

# DAMAGE DETECTION IN A BEAM USING CROSS-CORRELATION ANALYSIS OF VIBRATION RESPONSE

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## ABSTRACT

*This work involves the analysis of composite beam which has been modeled in SOLIDWORKS and simulation analysis has been done in ANSYS APDL to validate the damage detection approach. The responses of undamaged and damaged beam are recorded and used in cross correlation approach to compare the cross correlation functions, where the cross correlation functions are determined using the impulse responses which are obtained through the above analysis. These impulse responses corresponds to the inherent dynamic properties of the structure, therefore by comparing the cross correlation functions of undamaged and damaged beam, damage can be identified.*

**Keyword:** - ANSYS APDL1, Beam2, Cross-Correlation3, and Vibration Response4

## 1. INTRODUCTION

In this work is to determine the damage detection techniques is the vibration analysis using cross-correlation technique which provides the more perfections, easier, simple as well as cheaper way in damage detections for localizing and quantifying the damages. Cross-correlation function describes the dependence between two sets of amplitude responses. In this analysis the response signals are accelerations and the deformations, however in this thesis accelerations and deformations values we will get from ANSYS mechanical APDL for solving the particular stated beams problems mentioned further. And then these values are used in MATLAB to perform the damage indicators by using normalized cross correlation function stated. Here the proposed method is easily able to detect the single & multiple uniform and no uniform damages occurred on the different locations of the beams. And by using cross correlation function a more sophisticated algorithm which can be used to detect damage indicators by using the acceleration or deformations values from ANSYS. Any finite element analysis involves several steps; all these steps can be categorized into following four sections:

1. Geometric Modeling using SOLIDWORKS.
2. Meshing using ANSYS MECHANICAL APDL.
3. General pre-processing.
  - i. Analysis type settings.
  - ii. Initial conditions.
  - iii. Boundary conditions.
  - iv. Load inputs.
  - v. Load steps.
  - vi. Solution/Solving.
4. General post-processing.

Following steps explains the whole processes that are involved in the analysis using ANSYS Mechanical APDL.

**Step 1:**

Geometry modeled in SOLIDWORKS, after that this geometry is imported to ANSYS Mechanical APDL, where we select the type of element that we going to be used in the analysis, in our case element used is a solid type i.e. SOLID 186. Further if there are any real constants, they are added.

**Step 2:**

Then we assign the geometric properties such as young's modulus, poisson's ratio, density and other properties of the material of the model. Further section properties such as thickness in the general plate and ply thicknesses and orientations in case of composite plate and similarly cross section in case of beam etc. are specified.

**Step 3:**

Then comes to the geometric modeling, Geometric modeling involves the modeling of the structure using key points, lines, areas and volumes. Model of the structure can be made using one or many of the above mentioned entities. Basically Geometry Modeling has been done using SOLIDWORKS.

**Step 4:**

After modeling, the model is meshed using free or mapped mesh, according to model we have choose mesh option such as line mesh, area mesh and volume mesh in the ANSYS Mechanical APDL. For the required accuracy of analysis we can use refinement option.

**Step 5:**

Then we choose analysis type such as static analysis, modal analysis, harmonic analysis, transient analysis etc. According to selected analysis type we apply initial, boundary conditions and loads. Load steps are defined in case transient analysis and the analysis type which involves application of loads at different time intervals.

**Step 6:**

Then solution is done using the current file or LS (load step) files.

**Step 7:**

Then post processing of the solution is done. Generally post processing involves collection of results, plots and animations of the analysis. The post analysis is done using Microsoft Excel Worksheet and MATLAB. The steps from 1 to 5 are called pre-processing i.e., which are done before solution and involves assigning material & section properties, geometric modeling and meshing. Whereas step 6 is solution step and step 7 is post processing includes the process after the solution which involves acquiring results, plots and animations if any.

## 2. DESCRIPTION OF THE MODEL

### 2.1 Model Parameters, Properties, Boundary Conditions and Load.

**Table 1:** Model Parameters and Properties

<b>Material Used</b>	<b>Aluminum composite</b>	<b>Length</b>	<b>0.35m</b>
<b>Young's modulus</b>	70Gpa	Width	0.025m
<b>Poisson's ratio</b>	0.3	Thickness	0.006m
<b>Density</b>	2700kg/m <sup>3</sup>	Boundary Conditions	Cantilever beam
<b>Material</b>	Isotropic and elastic	Applied Load	Impulse load of 6N
<b>Element type</b>	SOLID 186	Damage	for first 1ms time step V-Cut with angle of 45 <sup>0</sup> ,10mm depth

### 2.2 Data Collection from ANSYS APDL

#### 2.2.1 Preferences

ANSYS provides the platform for the structural, fluid, thermal, Flotran CFD and electromagnetic analysis and many more. According to the problem any one of the preferences is selected. Structural type is selected for the current analysis.

#### 2.2.3 Preprocessor

SOLID186 20 Node element is chosen for which there are no real constants.

#### 2.2.4 Material properties

In this section material properties are given.

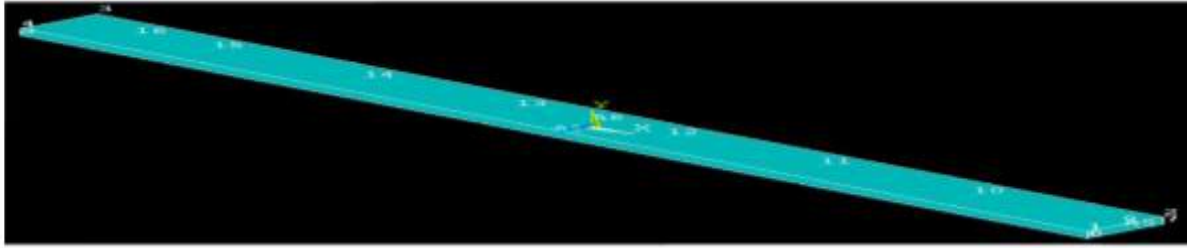
#### 2.2.5 Assumptions

Material is assumed to be linear, elastic and isotropic. Composite material is used in this analysis and standard properties are given as below:

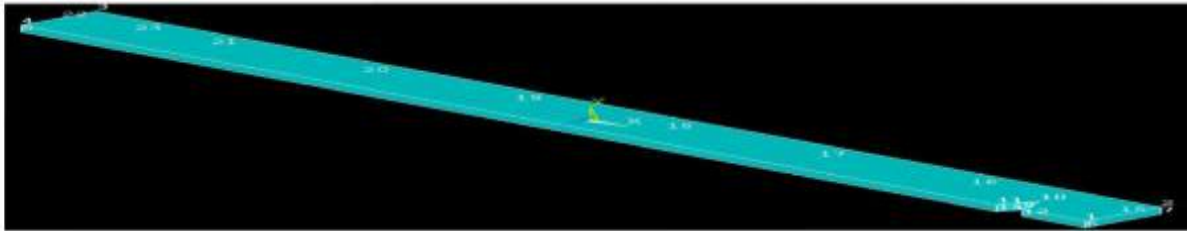
Young's modulus,  $E = 70\text{Gpa}$ ; Poisson ratio = 0.3; density,  $\rho = 2700\text{kg/m}^3$ .

### 2.3 Modeling

In this section there are many options to generate model which includes Create, Operate, Move/Modify, Copy, Reflect, Delete etc. Using key-points, lines, areas and volume, the beam model of **Length, L = 0.35m; Width, W = 0.025m and thickness T = 0.006m** is generated using CAD modeling software "SOLID WORKS" and the model is as shown below Also 8 hard points are given in modeling section which includes points from 1 to 7 separated by 0.05m apart and one load point located at 0.025m from fixed end. Then beam with a damage V-cut of 45o angle and 0.01m depth is introduced as shown in Fig 9.2 and shifted from the location between 1&2to other locations i.e., between 2&3, 3 & 4, 4 & 5, 5 & 6, 6 & 7 respectively. In case 1 the damage is between 1 & 2, and in the cases 2-6 the damages are between 2 & 3, 3 & 4, 4 & 5, 5 & 6, 6 & 7 respectively.



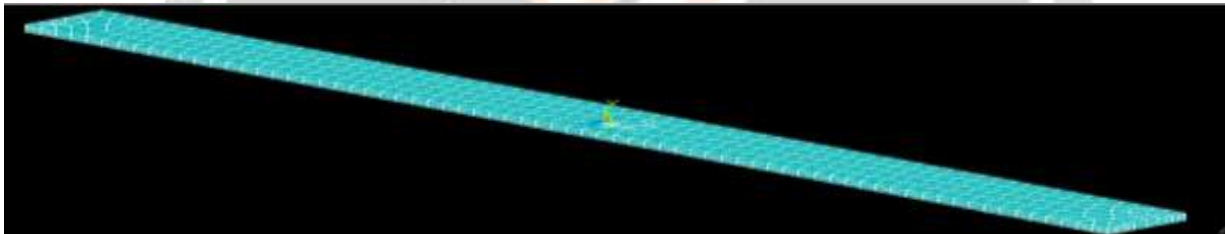
**Fig 1.1:** Model of an undamaged beam.



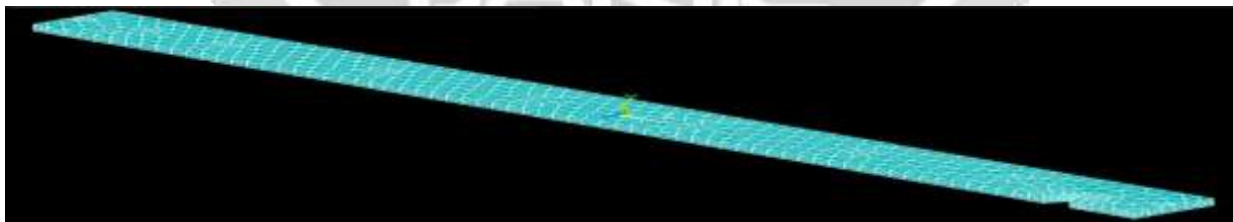
**Fig 1.2:** Damaged beams with damage between 1 & 2.

#### 2.4 Meshing

In this section the modeled beam is meshed using the tetrahedron elements, we can refine the mesh to increase the accuracy but it leads to increase in time to get solution. Meshing of un-damaged and damaged beam are as shown in figure



**Fig 1.3:** Meshing of undamaged beam model.



**Fig 1.4:** Meshing of beam with damage between 1 & 2

#### 2.5 Loads

In this section first analysis type is selected such as static, modal, harmonic, transient and etc. as per the requirement of the problem. In this thesis the transient analysis is selected for our analysis. In transient analysis, an impulse load of 6N is given for the time step 1 millisecond time period and then released, so the load steps are to be defined to solve the problem. According to this problem the first load step includes the conditions below 0 second time and boundary conditions of clamped end case at one end and free at other end. Second load step is defined from 0 second to 1millisecond and an impulse load of 6Nis applied in transverse direction at a point 0.025m away from the clamped edge. Third load step is defined from 1ms to 2s with time step increment of 1ms, in which the load is released.

## 2.6 Postprocessor

In postprocessor we can obtain results from general postprocessor for static problem and time history postprocessor for dynamic problem. Since our analysis is dynamic we obtain the time history displacement values in transverse direction. From the obtained time history displacements, time history acceleration values are calculated using central difference method.

## 3. RESULTS AND PLOTS

First of all **in case 1**, the displacements values with respect to the time are obtained at hard points 1, 2, 3, 4, 5, 6 and 7 of an undamaged cantilever beam as shown in Fig 1.1 using transient analysis as explained in the section 9 and then accelerations are calculated from the obtained displacements. Finally the calculated acceleration values are used to found Damage Indicators (DIs) between the location pairs 1-2, 2-3, 3-4, 4-5, 5-6 and 6-7 using the equations 1 to 5 as described in the section 4.

**In case 2**, the damage in the form of V-cut with  $45^\circ$  and 0.01m depth was introduced between the nodes 1 & 2 as shown in Figs. 1.2 to 1.3 and then the Damage indicators are found as above

**In case 3 and 4**, the depth of the damage is increased from 10mm to 13mm and 13mm to 16mm and then the similar approach is followed to obtain Damage Indicators.

**In case 5**, two damages of same dimensions as in case 1 having depth of 10mm and an angle of  $45^\circ$  are introduced at different locations as shown in Figure And in the similar way the Damage Indicators are found for each location pairs.

**In case 6**, two damages at same locations as in case 1 are introduced and depth of one among two damages is increased by 3mm i.e., from 10mm to 13mm as shown in Fig. 1.3 and Damage Indicators are found as above.

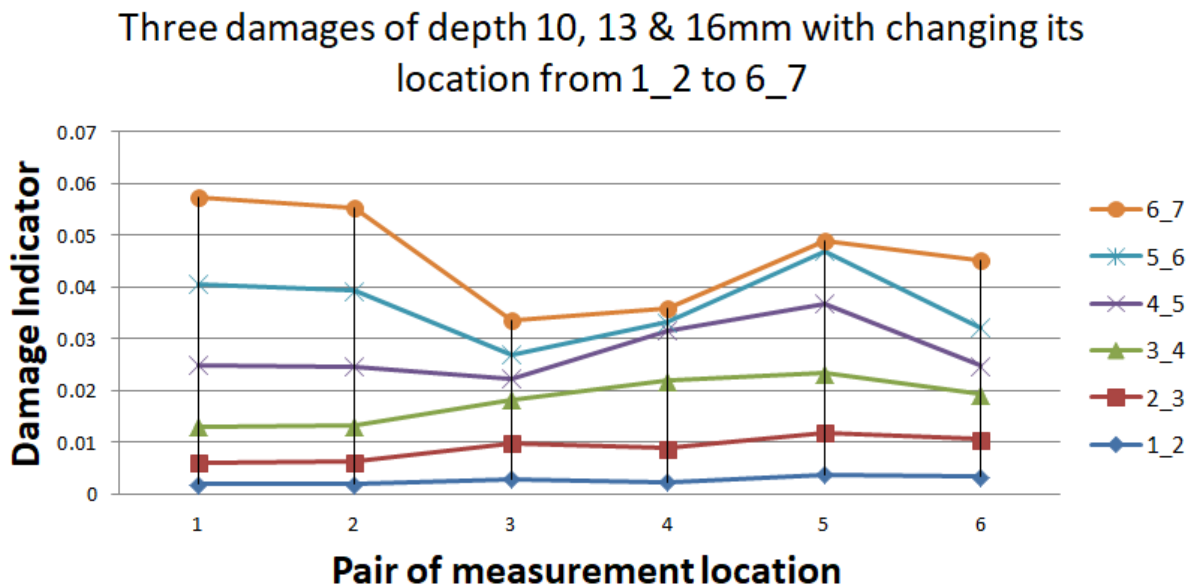
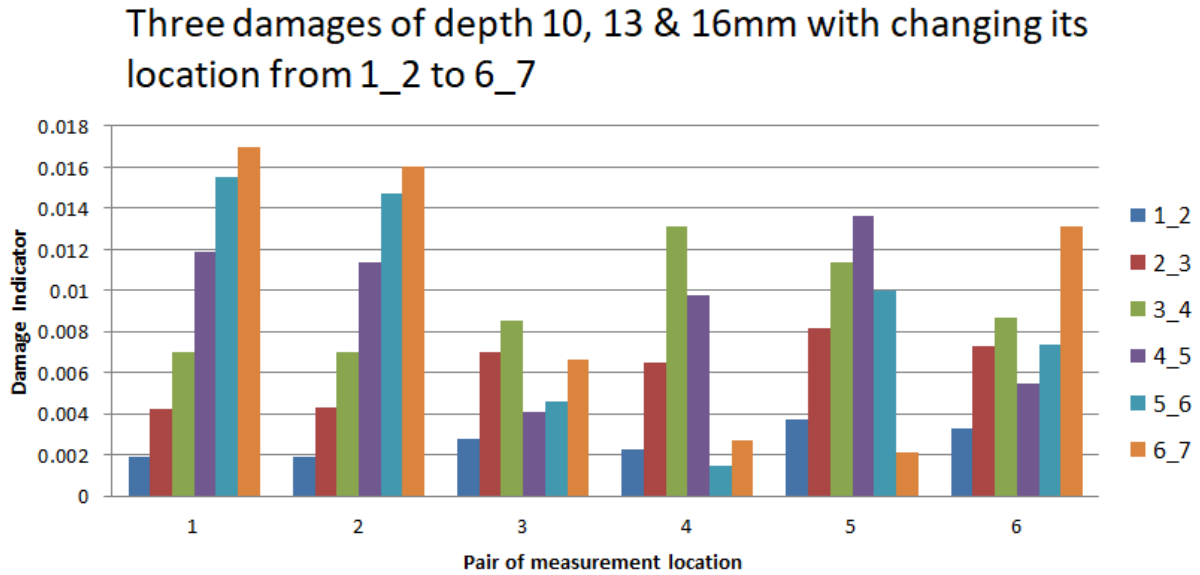
**In case 7**, two damages at same locations as in case 1 are introduced and depth of one among two damages is increased by 6mm i.e., from 10mm to 16mm as shown in Figure and Damage Indicators are found as above.

Finally, **in case 8**, three damages are introduced having the same angle of  $45^\circ$  and with different depths of 10mm, 13mm and 16mm as shown in and then Damage Indicators are found as above.

The table represents the undamaged and damaged specimens of the cross-correlation functions, to identify the damages in the beams. And for comparison maximum absolute values of normalized deterministic cross correlation functions are used which is denoted by  $r_{ij}$ . The value of  $r_{ij}$  ranges from 0 to 1 which measures the similarity between the two responses signals i.e. accelerations and deformations. When  $r_{ij}$  value is closer to 1 the signals are more similar to each other, and when the value is closer to 0 there is less similarity between them. When the damage occurred in the vicinity of DOFs i and j, then the value of  $r_{ij}$  of undamaged structure is different from that of damaged structure this is shown by the indicator termed as Damage Indicator DI. Which represents the maximum values of the normalized deterministic cross-correlation functions of damaged and undamaged structures respectively?

However the normalized cross correlation and damage indicators values can be determined by using MATLAB from the output deformation values from ANSYS APDL. Table shows Damage Indicators (DI<sub>ij</sub>) of DOFs i and j with three damages of depth 10 mm, 13mm and 16mm.





**Figure 3.1 Bar chart and Line graph for damage indicator using cross correlation function for three damages with 10mm, 13mm and 16mm depth cuts at different sections of the beam Represents the maximum values of damage indicator occurred in the section**

**4. EFFECT INCREASE IN DEPTH OF THE DAMAGE**

In this chapter we are analyzing the effect of damage indicator by increasing the depth of the cut sections damages, and we got that by increasing the depth the values of damage indicator are also increase which is clearly shown in the plots.

In this study, damage detection and localizing is validated by using cross-correlation function through vibration analysis. Comparison of maximum absolute values of normalized cross correlation functions between the undamaged and damaged beam indicates the effect of damage between the pairs of location. And the damage is located between the pairs of measurement nodes where the maximum values of Damage Indicators obtained. Later the damage depths are increased from 10mm to 13mm and then 16mm and observe that increase in the values of Damage Indicators due to the effect of increase in damage.

Further multiple damages are introduced and observed that the peak values of Damage Indicators shows all the locations of the damages occurred in the beam.

By this it has seen that this numerical study of Vibration Response Using Cross correlation Analysis working well in detection of uniform and no uniform single and multiple damages. And this study is validated by the experimental data obtained by. M. Diwakar, N. Patil, and Mohammed Rabius Sunny [13] with tis data the observation are CFD data is +3% more than that of Test data. In actual scenario CFD data with 5% differences is acceptable with test data. Also this study can be extended for multiple excitations, hoping so the method followed in this thesis may give an appropriate result for multiple unknown excitations.

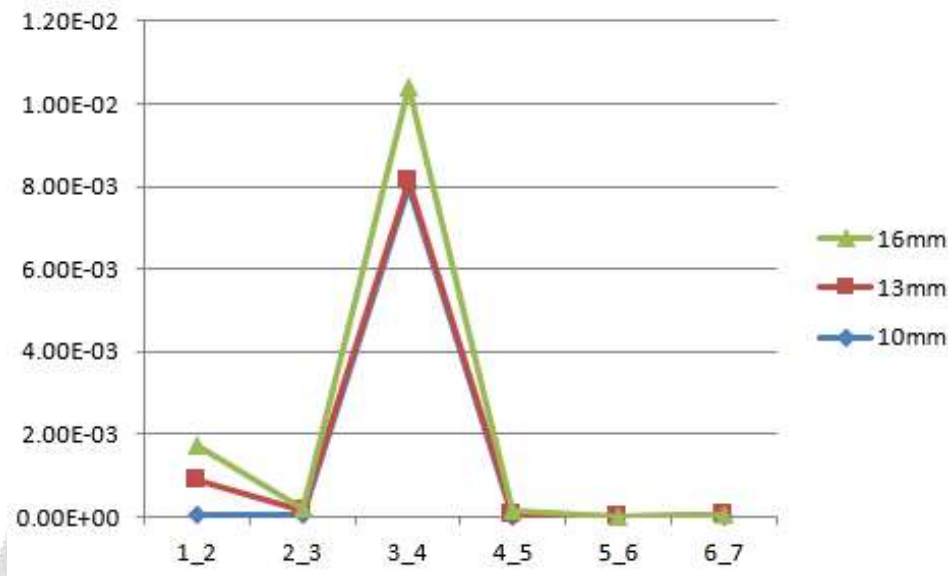


Figure 4.1 Damage b/w the locations 1 & 2

## 5. CONCLUSIONS

A structural damage-detection technique using vibrational responses through the cross-correlation function and computational and numerical study is proposed. Acceleration and deformation histories have been obtained through computational and numerical study. And then this historical data is used in the MATLAB to determine the damage indicators which has been formed through cross-correlation analysis of the deformation histories. The efficiency of detecting the damage status in specimens with single and multiple damages has been demonstrated. The scope of the work will involve the incorporation of cases with small-size damages occurred in the structures to investigate the robustness and sensitivity of the technique.

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