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A REVIEW ON EVALUATION OF CRACK SIZE AND CRACK LOCATION ON CRACKED BEAM STRUCTURE USING FUZZY LOGIC TECHNIQUE

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ABSTRACT
Early detection of damage is of special concern for engineering structures. The traditional methods of damage detection include visual inspection or instrumental evaluation. A comparatively recent development for the diagnosis of structural crack location and size by using the finite element method and Fuzzy logics techniques. A method based on measurement of natural frequencies is presented for detection of the location and size of a crack in a cantilever beam. Here FEM software package is used for finite element analysis of both crack and un-crack cantilever beam Experiments is done for total 9 models of crack beam having different crack location and crack depth and it generates natural frequency for 3 modes ofvibration. Fuzzy controller here used comprises of three input variables (fnf, snf, tnf) with Gaussian MF and two output variables (rcl, rcd) are generated with Triangular MF. The proposed approach has been verified by comparing results obtained from fuzzy logic technique and finite element analysis.

LITERATURE REVIEW
S. Choudhury et.al (2013) proposed theory based on Crack detection of a cantilever beam using kohonen network techniques. The result shows that detection of damage in beam type structural elements is very essential to avoid a major failure or accident. Non-destructive testing of cracked cantilever beam, vibration methods make a good approach.

Pankaj charan jena et.al (2012) concluded on his paper on Faults detection of a single cracked beam by theoretical and experimental analysis using vibration signatures that approach evolved in this paper intimate location, size and depth of the open crack in beam of different end conditions i.e. cantilever beam, clamped-clamped beam and simply supported beam with rectangular cross section.

H. Nahvi et al. (2005) finds results that the finite element model of the cracked beam is constructed and used to determine its natural frequencies and mode shapes. It is found that the crack location, as well as crack size, has noticeable effects in the first and second natural frequencies of the cantilever beam.

Prashant M. Pawar et al. (2003) studied the genetic fuzzy logic is one of the alternatives for NDT techniques in the areas where results are not predictable. The genetic fuzzy system greatly reduces the time needed to develop the rule base by optimally selecting the fuzzy sets. It is also more accurate than a manually developed fuzzy system.

S.Orhan et al. studied the order to identify the crack in a cantilever beam. Single- and two-edge cracks were evaluated. However, dynamic response of the forced vibration better describes changes in crack depth and location than the free vibration in which the natural frequencies corresponding to a change in crack depth and location only is a minor effect. The Euler– Bernoulli beam model was assumed. The crack is assumed to be an open crack and the damping has not been considered in this study.

F. Leonard et al. proposed a study on spectrograms of the free-decay responses showed a time drift of the frequency and damping: the usual hypothesis of constant modal parameters is no longer appropriate, since the latter are revealed to be a function of the amplitude.

Karthikeyan et al. studied and establish an identification procedure for the detection, localization, and sizing of a flaw in a beam based on forced response measurements. The experimental setup consisted of a circular beam, which was and inaccurateness caused by the complicated expression of the analytical SIF solution in crack modeling.

MATERIALS AND METHODS

SPECIMENGEOMETRY:
Structural steelbeamshave beenconsideredformakingspecimens.Thespecimenswerecutto sizefromready-maderectangular bars.Total10 specimenswerecuttothesizeaslength700 mmandcrosssectionareais 32mmX5mm.Themodulusofelasticity anddensitiesofbeams havebeenmeasuredtobe210GPaand7850Kg/m^3.

ManufactureofCracked Specimen:
Thecrackwasintroducedbywirecutmachining.Thewirediameterwas0.3mm.The width of the slot obtained thereby is 0.35 mm. The slotisrectangularin section. In the experiments various crack location sx.Crack location from fixe dendx and crack depth sb at each crack location are given.

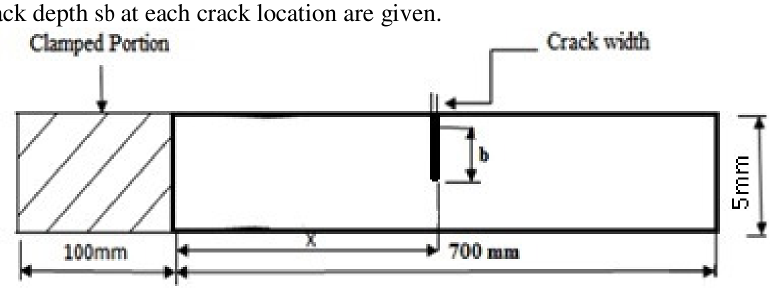

Fig.1 Crackedrectangular BeamSpecimen

Table.1 Different Beam models and their dimensions

Beam Model No.	Material	Cross section dimension (mm)	Cracked/Uncracked	Position and location of crack	
				Crack depth (mm)	Crack location (mm)
1	Structural Steel E= 210×10^9 N/m^2, ρ = 7850 Kg/m^3,length = 0.7m.	32×5	Uncracked	0	0
2		32×5	Cracked	1	175
3		32×5	Cracked	2	175
4		32×5	Cracked	3	175
5		32×5	Cracked	1	350
6		32×5	Cracked	2	350
7		32×5	Cracked	3	350
8		32×5	Cracked	1	525
9		32×5	Cracked	2	525
10		32×5	Cracked	3	525

The terms RCD and RCL are considered and calculated by the formula,

$$RCD = \frac{\text{depthofthecrack}}{\text{depthofthebeam}} \; \& \; RCL = \frac{\text{distanceofcrackgromfixedend}}{\text{lengthofthebeam}}$$

METHODS & EXPERIMENTATION:
1) ANALYTICAL METHOD:
GOVERNING EQUATION FOR FREE VIBRATION OF BEAM:
The Euler- Bernoulli beam model is assumed for the theoretical formulation. The differential equation for transverse vibration of thin uniform beam is obtained with the help of strength of materials. The beam has cross section area A, flexural rigidity EI and density of material ρ. Consider the small element dx of beam is subjected to shear force Q and bending moment M, as shown in figure 4.3.While deriving mathematical expression for transverse vibration, it is assumed that there are no axial forces acting on the beam and effect of shear deflection is neglected. The deformation of beam is assumed due to moment and shear force.

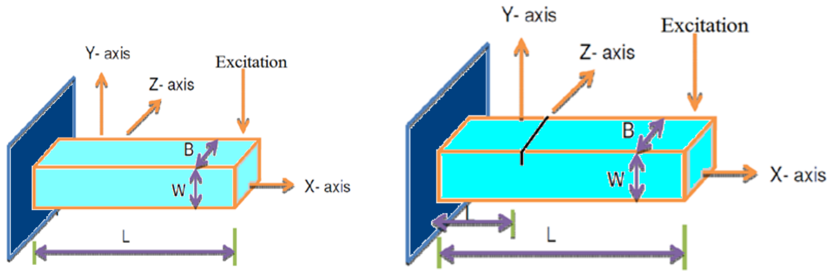

Fig.2 Uncracked & cracked cantilever beam model

The net force acting on the element,

$$Q - \left(Q + \frac{\partial Q}{\partial x}dx\right) = dm * acceleration$$

$$-\frac{\partial Q}{\partial x}dx = (\rho A dx)\frac{\partial^2 y}{\partial t^2}$$

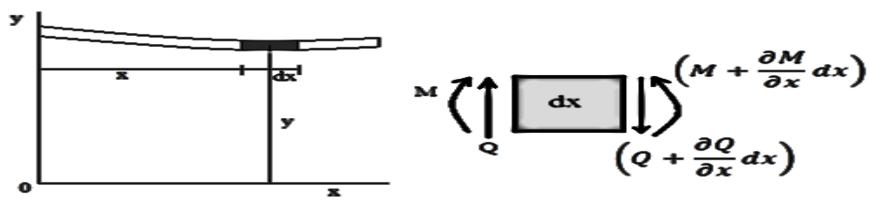

Fig.3 Shear Force and Bending Moment acting on beam element

$$\frac{\partial Q}{\partial x} + \rho A\frac{\partial^2 y}{\partial t^2} = 0 \ldots\ldots\ldots\ldots \mathbf{1}$$

Considering the moments about A, we get

$$M - \left(M + \frac{\partial M}{\partial x}dx\right) + \left(Q + \frac{\partial Q}{\partial x}dx\right)dx = 0$$

$$-\frac{\partial M}{\partial x} + Q + \frac{\partial Q}{\partial x}dx = 0$$

So $Q = \frac{\partial M}{\partial x}$ higher order derivatives are neglected here $\left(\frac{\partial Q}{\partial x}dx = 0\right)$

$$\frac{\partial Q}{\partial x} = \frac{\partial^2 M}{\partial x^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2}$$

From the above two equations 1 and 2, we get

$$\frac{\partial^2 M}{\partial x^2} = \rho A\frac{\partial^2 y}{\partial t^2} \ldots\ldots\ldots\ldots\ldots \mathbf{3}$$

We know from strength of materials that

$$M = -EI\frac{\partial^2 y}{\partial x^2}$$

$$\frac{\partial^2 M}{\partial x^2} = -EI\frac{\partial^4 y}{\partial x^4} \ldots\ldots\ldots\ldots \mathbf{4}$$

Comparing equation 3and 4 we get,

$$\frac{\partial^4 y}{\partial x^4} + \left(\frac{\rho A}{EI}\right)\frac{\partial^2 y}{\partial t^2} = 0 \ldots. \mathbf{5}$$

This is the general equation for transverse vibration. Thus the natural frequency can be found out by this theory as,

$$\boldsymbol{\omega_n = C * \sqrt{\frac{EI}{\rho A l^4}}} \ldots\ldots \mathbf{6}$$

C= Constant C_1=0.56, C_2= 3.52 ,C_3= 9.82 for first,second & third mode

Due to presence of crack, moment of inertia of the beam changes and correspondingly the natural frequency also changes. For a constant beam material and cross section the reduced moment of inertia will be found by relation below.

$$\mathbf{I_1 = I - I_c \ldots\ldots\ldots.7}$$

Where,
I_1=Moment of inertia of a cracked beam, I=Moment of inertia of Uncracked beam,
I_c=Moment of inertia of cracked beam element.
Using equation 6,7 and 8 we can find out the different modes of natural frequencies for the cantilever beam.

EXPERIMENTAL SETUP

Experimental analysis was performed to find out the three modal transverse natural frequencies ofacrackedcantileverbeam.Theline-diagramoftheExperimentalsetupforperforming the experiments is as shown in Fig.5.7. Several tests were conducted on cantilever beam specimens with single crack.

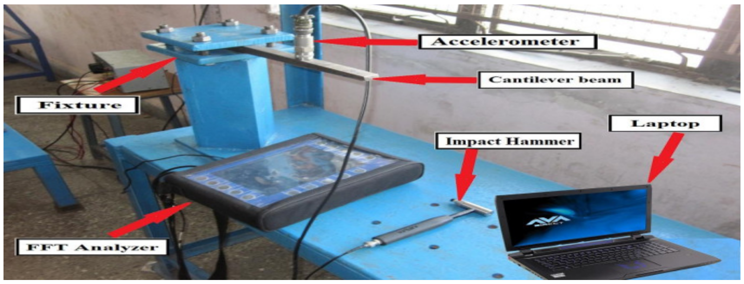

Fig. 4Experimental Set Up

IMPACT HAMMER

ToapplytheexcitationtothebeamanimpacthammertypeBrüel&Kjær8206-55940isused. ThehammerispoweredthroughanISOTRON1powersupply.

Some of the important features of the impact hammer that was used are;

- 22.7 mV/N sensitivity.
- Full-scale range of 220N.
- Upper frequency limit of 20 kHz

Fig. 5 Impact Hammer.

ACCELEROMETER

TheaccelerometerusedintheexperimentsincludesDela-TronIEPEaccelerometer(Type 4514) with 100mV/g, 1-10 KHz frequency range and 500g peak measuring range.

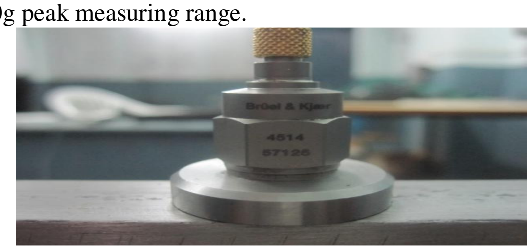

Fig.6Accelerometer.

FFT ANALYZER

B&KFFTanalyzer (Type 3050-B-040), modelLAN-XI 51.2KHzwith4channelsinput module,Data acquisition and analysis soft ware(B&K PULSE14.1.1)is used to measure vibration signals from beam.TheFFT of analog signals and vibration spectrum in frequency domain is obtained with the help ofPULSE 14.1.1 analysis software. The dynamic signal analyzer so performs the trans formations and calculations necessary to convert the two

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measured time domain signals into a frequency responsefunction.Upperfrequency forthe measurement was set to 5 kHz.

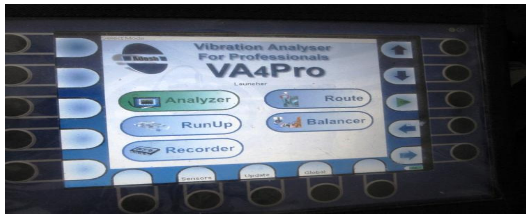

Fig.7FFT analyzer.

FINITE ELEMENT MODELING

ANSYS 15.0finite element program is used to generate natural frequencies of the intact and cracked beams. For this purpose, the key points were first created and then line segments were formed. The lines were combined to create an area, in the end, this area was extruded and three-dimensional cracked beam model was obtained as shown in Fig. 8. The crack width is 1 mm on the top surface of the beam and crack goes through the depth of the beam. Cantilever boundary conditions can also be modeled by constraining all degrees of freedoms of the nodes located at the left end of the beam. Fig. 8shows the finite element mesh model of the beam. Subspace mode extraction method was used to calculate the natural frequencies of the beam. Ten modes were selected to extract and first three natural frequencies were calculated for intact and cracked beams. These procedures were repeated for 9 damage scenarios. show natural frequencies of the cracked beam obtained from experimental and finite element analyses.In the finite element analysis, the natural frequencies of the cracked beams were found out to verify the experimental results.

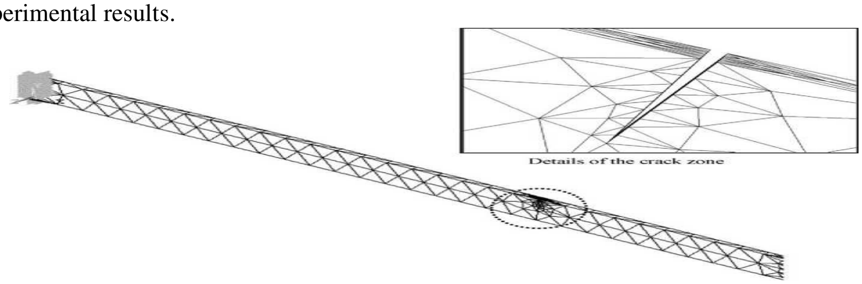

Fig.8 FEM Analysis of cracked beam

It shown that finite element results are in good agreement with the experimental results.Simulation resultsIn the finite element analysis, the natural frequencies of the cracked beams were found out to verify the experimental results. It was shown in that finite element results were in good agreement with the experimental results.

CRACK DETECTION USING FUZZY INTERFACE SYSTEM

The fuzzy controller developed has got three input parameters and two output parameters.

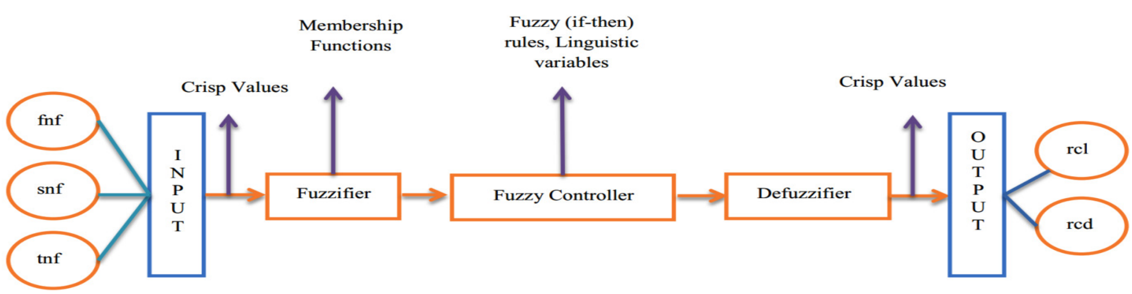

Fig.9 Fuzzy Interface system

The linguistic term used for the inputs are as follows;

- First natural frequency = "fnf';
- Second natural frequency = "snf";
- Third natural frequency = "tnf';

The linguistic term used for the outputs are as follows;

- Relative crack location = "rcl"
- Relative crack depth = "rcd"

Here a new approach can be suggested which is based on the combination of both ANSYS and Fuzzy, in which natural frequency obtained by modal analysis in ANSYS can be used as input for fuzzy controller for determination of accurate value of crack depth and crack location.

CONCLUSIONS &PROBABLE OUTCOMES

The present investigation based on the Fuzzy Controller, Numerical Analysis and the FEA Analysis& Experimentation has following probable outcomes.

- Comparative Investigation of natural frequency of vibrations by Numerical Analysis and the FEA Analysis & Experimentation.
- Inputs for FEA & Experimentation are crack location and crack depth and outputs are natural frequency for different modes of vibration whereas inputs for fuzzy controller are natural frequency and outputs are crack depth and crack location.
- Fuzzy controller is developed with Gaussian membership function for inputs and Triangular membership function for output and results shows that Gaussian MF predicts more accurate results than Triangular.
- Crack depth and crack location of a beam can be predicted by fuzzy controller is within nanoseconds. Hence it saves considerable amount of computation time.
- When the crack location is constant but the crack depth increases, the natural frequency of the beam decreases.
- By Comparing the Fuzzy results with the FEA results it is observed that the developed Fuzzy Controller can predict the relative crack depth and relative crack location in a very accurate manner.

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