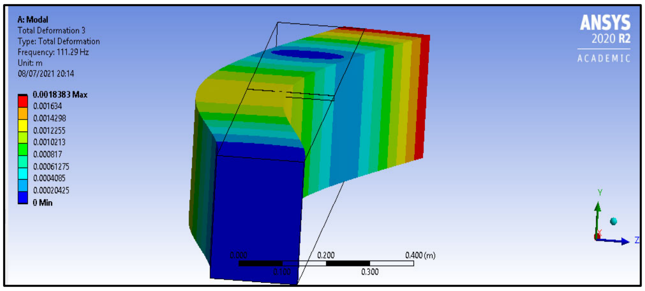

Fig. 8. Mode shape of 3rd natural frequency of cantilever beam

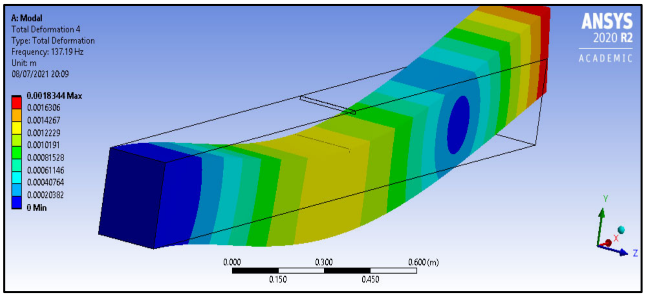

Fig. 9. Mode shape of 4th natural frequency of cantilever beam

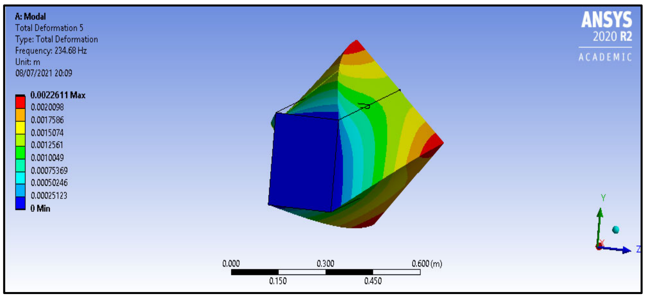

Fig. 10. Mode shape of 5th natural frequency of cantilever beam

The 2nd natural frequency obtained from modal analysis is 22.59 Hz and deformation observed is 1.84 mm. The 4th natural frequency obtained from modal analysis is 137.1 Hz and deformation observed for this frequency is 1.83 mm. From the modal analysis, the mass participation factor along all the degrees of freedom is determined. The maximum mass participation factor is observed for z direction with magnitude of 0.86. The low participation factor is observed for ROT_x direction (Tab. 1).

The 1st natural frequency obtained from FE simulation is 18.12 Hz which is in close agreement with fundamental frequency value given in literature [17] (Tab. 2).

Table 1.
Mass participation factor along ROT_z

Mode	Frequency, Hz	Ratio of effective mass to total mass
1	18.1	0.61
2	22	.86e-8
3	111	.19
4	137	.51e-8
5	234	.12e-8
6	302	.66e-1
	Sum	.868

Table 2.
Fundamental frequency comparison

1st natural frequency from FEA simulation, Hz	1st natural frequency from literature [17], Hz	Percentage difference
18.1	17.91	1.06

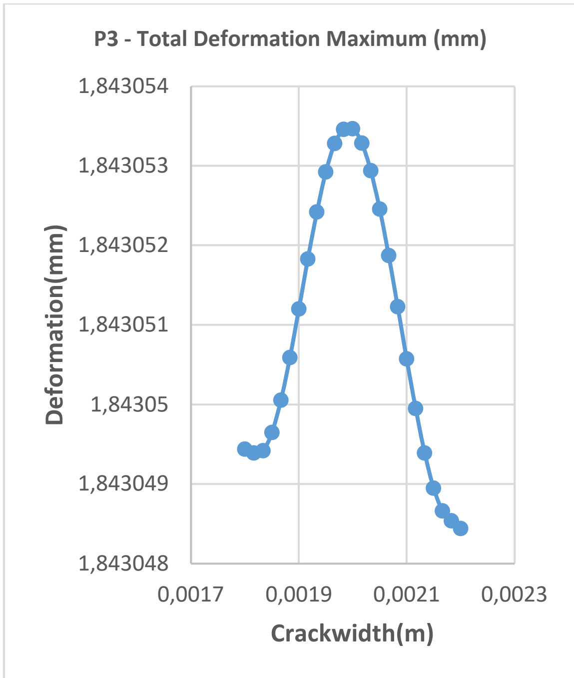

Fig. 11. Deformation vs. crack width

The deformation vs. crack width obtained from Taguchi optimization is shown in Figure 11. It can be observed that deformation initially increases with increase in crack width and reaches maximum value at 0.002 m crack width. The deformation then decreases with increase in crack width and reaches minimum at 0.0022 m crack width. The deformation vs. crack height variation is shown in Figure 12. The deformation increases linearly with increase in crack height. The deformation is minimum at 0.009 m crack height and then increases linearly and reaches maximum value at 0.011 m crack height.

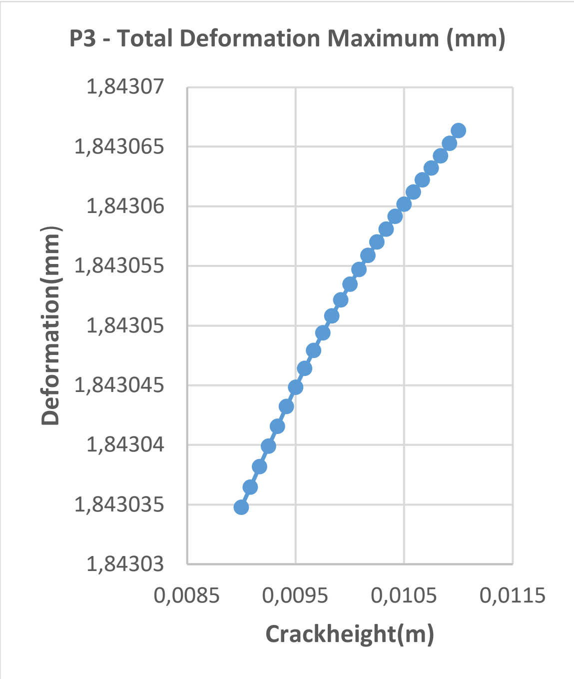

Fig. 12. Deformation vs. crack height

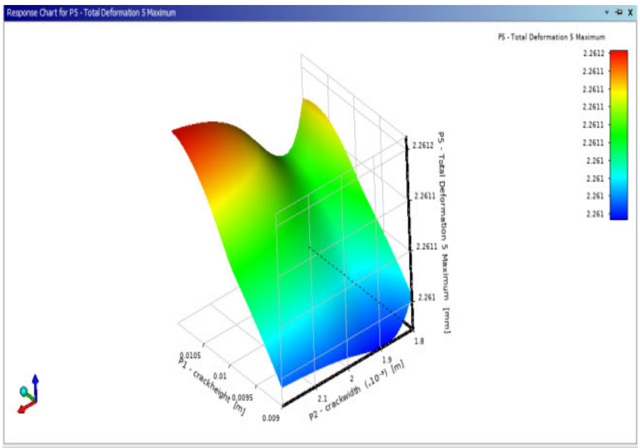

Fig. 13. Response surface plot of deformation

The response surface plot of deformation shows highest magnitude of deformation as represented by red colour and minimum magnitude of deformation as shown by dark blue colour (Fig. 13). The maximum deformation is observed for crack height value ranging from 0.0105 m to 0.011 m and crack width ranging from 0.0021 m to 0.00219 m.

5. Conclusions

1. The FEA is viable tool to determine natural frequencies and mode shapes of cantilever beam. The effect of dimensional parameters of crack on vibration characteristics of cantilever beam is studied.
2. The mass participation factor along all the directions is evaluated and it is found that the mass participation is maximum along rotational Z direction which signifies that any external excitation along this direction is more likely to cause resonance as compared to *x* and *y* directions.
3. The research findings have shown that crack depth or crack height have significant effect on magnitude of deformation and natural frequency.
4. Therefore, any kind of irregularity or discontinuity resulting in crack initiation or crack propagation would cause change in vibration characteristics.

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