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Modal Analysis of crack and uncrack cantilever beam using Ansys workbench with piezoelectric material

Structural Health Monitoring

[1]Manik Maiti
[1]Assistant Professor
[1]Department of Civil Engineering[1]Global Institute of Science and Technology, ICARE Complex, GIST Campus, Hatiberia, Haldia, Purba Medinipur, West Bengal, India.

Abstract: The objective of this research paper is to determine the deformation in Natural Frequency in different mode of a solid steel cantilever beam and a cracked cantilever beam when a load is placed on it. In this thesis report, FEM Methods has used for predicting the deformation the method adopted to fulfil this objective is that by Ansys workbench, 2023 version, piezoelectric material is placed under the cantilever beam and simulation is done. The result obtained by using these methods shows that at a certain frequency the value of the deformation in the cracked steel beam is decreasing.

***IndexTerms* - Structural Health Monitoring, Ansys Workbench, Cantilever Beam With Crack And Uncrack, Modal Analysis.**

I. INTRODUCTION

Engineering structures are so designed and constructed that stability, strength, stiffness and durability are ensured during their life time for all anticipated loads. The beams are among these that are used most frequently and have a wide range of engineering-oriented practical applications. They undergo both static as well as dynamic loads of elements. It is necessary to build a structure that will function safely for the duration of the service period. Nevertheless, some fractures would cause a specific kind of deformation failure in the structure. The infinitesimal changes either intentionally or unintentionally that are introduced in a structure, leading to the adverse effects on the prevalent or further performance of that structure is usually referred as damage. It can cause the failure of structure as a whole or any individual element can fail. Due to fast paced economic growth of the industrial buildings, damage can be considered as one of the main factors and aspects relevant to structural analysis and structural engineers need to ensure damage free elements in structures. The most common structural defect that is discovered when studying structures is the persistence of cracks. Cracks in any element of a structure are undesirable and it is most often found in structures at the start of their service or may develop later over a period of time. The interesting basic model for many enriching structural engineering applications, which are widely used in structural components under controlled conditions, is explored in the analysis of beams. Examples includes the structures that are modeled with the structural element such as beam-like elements like aircraft wings, spacecraft antennae, helicopter rotor blades and robot arms. Many other structures to be considered as examples are beam like model elements are lengthy bridges, high rise buildings and robotic arms. The presence of fracture in structural elements can have a significant impact on the dynamic responses of the entire structure. Cracks when widen and propagate can cause catastrophic failure of any types of structures. Cracks can be detected and predicted, and subsequent corrective action in the impending mechanical, electrical, and process-related issues can be taken using variations in dynamic responses, characteristics of structures or structural elements due to the initiation, growth, and propagation of cracks. Monitoring the vibration can reveal issues with machinery equipment and continuous process systems. Hence it is important to understand the post cracking behavior of beams subjected to vibration. There is a need to develop effective techniques for the analysis cracked beams under vibration. In the present work an attempt has been made to understand the behavior of beams under vibration and theoretical and numerical analyses are carried out to perform vibration analysis of beams in normal and post crack stages. Vibration analysis is a general method used to find defects of structures like fractures. It offers an inexpensive, effective and efficient way of nondestructive testing

(NDT). The existence of cracks /localized damage within the structures drastically minimizes the stiffness and enhances damping within the element. In vibration theory it is well known that reduction in natural frequencies with modifications of vibration modes in structures is associated with reduction in the stiffness. Properties such as damping and stiffness will be influenced by its dynamic loading due to existence of fracture in structural component. The frequencies and respective mode shape of structures provides info regarding the positional and depth data of the cracks. Due to the existence of fractures in the structures, increase in local flexibility is detrimental for entire structure towards dynamic behavior to a considerable level. This also decreases the natural frequency which varies the mode patterns of the vibration. Identification of such differences likely yields in detection of cracks leading to fracture. As time progresses, structural defects like cracks initiated in all structures are subjective to degenerative effects ultimately leading to a catastrophic-failure/breakdown of the structures. Thus, the quality of manufactured products should be ensured by periodical inspection which is very important. In structural elements, cracks or other defects will influence the dynamic behavior and changes the stiffness as well as damping properties. Information regarding the location and damage dimensions are directly related with natural frequencies with respect to structure. Stiffness of entire structure decreases due to the occurrence of damages and natural frequency which provides the efficient method for detecting damage identification. Finite element method shortly known as FEM is very effective tool for analyzing and developing solutions to various vibration problems in structures which provides an advance-numerical discretization scheme. In structural mechanics FEM plays a major role. FEM is a general purpose numerical method and is widely used in the analysis of structures for static and dynamic loads to determine the responses. In the early 1970s Bellman and his associates first developed the differential quadrature method (DQM). They aimed to offer an efficient numerical method to solve partial differential equations of non-linear type. Since then this method is successfully applied to various problems. By using Lagrange multipliers the boundary conditions of beams are satisfied as per damaged or undamaged condition the behaviour of members of the structure varies. Damages like cracks in members cause most of the structures to fail. Cracks also reduce the stiffness and frequency of structures. So, to examine the dynamic behavior, many experiments are carried out. The objective of the present work is to examine the natural frequency and mode shape of a cantilever beam with single crack in highly stressed zone and also to verify frequency with an analytical value. These structures within the service-life are subject to various means to know the effects of dynamic-loading, corrosive medium, temperature within additional types of damages Alloy beams are widely used in aircrafts and machinery structures. Fatigue cracks which are caused by cyclic loading action due to vibration are the main cause of initiating cracks and subsequent failure of beams. This also leads to the change in natural frequencies. Since fatigue-cracks are potential means of sources leading towards catastrophic structural failure, early detection of such cracks is important for both safety and economic reasons. Due to numerous reasons cracks are present in several structures. Modification in stiffness and in the mechanical behavior of complete structure occurs because of existence of the crack in the structure which results in damage to huge extent. Unlimited fatigue strength causes fatigue under service-conditions leading towards the formation of cracks. Smaller cracks typically spread throughout the beam and are more common. If the size of cracks in beams reaches crucial size, then rapid structure breakdown is formed due to the lack of undetected cracks. Therefore, to detect cracks natural frequency measurements are used. Since sudden failure leads to serious damage or injury due to high node operation, early crack detection is important. Due to the existence of cracks, the crack section is modeled as modified beam element. Several studies show that it is important to detect the cracks as early widening and development of more cracks that are undetected leads to modification of vibration modes and natural frequencies.

II. GEOMETRY PARAMETERS

Table 1 Parameter for the schematic shown in Figure 1

Geometry Parameters	Value (mm)
Length of Beam (L)	3000
Position of crack (L1)	1500
Thickness of beam (H)	300
Thickness of patch (hp)	5
Length of patch (Ip)	400
Length of mass (Lm)	50
Thickness of mass (tm)	20.779

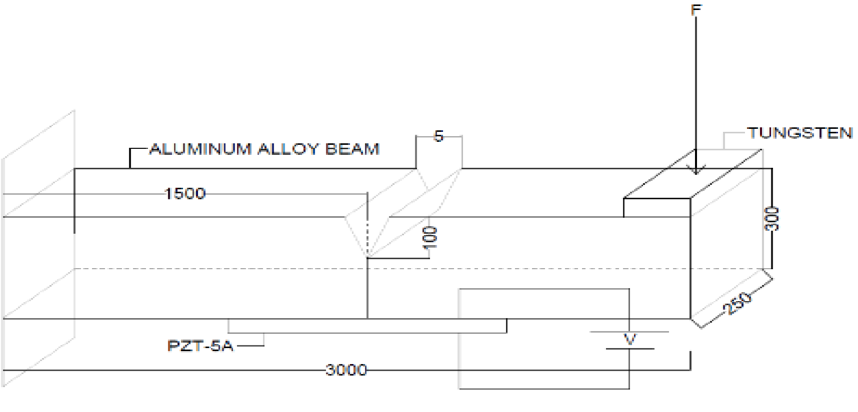

Figure 1 Three-dimensional schematic of beam with patch

III. ENGINEERING PROPERTY

Modal analysis and harmonic analysis of 3 meter cantilever beam whose cross sectional area is 0.25 meter width and 0.3 meter depth beam has been done. For that, 3 types of materials have been taken, the first is aluminum alloy, the second is pzt-5A and the third is Tungsten, the properties of all these materials such as density of aluminum alloy = 2770 Kg/m³, Young's modulus 7.1e + 10 Pa, Poisson’s ratio = 0. 33. Similarly Pzt-5A whose density is 7750 Kg/m³, in this way Tungsten whose density is 19250 Kg/m³, Young's modulus 4.1e+11pa In this way all the data which is given in the table below. Also anisotropic elasticity, anisotropic relative permittivity and piezoelectric matrix in tabular format are shown below.

i)Tungsten

Density	19250	kg/m³
Structure:-		
Isotropic Elasticity		
Derive from	Young's Modulus and Poisson's Ratio	
Young's Modulus	4.1e+11	Pa
Poisson's Ratio	2.8472e+11	Pa
Bulk Modulus	2.8472e+11	Pa
Shear Modulus	1.627e+11	Pa
Isotropic Secant Coefficient of Thermal Expansion	1.2e-05	1/°C
Compressive Yield Strength	2.5e+08	Pa
Tensile Ultimate Strength	4.6e+08	Pa
Tensile Yield Strength	2.5e+08	Pa
Thermal:-		
Isotropic Thermal Conductivity	60.5	W/m·°C
Specific Heat Constant Pressure	434	J/kg·°C
Electric:-		
Isotropic Thermal Conductivity	60.5	W/m·°C
Specific Heat Constant Pressure	434	J/kg·°C
Magnetic:-		
Isotropic Relative Permeability		10000

ii) Aluminum Alloy

Isotropic Elasticity		
Derive form	Young's Modulus and Poisson's Ratio	
Young's Modulus	7.1e+10	Pa
Poisson's Ratio		0.33
Bulk Modulus	6.9608e+10	Pa
Shear Modulus	2.6692e+10	Pa
Isotropic Secant Coefficient of Thermal Expansion	2.3e-05	1/°C
Compressive Ultimate Strength	0	Pa
Tensile Ultimate Strength	3.1e+08	Pa
Tensile Yield Strength	2.8e+08	Pa
Compressive Yield Strength	2.8e+08	Pa
Thermal:-		
Specific Heat Constant Pressure	875	J/kg·°C
Magnetic:-		
Isotropic Relative Permeability		1

Table 2 Material Properties of host Beam and Tungsten

Material	Young's modulus Y (GPa)	Poisson's ratio	Density	Coefficient of thermal expansion	Bulk modulus	Shear Modulus
Tungsten	4.1E+11	0.26	19250	1.2E-5	2.8472E+11	1.627e+11
Aluminum Alloy	7.1E+10	0.33	2770	2.3E-5	6.9608E+10	2.6692E+10

iii) PZT-5A

Table 3 Polarization in Y-Direction, Permittivity at constant strain

1.99E-09	0	0
0	5.78E-10	0
0	0	1.99E-09

Table 4 Piezoelectric Matrix: - d matrix, strain/ Efield

0	-5.35116	0
0	15.78347	0
0	-5.35116	0
12.29474	0	0
0	0	12.29474
0	0	0

Table 5 Anisotropic Electricity:-Polarization in y-Direction Stiffness at Constant field

1.20E+11	7.51E+10	7.52E+10	0	0	0
7.51E+10	1.11E+11	7.51E+10	0	0	0
7.52E+10	7.51E+10	1.20E+11	0	0	0
0	0	0	2.11E+10	0	0
0	0	0	0	2.11E+10	0
0	0	0	0	0	2.26E+10

IV. RESULTS AND DISCUSSION

Total Deformation of Uncrack and Crack cantilever beam (Modal Analysis)

Total Deformation of Uncrack beam

Fig.2 illustrate the total deformation of crack beam Mode-1, Mode-2, Mode-3 respectively. By modal analysis, the total deformation value of different mode wise is 0.078827m in Mode-1 at frequency 22.352Hz. Similarly the total deformation value 0.078747m in Mode-2 at 26.766 Hz frequency and the total deformation value 0.078644m in Mode-3 at 135.42 Hz frequency. As described in Table No. 2

Table 6 Total Deformation of Uncrack beam

Mode	Frequency in Hz	Total Deformation in mm
Mode-1	22.352	78.827
Mode-2	26.766	78.747
Mode-3	135.42	78.644

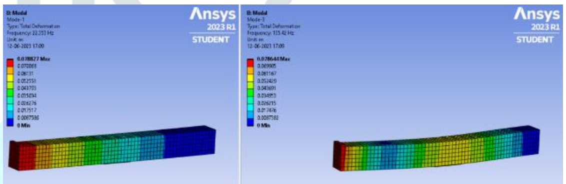

Figure 2 Total Deformation of Uncrack Beam for Modal Analysis

Total Deformation of Crack beam

Fig.3 illustrate the total deformation of crack beam Mode-1, Mode-2, Mode-3 respectively. By modal analysis, the total deformation value of different mode wise is 0.079158 m in Mode-1 at frequency 22.202 Hz. Similarly the total deformation value 0.079830 m in Mode-2 at 26.15 Hz frequency and the total deformation value 0.077628 m in Mode-3 at 131.87 Hz frequency. As described in Table No. 7

Table 6 Total Deformation of crack Beam for Modal Analysis

Mode	Frequency in Hz	Total Deformation in mm
Mode-1	22.202	79.158
Mode-2	26.15	79.830
Mode-3	131.87	77.628

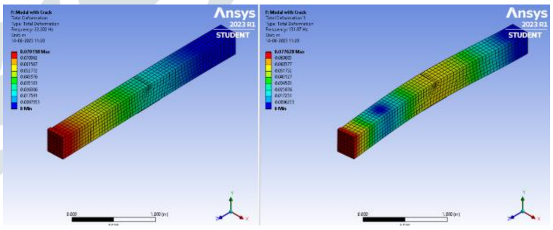

Figure 3 Total Deformation of Uncrack Beam for Modal Analysis

V. CONCLUTION

The result obtained by modal analysis of 3 meter span steel cantilever beam shows that the value of deformation of cracked beam is higher than that of uncracked beam but only at maximum frequency the value of deformation is decreasing in cracked beam.

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