Dr. Ambedkar Institute of Techonolgy
Department of Mechanical Engineering

The documents enclosed are verified and approved.

HOD
Dept. of Mechanical Engineering

HOD
Department of Mechanical Engineering
Dr. Ambedkar Institute of Technology
Bengaluru - 560 056.

REVA UNIVERSITY
Bengaluru, India

CHAIR PERSONS LIST- ICRRETMCE-2018

School of Mechanical Engineering

	Timing	Materials	Design	Thermal	Production
Day 1 13/7/18	10.00-11.00	**Inauguration**			
	11.00-11.45	**Key note address 1 (Dr Jagadish)**			
	Session 1 (11.45-1.00)	Ext. Dr Saravanabavan D (DSU) Int- Dr NJ	Ext. Dr Keerthi Prasad (VVIT) Int- Dr MLH	Ext. Int- Dr Ramesh DK (UVCE) Int. Dr.SG	Ext. Dr Siddaraju (MSRIT) Int- Dr.B Somasundar
	2.00-2.45	**Key note address 2 (Dr K. Prashantha, France)**			
	Session 2 (2.45-5.00)	Ext. Dr. **Kalappa Prashantha** Int – Dr KSN	Ext. Dr Keerthi Prasad (VVIT) Int- Dr Hemanth K	Ext. Dr. **Bale V Reddy** Int- Dr Manjunath S H	Ext. Dr Siddaraju (MSRIT) Int-Dr Raju B S
Day 2 14/7/18	**9.00-9.30**	**Key note address 2 (Dr Bale V Reddy, Canada)**			
	Session 3 (09.30 - 11.00)	Ext. **Dr T N Raju** Int. Dr Devaraj S	Ext. Dr. PHV Sesha Talpa Sai Int. Dr KSN/Dr NCH	Ext. Dr Kapilan (NCET) Int- Dr CDH	**(Materials)** Ext. Dr Shinanand (UVCE) Int- Dr Dasharath
	Session 4 (11.15 - 1.00)	Ext. Dr Drakashyani (Sir MVIT) Int. Dr Raju B S	**(Materials)** Ext. Dr MLH Int- Dr SHM	Ext. Dr Kapilan (NCET) Int- Dr CDH	**(Materials)** Ext. **Dr Lokesh M** Int- Dr Devaraj S
	Session 5 (2.00-3.30)	Valedictory function			

Co-convener

9/7/18
Convenor-ICRRETMCE-2018

INSTITUTION'S INNOVATION COUNCIL
(Ministry of HRD Initiative)

MVJ COLLEGE OF ENGINEERING
Since 1982
Engineering A Better Tomorrow

IQAC

IWS

An Autonomous Institute
(Affiliated to VTU, Belagavi, Approved By AICTE, New Delhi,
Recognized by UGC with 2(f) & 12(B) Status
Accredited By NBA and NAAC)

Certificate of Appreciation

Certificate ID MVJCE/2ND ICARME-21/KNA 004

This certificate is presented to Dr T N RAJU, Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bangalore for delivering a keynote address at the "2nd International Conference on Advanced Research in Mechanical Engineering - 2021"(2nd ICARME-21), organized by the Department of Mechanical Engineering, in association with IWS, IIC and IQAC-MVJ College of Engineering, Bengaluru, on 29th and 30th April 2021.

Anand

Dr. Vivekanand Huddar
HOD ME , MVJCE.

Dr. P Mahabaleswarappa
Principal, MVJCE.

Manjunath H S <manjunath.me@drait.edu.in>

Fwd: Invitation to be the Chief Guest for Mechanical Engineering Dept. (Fest)

Sharath Kumar S N <sharathgstar@gmail.com> Thu, Nov 10, 2022 at 3:00 PM
To: manjunath.me@drait.edu.in

---------- Forwarded message ---------
From: **RAJU T N** <rajutn.me@drait.edu.in>
Date: Thu, Nov 10, 2022, 2:52 PM
Subject: Fwd: Invitation to be the Chief Guest for Mechanical Engineering Dept. (Fest)
To: Sharath Kumar Ait <sharathgstar@gmail.com>

Get BlueMail for Android
On 14 Jul 2022, at 1:45 pm, thanuj <thanuj@rrce.org> wrote:

> Greetings of the day...
>
> Dear Sir,
> Department of Mechanical Engineering of Rajarajeswari College of Engineering, Bengaluru warmly inviting you to be the Chief Guest for the Dept. Fest (Dept. Of Mechanical Engineering) on 27th June 2022.
>
> The Program starts at 10:00am.
> We are very great full to you for having accepting our invitation and encourage our Dept students with your knowledgeable talk.
>
> We the undersigned being the conveners of the fest cordially invite you for this mega event.
>
> Thanks for accepting our invitation.
>
> With ward regards;
> Prof. Thanuj Kumar M.
> and
> Prof. Radhakrishna R. K.
> Conveners
> Dept. Fest
> Dept. of Mechatronics Engineering,
> Rajarajeswari College of Engineering.
> Bengaluru.
>
> Get Outlook for Android

Manjunath H S <manjunath.me@drait.edu.in>

Fwd: PhD Review Meeting-External Examiner

Sharath Kumar S N <sharathgstar@gmail.com> Thu, Nov 10, 2022 at 3:00 PM
To: manjunath.me@drait.edu.in

---------- Forwarded message ---------
From: **Dr. Raju T N** <rajutn2005@gmail.com>
Date: Thu, Nov 10, 2022, 2:49 PM
Subject: Fwd: PhD Review Meeting-External Examiner
To: Sharath Kumar Ait <sharathgstar@gmail.com>

---------- Forwarded message ---------
From: **Dr. S Devaraj** <devaraj.s@reva.edu.in>
Date: Tue, Jan 23, 2018 at 11:14 AM
Subject: PhD Review Meeting-External Examiner
To: rajutn2005@gmail.com <rajutn2005@gmail.com>
Cc: Dr.K S Narayanaswamy <dir.me@reva.edu.in>

Dear Sir,

I would like to inform you that, School of Mechanical Engineering Reva university is conducting the bi-annual review meeting to see the progress of the research scholars on 27-01-2018. In view of this, you have been appointed as a external examiner to review the progress of the research scholar. We look forward to a positive confirmation. Kindly confirm your acceptance for the date.

Time: 9 am
Venue: School of Mechanical Engineering
Date: 27-01-2018

Dr. S. Devaraj

Professor and R&D Co-ordinator

School of Mechanical Engineering

REVA University

Bengaluru-64

--

With regards,
Dr.T.N. Raju
Associate Professor and HOD
Department of Mechanical Engineering
Student Welfare Officer
Dr. Ambedkar Institute of Technology
Bangalore-560 056
Mob: 9620397639
Email:rajutn2005@gmail.com/raju.tn@dr-ait.org

Manjunath H S <manjunath.me@drait.edu.in>

Fwd: REVA Conclave-Keynote Speaker

Sharath Kumar S N <sharathgstar@gmail.com> Thu, Nov 10, 2022 at 2:59 PM
To: manjunath.me@drait.edu.in

---------- Forwarded message ---------
From: **Dr. Raju T N** <rajutn2005@gmail.com>
Date: Thu, Nov 10, 2022, 2:46 PM
Subject: Fwd: REVA Conclave-Keynote Speaker
To: Sharath Kumar Ait <sharathgstar@gmail.com>

---------- Forwarded message ---------
From: **Dr. S Devaraj** <devaraj.s@reva.edu.in>
Date: Mon, Feb 12, 2018 at 4:41 PM
Subject: REVA Conclave-Keynote Speaker
To: rajutn2005@gmail.com <rajutn2005@gmail.com>
Cc: Dr.K S Narayanaswamy <dir.me@reva.edu.in>

Dear Sir,

Greetings from REVA University!!

Wish you a happy and Prosperous New Year!!

This is to bring to your kind notice that we are organizing a first REVA Research Conclave (RRC) in association with Education Promotion for India (EPSI) on 1-2, March, 2018. The theme of RRC is "**Digitization: Challenges and Opportunities for Society and Economy".** The objectives of RRC are to provide a platform for great thinkers from science, industry, academia and society to share their views on a wide range of topics across the streams and also to provide a platform for researchers to showcase their research outcomes before expert panelists and seek future directions.

As part of RRC, we have organized progress review meeting for our PhD research Scholars. In view of this, we are very happy to inform that you have been invited as a key note speaker on 02-03-2018. The subject is shape memory alloys and its characterization techniques. Key note speaker time duration is one hour. Also, I would like to remind you that to submit the article on shape memory alloys on or before 14^{th} of February without fail.

We look forward to a positive confirmation. Kindly confirm your acceptance for the date and oblige.

Thanking you,

Dr. S. Devaraj

Professor and R&D Co-ordinator

School of Mechanical Engineering

REVA University

Bengaluru-64

--
With regards,
Dr.T.N. Raju
Associate Professor and HOD
Department of Mechanical Engineering
Student Welfare Officer
Dr. Ambedkar Institute of Technology
Bangalore-560 056
Mob: 9620397639
Email:rajutn2005@gmail.com/raju.tn@dr-ait.org

SIDDAGANGA INSTITUTE OF TECHNOLOGY

(An Autonomous Institution affiliated to Visvesvaraya Technological University, Belgavi, Approved by AICTE, New Delhi, Programme Accredited by National Board of Accreditation, New Delhi, An ISO 9001- 2008 QMS Certified)

Dr. Sree Sree Sivakumara Swamiji Road, Tumakuru– 572103, Karnataka

Ph: 0816–2214050

Dr. H R Purushotham Mob:9480637616

Prof. & Head - MED Email: hodmed@sit.ac.in

STRICTLY CONFIDENTIAL

To, Date: 09th July 2022

Dr. Satish S
Professor,
MED, Dr. AIT,
Bengaluru

I am pleased to invite you for EVEN sem (2022) UG BOE Meeting of Mechanical Engineering Dept. scheduled to be held on 11.07.2022 at 2:00 p.m. at COE, SIT, Tumakuru.

Your kind cooperation is solicited.

Thank you

Yours Sincerely

Dr. H R Purushothama
Chairman, BOE
Department of Mechanical Engineering
Siddaganga Institute of Technology
Tumakuru – 5472103
Karnataka.

Siddaganga Institute of Technology, Tumkur

(An Autonomous Institute Affiliated to Visvesvaraya Technological University, Recognized by AICTE & Accredited by NBA, New Delhi)

Department of Industrial Engineering & Management

Ph: Direct: +91-816-2214045, Fax: +91-816-2282994.

E-mail: gvpshankar@sit.ac.in, **Mobile:+91-98454-30739**

Ref. No.BOS/16-17/Appointment

Date: 24-07-2017

To,

Dr. T. N. Raju
Associate Professor
Dept. of Mechanical Engineering
Dr. A.I.T.,
Bengaluru

Sir/Madam,

Sub: Appointment as Member of Board of Studies - reg.

I am happy to inform you that the board of studies meeting in Industrial Engineering and Management, S.I.T., is scheduled to be held on 25.7.2017 at 11.30 am Chamber of Head of the Department for discussion and approval of inclusion of new elective subject Computer Aided Design and Analysis for sixth semester and it is my pleasure to invite you to participate in the board of studies meeting.

I request you to accept our invitation and oblige.

Yours Sincerely

Chairman
B.O.S and B.O.E of IEM
S.I.T.-Tumkur

SIDDAGANGA INSTITUTE OF TECHNOLOGY-TUMKUR
(An Autonomous Institute Affiliated to Visvesvaraya Technological University, Recognized by AICTE & Accredited by NBA. New Delhi)
Department of Industrial Engineering & Management
Ph: Direct: +91-816-2214045, Fax: +91-816-2282994.
Email:jpganjigatti@sit.ac.in, Mobile:+91-9964313284

Ref. No.BOS/17-18/Appointment Date: 08/06/2018

To,

Dr. T. N.Raju
Associate Professor
Dept. of Mechanical Engineering
Dr.A.I.T.,Bengaluru, Karnataka 560056

Sir/Madam,

Sub: Appointment as Member of Board of Studies - reg.

I am happy to inform you that the board of studies meeting in Industrial Engineering and Management, Siddaganga Institute of Technology-Tumkur, is scheduled to be held on 15.6.2018 at 10.00 am in the Chamber of Head of the Department for Inclusion, discussion and approval of new core and elective subjects Scheme for III, IV, V, VI, VII and VIII Semester as per new credits system (175 Credits) suggested by Visvesvaraya Technological University, Belagavi on for with AICTE for the Academic Year 2018-19 onwards. It is my pleasure to invite you to participate in the board of studies meeting and contribute your expertise knowledge in finalization scheme of undergraduate course in Industrial Engineering and Management.

I request you to accept our invitation and oblige.

Thanking you

Yours sincerely

(Dr. J. P. Ganigatti)
Chairman, BOS & BOE
Dept. of Ind. Engg. & Mngt.,
SIT, TUMKUR – 572 103

19 Aug 2016

Invitation to Chair the session

To
Dr. Raju.T.N
Professor
Department of Mechanical Engineering
Dr. A I T
Bangalore

Dear Sir,
Greetings from AMMMT 2016 Organizing Committee,

We are delighted to inform you that, owing to your expertise and achievement, we invite you to chair one of the research paper presentation session on 23rd September 2016 from 2.00 to 4.00 p.m., in the **3rd International Conference on Advanced Materials, Manufacturing, Management and Thermal Sciences (AMMMT 2016)**, which will be held in **Tumkur, Karnataka, India during September 23rd & 24th , 2016.** You can have an overview of the conference AMMMT 2016 at: **http://ammmt-2016. sit.ac.in.**

We sincerely hope you will accept our invitation & thank you in advance for the same. We are looking forward to your early and positive reply.

Best regards!

Organizing Committee
AMMMT-2016
Dept. of Mechanical Engineering
Siddaganga Institute of Technology
Tumkur -572103, Karnataka, India

NOVEL METHOD FOR STRUCTURAL DAMAGE IDENTIFICATION USING REAL-TIME MONITORING ALGORITHMS

Synopsis submitted for Pre-Ph. D Thesis submission Colloquium

in

Mechanical Engineering

by

Shivasharanayya Swamy

(SRN – R15PME07)

Guide

Dr. D. Mallikarjuna Reddy

School of Mechanical Engineering

Rukmini Knowledge Park, Kattigenahalli, Yelahanka, Bengaluru – 560 064

2018

NOVEL METHOD FOR STRUCTURAL DAMAGE IDENTIFICATION USING REAL-TIME MONITORING ALGORITHMS

Synopsis submitted for Pre-Ph. D Thesis submission Colloquium

in

Mechanical Engineering

by

Shivasharanayya Swamy

(SRN – R15PME07)

Guide

Dr. D Mallikarjuna Reddy

Former Associate Professor, School of Mechanical Engineering, REVA University, Bangalore.
Associate Professor & Head
Dept. of Design and Automation, School of Mechanical Engineering, VIT University, Vellore, India

School of Mechanical Engineering

REVA UNIVERSITY

Rukmini Knowledge Park, Kattigenahalli, Yelahanka, Bengaluru – 560 064

2018

REVA UNIVERSITY
Bengaluru, India

SCHOOL OF MECHANICAL ENGINEERING

Declaration

I **Shivasharanayya Swamy** certify that the Thesis entitled **"Novel Method for Structural Damage Identification Using Real-Time Monitoring Algorithms"** submitted by me for Pre Ph. D viva-vose submission colloquium of the REVA University is based on the results of the research work carried out by, me and reported by me under the guidance and supervision of **Dr. D Mallikarjuna Reddy**

Bengaluru

Date: 14-09-2018

Shivasharanayya Swamy

Certified that **Mr Shivasharanayya Swamy** has carried out the research and has prepared synopsis for Pre-PhD Colloquium on the above mentioned topic under our guidance and supervision. His research progress is satisfactory and is ready to submit the thesis within the prescribed period.

14/9/18

Dr. D. Mallikarjuna Reddy

Research Supervisor
Head of the Department
Department of Design & Automation
School of Mechanical Engineering (SMCE)
Vellore Institute of Technology (VIT)
Deemed to be University under section 3 of the UGC Act, 1956
Vellore – 632 014, Tamil Nadu, India

TABLE OF CONTENTS

Sl. No.	Description	Page No.
I	Introduction	1
II	Critical Review of Literatures and identification of Research gaps	3
III	Statement of the Research Problem	8
IV	Objectives of Research	8
V	Studies on Application of the Power Spectral Density for Damage Identification and Location in Beam Structures	8
VI	Experimental Damage Identification in Composite Material by Using Modal Assurance Criterion	15
VII	Numerical and experimental evaluation of spatial wavelet method for damage detection in isotropic beam structures	23
VIII	Damage Detection in Composite Wind Turbine Blade Spar Model by using Spatial Signal Processing	39
	Conclusions	45
	References	46
	List of Publications	51

I. INTRODUCTION

The condition monitoring of existing common structures namely, structures, bridges, spans, airport structures, ports, and water treatment plants are essential to anticipate potential cataclysmic occasions and for arranging the future interests in repair and restoration of the foundations. The way toward executing condition/damage detection and monitoring strategy for aerospace, civil and mechanical engineering infrastructure is regularly referred to as Structural Health Monitoring (SHM). Here, damage is characterized as changes to the material and geometric properties of these systems, including changes to the limit conditions and system availability, which antagonistically influence the system's performance [1]. The SHM procedure includes the perception of a system after some time utilizing intermittently tested dynamic reaction measurements from variety of sensors and the extraction of damage-sensitive features from these measurements and factual examination of these highlights to decide the present condition of system wellbeing [2]. During extraordinary occasions, for example, earth quakes or impact stacking, SHM is utilized for quick condition screening and intended to give, in close constant, dependable data with respect to the trustworthiness of the structure.

Current nondestructive damage recognition (NDD) systems are either visual or depend on test strategies, for example, acoustic or ultrasonic methods, attractive field methodology, radiography and so on. All in all, numerous exploratory techniques require that the damaged location be recognized from the earlier and that the section of the structure being inspected must be effortlessly available. Subjected to these imperatives, these strategies can identify damage on or close to the surface of the structure. The structural designing group is particularly attentive of the constraints of the condition assessment with respect to visual examinations regularly utilized as a part of current practice.

One approach to conquer the beforehand specified confinements is by utilizing worldwide damage identification strategies. Structural damage identification based on changes in dynamic characteristics which provides a global way to evaluate the structural condition. These techniques depend on the modal parameters (i. e., natural frequencies, mode shapes, modal damping ratios, and so on.) are an element of the physical properties of the structure (stiffness, damping, mass and boundary conditions). So, changes in the stiffness or flexibility of the structure may cause changes detectable from modal properties. The requirement for new basic damage recognition strategies that can be connected to complex structures has prompted the improvement of systems that look at changes in the vibration attributes of the structure [2]. In perspective of the above, it is critical to analyze a portion of the worldwide damage recognition procedures for the auxiliary damage recognizable proof at present being used. One center issue of the worldwide vibration-based damage location techniques is to look for some damage lists that are touchy to basic damage [3]. The damage lists that have been exhibited with different level of accomplishment incorporate characteristic frequencies, mode shapes, mode shape ebb and flow, modular adaptability, modular strain vitality, and so on. The basic damage is normally neighborhood wonder, which has a tendency to be caught by higher recurrence its in vibration signals. The vast majority of vibration-based damage appraisal strategies require the modular properties that are gotten from the deliberate flags through the system recognizable proof procedure in light of Fourier Transform (FT). The unfaltering state Fourier change examination has the drawback of worldly or spatial data and in this way it is difficult to decide when and where specific occasion happened. To defeat this troublesome Wavelet change has been utilized as of late which has the fundamental favorable position of performing nearby investigation of a flag, i.e., zooming on any interim of time or space. Wavelet examination is along these lines equipped for uncovering some concealed parts of information that other flag investigation method neglect to identify and this property of wavelets is critical in damage identification applications.

The impacts of damage on a structure can be delegated straight or nonlinear. A direct damage circumstance is characterized as a situation where at first straight versatile structure stays direct flexible after damage. The adjustments in modular properties are the aftereffect of changes in the geometry or potentially the material properties of the structure, however the auxiliary reaction can in any case be demonstrated utilizing direct conditions of movement. Nonlinear damage alludes to a situation when first direct versatile structure acts in a nonlinear way after the damage has happened [1].

The condition monitoring of existing structures such as buildings, highway and railways bridges and structures of airports, ports, and water treatment plants is crucial to prevent potential catastrophic events and for planning the future investments in repair and rehabilitation of this infrastructure. The structural health monitoring (SHM) involves condition or damage detection process and monitoring strategy for different applications like aerospace, civil and mechanical engineering and modern infrastructure. Here damage is defined as changes in the material or geometric properties or both of the above said applications, including changes in the boundary conditions and system connectivity, which adversely affect the performance of systems. [1]

The Structural health monitoring process includes the observation of a system in excess of time using periodically sampled dynamic response measurements using collection of sensors, the extraction of damage response from these measurements and statistical analysis of these to determine the current state of system health condition [2].

Four different levels of damage identification are as follows:

1: First step includes prediction of the damage in the structure.

2: Identification of the geometric location of the damage along with the first step.

3: Quantification of the severity of the damage.

4: Determination of the remaining service life of the structure.

Structure model will not be utilized in the modal based damage identification methods which provide the first two level of damage identification. When modal based methods are joined among a structural model, Level 3 damage detection can be obtained in some cases. Level 4 prediction is normally associated with the field of fracture mechanics applications, fatigue life analysis and structural design assessment [4].

Damage being discrete to start with and detection being global, techniques such as using wavelet transform are increasingly finding application in SHM. The present thesis addresses different aspects of wavelet applications to numerical and experimental investigations on several basic structures such as beam, plate and also on a bridge model. Initially well-known existing damage identification methods are evaluated and compared, by applying them to beam and plate structures.

II. Critical Review of Literatures and identification of research gaps

Due to its importance, damage detection has attracted considerable attention from the engineering research community in the past several decades. For structures that require high reliability such as aerospace vehicles, transportation systems, offshore platforms and various civil structures, etc., it is vital to maintain systems at an optimally healthy condition. A fundamental requirement in the maintenance program is the ability to determine the existence of any damage that potentially threatens the performance of structures.

There regularly exist circumstances where coordinate utilization of modular parameters isn't delicate to the nearby harm. Impressive endeavors have been spent by scientists to look for elective markers to distinguish harm. A few endeavors were utilizing determined modular parameters, for example, mode shape ebb and flow and modular strain vitality.

Stubbs and Osegueda [5] reported a process for crack investigation due to changes in modal characteristics. The formulae related to variations in stiffness of structural members for irregularity in modal stiffness were identified with the application matrix structural analysis. Damage defined as a reduction in the stiffness of any one of the elements in possible location in forming the structure. A general inverse problem was solved with the stiffness reductions. The authors proved that the prediction of crack(damage) locations in structural elements and its magnitudes. Damages were identified at single and multiple locations in a simply supported beam, the different damage cases were investigated by formulation, identified damage was 91 percent of the time.

Salawu and Williams [6] analysed the performance of damage detection methods. Based on changes in Eigen parameters was one method and the others use system identification and model updating procedures. The results indicated that Eigen parameter method is the very much suitable, although it was failed for detecting the damage in a lightly stressed zone.

Ren and De Roeck [7] showed that, based on changes in frequencies and mode shapes of vibration curvatures predicting damage, its location and severity can be possible. The method is applied at an element level with FE modal. The element damage expressions were formulated using Eigen value equations which characterized the dynamic behavior. More solving methods are discussed and compared. Verification of the method was carried out by simulating a number of damage situations in beams, predicted the accurate location and damage severity. The demonstration was done by multiplication of damaged Eigen value equations with the undamaged or damaged mode shapes provides more equations and guarantees the damage localization.

Pandey et al. [8] proposed a method curvature mode shape for detecting and locating damage position in the structure. By using cantilever and simply supported analytical beam models, they have shown that the absolute changes in the curvature mode shapes are localized in the region of damage and hence, they can be used to detect damage in a structure. The displacement mode shapes of the two models have obtained by the use of finite element method. Curvature mode shapes were calculated from the displacement mode shapes by using a central difference approximation. However, there was increasing size of damage by the changes in the curvature mode shape, the method was not able to find exact amount of reduction in stiffness in damaged element.

Salawu and Williams [9] has suggested the two methods and they are the performance of the curvature mode shape method and the mode shape relative difference method. Their prediction says that the experimental data shows poor performance. The results have shown that the procedures were not satisfactory in predicting severe damage cases and were unable to satisfactorily differentiate between damage cases with close degrees of severity.

Chance, et al. [10] found that numerically calculating curvature mode shapes resulted in unacceptable errors. They used measured strains instead of using curvature calculated from mode shapes, which improved results dramatically. They concluded that strain mode shape facilitated the localization of crack markedly.

Liew and Wang [11] was the first to satisfactorily report the use of the wavelet theory for damage detection in structure. The crack detection uses the wavelet theory which applied to a simply supported beam. Mathematical model was proposed for the cracked beam and the wavelet expressions in the space domain. To compare the simply supported destruct beam was analyzed using both the Eigen theory and based on wavelet theory.

Sampaio et al. [12] reported a FRF curvature method that covers three steps of the process of damage location, viz. existence, localization, and extent. Two methods were described theoretically and compared the mode shape curvature method and the damage index method. The generated data numerically by a lumped-mass system and experimental from a real bridge were taken to illustrate the use of the projected procedure.

Quek et al., [13] analysed the compassion or sensitivity of spatial wavelet method in identification of cracks in structures like beams. The different crack individuality effects (length, orientation, width of slit) and boundary conditions are investigated. The results show that the wavelet transform is a useful tool in detection of crack in beam structures.

Kim et al. [14] showed a method to detect and estimate size of damage in structures for which some natural frequencies or some mode shapes are existing. Frequency based damage detection method and a mode shape based damage detection method are presented. A damage index algorithm to locate and estimate the severity of damage from changes in modal strain energy is formulated. The FBDD method and the MBDD method were evaluated for several damage situations by locating and sizing damage in numerically simulated pre-stressed concrete beams.

Ovanesova and Suarez [15] used the wavelet transformations analysis to locate cracks in structural frameworks, like beams, plane frames and explained that this procedure could locate the localization of cracks by using response signals from any of static/dynamic loading conditions. After the selection of suitable wavelet, the method is able to diagnose damage data from response signals has showed in the results.

Loutridis et al. [16] proposed crack detection method based on wavelet analysis in double-cracked cantilever beams with different crack depths. The fundamental mode vibration for the beam was analyzed by continuous wavelet transformations (CWT) also damage extent was given by intensity factor. The method was validated both analytically and experimentally in beams having cracks of varying depth at different positions.

Catbas et al. [17] discussed on different aspects of model improvement in design considerations, instrumentation, finite element modeling and simulating defect scenarios. After generating the mathematical and the physical models, evaluation studies are carried out to reliably finding the eigen values, eigenvectors and modal scaling from the measurement data. Whereas in simulated defect, displacements and curvatures were used to analyze.

Edwin Reynders et al. [18] presented the quasi-static flexibility of damage localization and quantification. The flexibility matrix derived from experiment combined with a virtual load, which causes nonzero stresses in the structure, during this period local stiffness variation is examined.

Vimal Mohan et al. [19] studied on a concept of Damage Location Assurance Criteria (DLAC) to analyze defect. Finite element technique was used in this work and mathematical models were developed for cantilever beam on three different defect positions.

Andrzej Katunin [20] the wavelet-based algorithms were applied there in order to detect, localize and classify internal defects in composite structures. The graphical user interface in Matlab environment was provided for testing purposes of the benchmark. But, location of defects was not addressed.

T.-T.-H. Le et al. [21] investigated on damaged and undamaged system using Euler–Bernoulli beam. In their work they discussed on quantification modifications using the transverse vibrations along with axial force. Based on the output mass density and bending stiffens defects were analyzed, also Validation of the results was compared with experimental data.

Naresh Jaiswal and Deepak Pande [22] In thier work, Discrete Wavelet Transform (DWT) was used to investigate the spatial signals i.e. mode shapes of the beam. The spatial version of wavelet transform analyzes the signal by using the wavelet filter of particular spatial frequency band to translate along a length of beam axis.

Review of these papers indicate that methodologies based on modal curvature, FRF curvature require undamaged (baseline) data, and modal strain energy and numerical differentiation for effective damage identification [23]. But, such an approach often is not suitable for a class of structures where undamaged condition is unknown and cannot be acquired experimentally. This section of structures primarily includes old structures where damage condition is unknown [24]. Also these methods had inherent errors due to numerical differentiations and integrations.

Over View of Literature

Existing damage detection techniques can be categorized into two main areas one is experimental based and another one is finite element based. Vibration based damage detection methods mostly depends natural frequency, modal vectors etc. Various studies have done on vibration based structural damage detection in beam and plate structures. Proper experimental setup selection and implementation is necessary to achieve relative to theoretical results vibration based damage detection techniques need additional intelligence technique to enrich the damage quantification problem.

Research Gap

Most of the damage detection algorithms depends on undamaged data of the structure, practically which is very hard to obtain the data. Modal Assurance Criteria (MAC) not used for delamination detection. Usage of Wavelets based damage detection method in Isotropic and composite structures is very few. Damage quantification needs additional intelligence technique to ensure the optimum results. Early detection stage of the damage in the sructure is still challenging task.

III. Statement of the Research Problem

Reviews of papers on damage identification methods based on wavelet transform indicate that no research clearly addresses the factors affecting the damage identification process. These factors include the study of effect of different boundary condition, reduced spatial sampling, using different spatial inputs to wavelet transform. Another important observation is that no literature addresses the problem of wavelet transform based damage identification in composites beam structures [25].

IV. Objectives of research work

The objective of proposed research is to

- Evaluate the beam modal in presence of damage with modal parameters like natural frequency, mode shapes and power spectral density methods
- Study the effect of damage on Modal Assurance Criterion (MAC)
- To show the effectiveness of the Continuous Wavelet Transform (CWT) in damage identification of isotropic and composite beam by means of its capability to locate and quantify small levels of single and multiple damages using essentially first vibration mode shape.
- To carryout numerical simulation and will be experimentally verified to derive quantitative parameters as indication of level of damage utilizing a simple structural beam model.
- To verify the feasibility of the CWT method for different spatial signal (modal strain energy data) given as input to wavelet transform.

V. Studies on Application of the Power Spectral Density for Damage Identification and Location in Beam Structures

In this section the effectiveness of using root mean square value of power spectral density function and to establish its capability to detect and localize damage. Severity of damage is found out by damage index method. This method is very useful in real time damage identification in structures.

Introduction

Significant work has been done in the area of detecting damage in structures using changes in dynamic response of the structure. Because the natural frequencies and mode shapes of a structure are dependent on the mass and stiffness distribution, any subsequent changes in them should, theoretically, be reflected in changes in the frequencies and mode shapes and their sensitivities to damage level [9]. Consequently, structural safety and functionality will be significantly improved and a condition-based maintenance procedure can be developed [6].

Cantilever Beam model and damage scenarios:

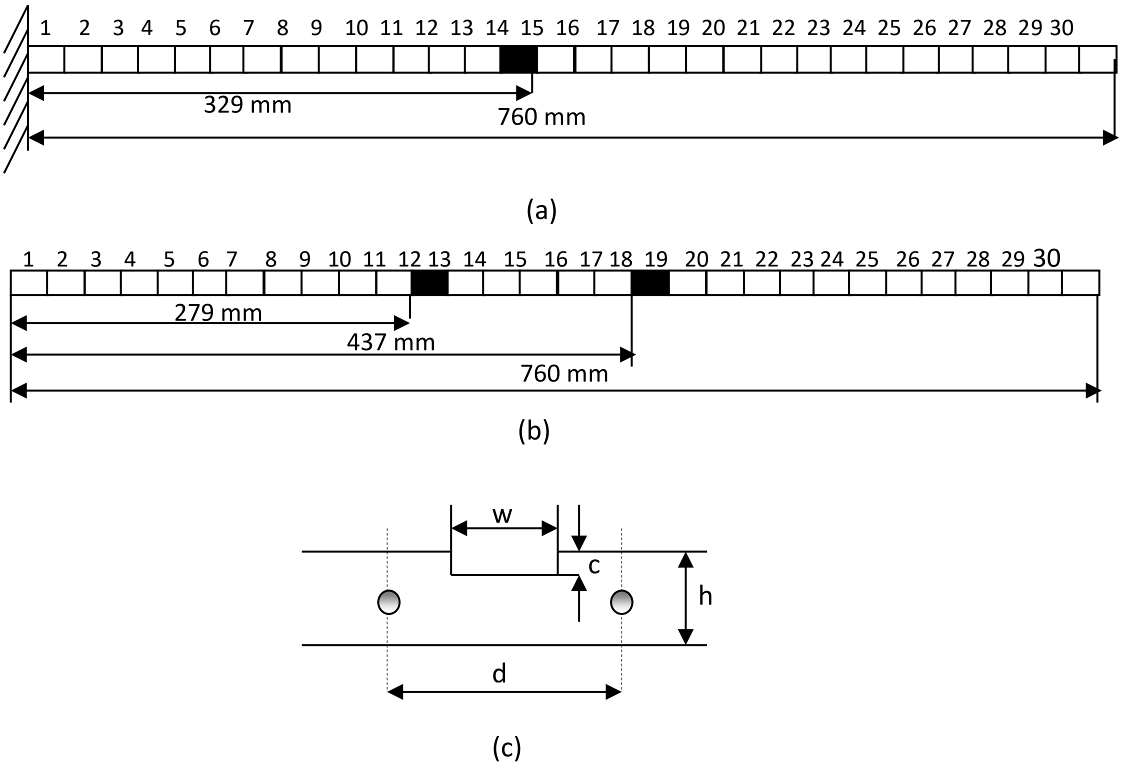


Figure 1. Cantilever beam with damage simulation (a) damage at Single location (b) damage at two locations (c) Damage geometry

A cantilever beam of rectangular cross section of dimension 760mm x 30mm x 20 mm with Young’s Modulus of 200 GPa and density of 7860 kg/m^3 is used for numerical simulation to evaluate power spectral density for damage identification and location. For finite element purpose [1] the beam is divided into 30 two node one-dimensional elements as shown in Figure 1(a). Damage is defined as c/h ratio, where ‘c’ gives the depth of damage and ‘h’ is the height of beam as shown in Figure 1(b).

The parameter ‘d’ represents the spatial sampling distance which is the distance between successive measurement to obtain mode shape and w is the width of cut which is equal to the width of an element. Five simulated damage scenarios are given in Table 1 where first three cases corresponds to damage at single location and last two corresponds to damage at two location. In the present study damage is simulated by reducing the area moment of inertia of a desired element. Reduction in stiffness is calculated as the ratio of difference between the area moment of inertia of undamaged and damaged element to undamaged area moment of inertia.

Table 1. Simulated damage scenarios and reduction in stiffness.

Damage scenario (CD: Cantilever damaged)	Damaged element Number	c/h	Reduction in stiffness (Damage severity)
CD 1	14	0.2	0.48
CD 2	14	0.15	0.38
CD 3	14	0.1	0.27
CD 4	12 and 18	0.15	0.38
CD 5	14and 15	0.1	0.27

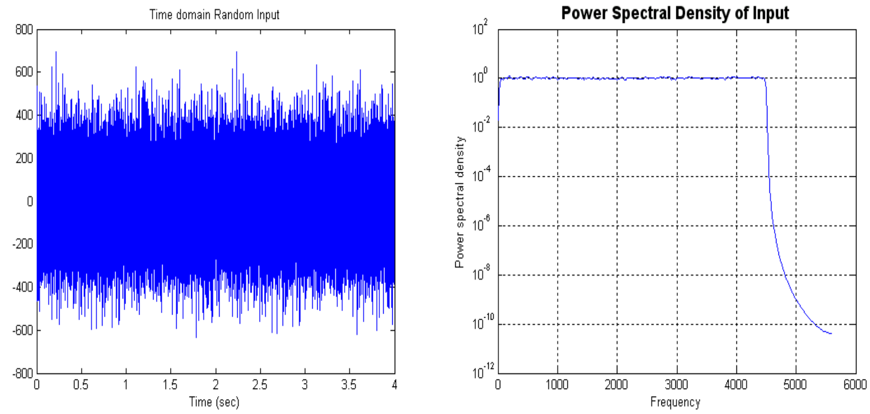
Results and Discussions:

For each damage scenario, the dynamic characteristics (frequencies and mode shapes) before and after the damage were numerically evaluated, with programs coded in MATLAB 7.0. The first five frequencies are listed in Table 2.

Table 2. First five natural frequencies for all damage scenarios.

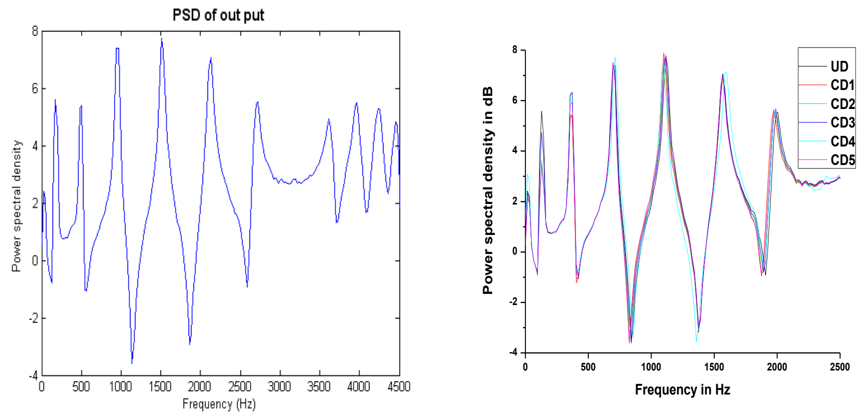
Damage Scenario	Natural frequency (Hz)				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode5
Undamaged	28.426	178.14	498.81	977.48	1615.9
CD1	28.082	174.02	493.95	966.55	1578.1
CD2	28.198	175.38	495.52	970.08	1589.8
CD3	28.291	176.48	496.82	973.01	1599.9
CD4	27.909	170.02	483.85	964.83	1533.2
CD5	28.181	174.62	496.12	964.93	1592.9

For the cantilever beam vibration test a random excitation is applied to the structure. Figure 2a shows the general random signal representing input force. The random signal is specified so that it would have a uniform power spectral density (PSD) in the range of frequency 0 to 4500 Hz as shown in Figure 2b. The output response of the PSD in range of 0 to 4500 Hz shown in Figure 3a.



(2a) (2b)

Figure (2a). General random signal representing input force. (2b) Power spectral density of a random input force in the frequency range 0 to 4500 Hz.



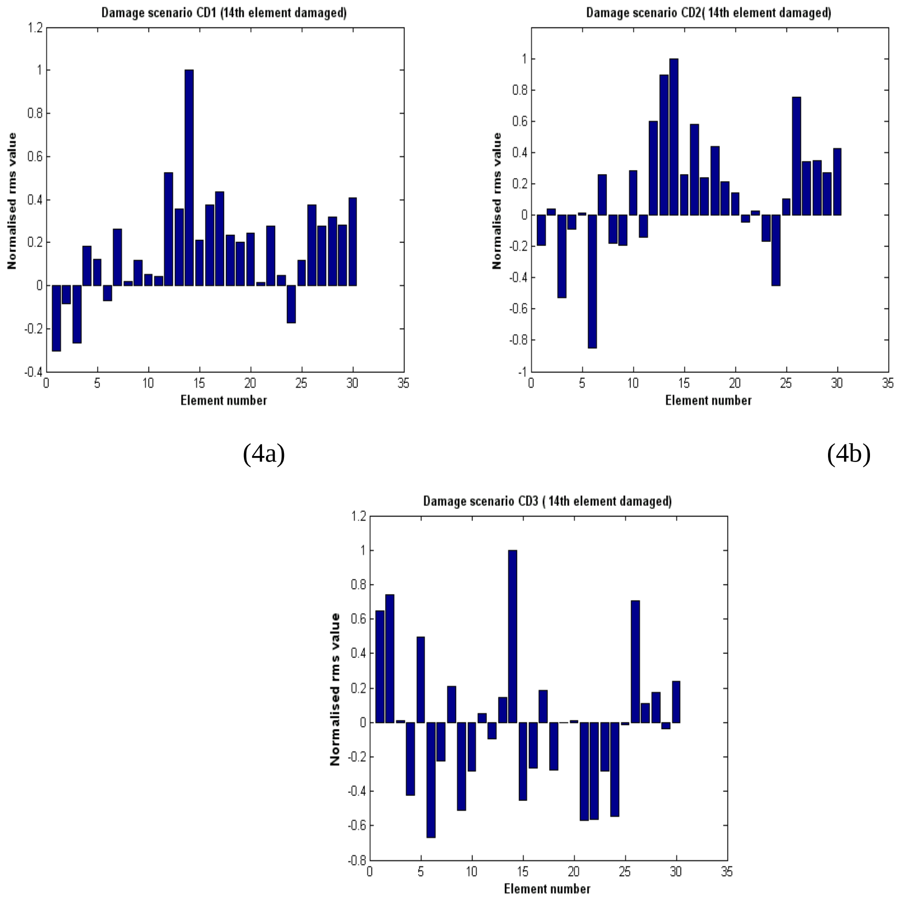
(3a) (3b)

Figure (3a) Output response of power spectral density in the frequency range 0 to 4500 Hz. (3b) Power spectral density for undamaged and damaged cases.

The PSD's for the typical location before and after damages are plotted as shown in Figure 3b with in the range of frequency interest. It shows a clear shift in frequencies i.e. decrease in frequencies with respect to increase in damage. In the analytical section specified that RMS values of the PSD could be used to identify damage. So the RMS value of PSD's for undamaged and damaged structures from all elements of the beam collected and the selection of difference in the RMS values as feature of damage detection and localization [26].

Case 1: Single damage scenarios:

Figure 4a shows the absolute difference in RMS values of power spectral density for damage scenario (CD1) between the intact beam and the damaged beam. This feature is also normalized by setting the largest value equal to 1. The maximum difference value for each RMS values of power spectral density occurs in the damage location. In other areas of the beam this characteristic is much smaller. The same analysis is performed to for the other damage scenarios (CD2) and (CD3) and analogous results were obtained. Each plot shows peak at the damage location as observed in Figure 4b and 4c. Therefore this feature successfully identified the position of the damage along the length of the beam.



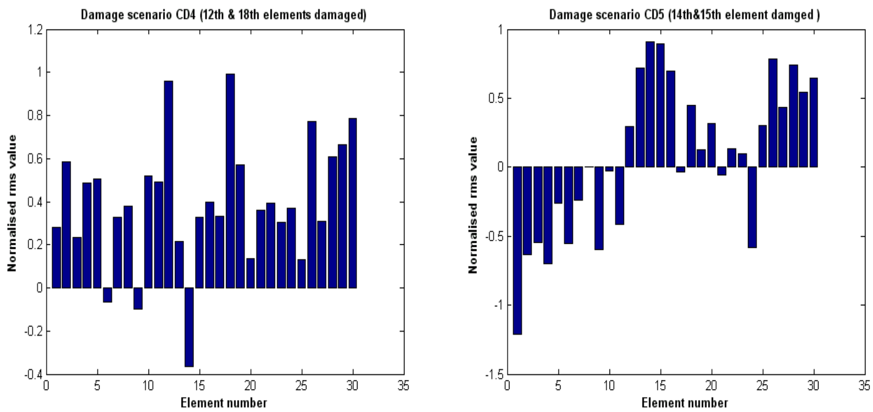
(4a) (4b)

(4c)

Figure 4. Variation of normalized RMS value V/s element number for damage scenario (a) CD1. (b) CD2. (c) CD3.

Multiple Damages Scenarios:

In order to investigate the behavior of RMS values when multiple damages are present in the beam, the same analysis is performed for a beam containing damage at two locations.



(5a) (5b)

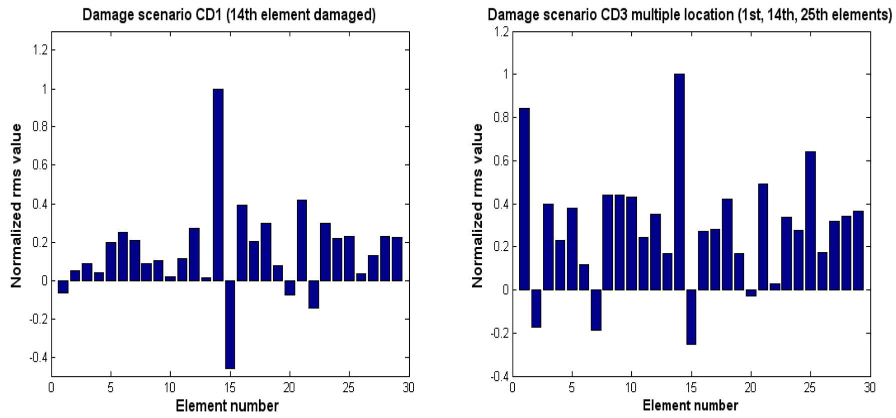
Figure 5. Variation of normalized RMS value V/s element number for damage scenario (a) CD4. (b) CD5.

The first of the multiple damage scenarios is 12th and 18th elements get reducing the area moment of inertia by c/h= 0.15 i.e. (CD4) as shown in Figure 1b. RMS values of PSD's were calculated for this multiple damaged and intact beam and then result is plotted as shown in Figure 5a. The second multiple damage scenario is side by side elements (14th and 15th) get reducing the area moment of inertia by c/h= 0.1 i.e. (CD5) Then the results are plotted as shown in Figure 5b.

It clearly showed that procedure suitable for real application where, in most cases, structures may contain several defects at the same time.

Case 2: Fixed - Fixed beam case:

Similar analysis has been carried out for the same beam with fixed-fixed boundary condition. In this section two damage cases have been studied. Single damage case (CD1) for 14th element and multiple damages case (CD1) for 1st, 14th, 25th elements. For single damage case the normalized RMS value has been plotted versus element number as shown in Figure 6a which clearly show the maximum normalized RMS value at the damage location.



(6a) (6b)

Figure 6. Fixed-fixed beam with damage locations (a) Variation of normalized RMS difference V/s element number for damage scenario, CD1. (b) Variation of normalized RMS difference Vs element number for damage scenario, CD1 for 1^{st} , 14^{th} , 25^{th} elements.

Similarly for multiple damage case Figure 6b shows the maximum normalized RMS valves at 1^{st}, 14^{th} and 25^{th} elements. This method is more sensitive to locate damage even at the boundaries. From this analysis we can say that the method is very useful in real time damage identification for bridge like structures.

Damage quantification:

Power spectral density of RMS values are defined as $(PSD\_RMS)_U$ and

$(PSD\_RMS)_D$

for undamaged and damaged structure respectively, and can be utilized to determine the severity of damage by Damage Index (DI) [27].

$$DI = \sum_{i=1}^{N} \left| \frac{(PSD\_RMS_i)^2{}_D - (PSD\_RMS_i)^2{}_U}{(PSD\_RMS_i)^2{}_U} \right| *100 \qquad (1)$$

Where

$(PSD\_RMS)_U$ - Power spectral density root mean square value for undamaged case.

$(PSD\_RMS)_D$ - Power spectral density root mean square value for damaged case.

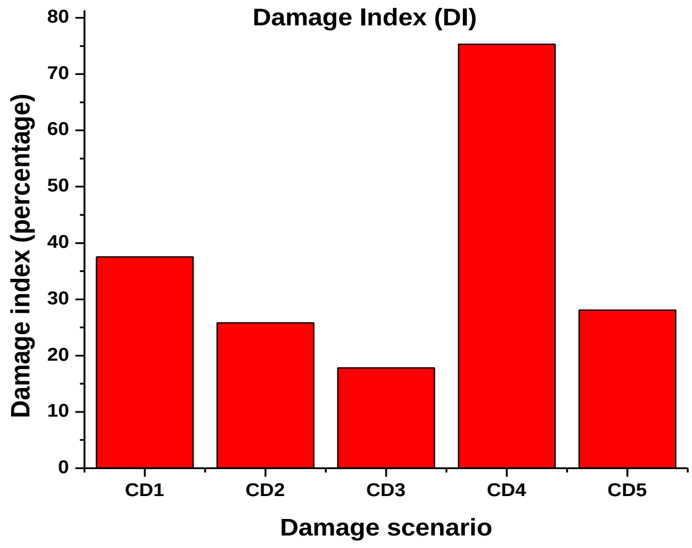


Figure 7. Damage index for different damage scenarios.

Figure 7 shows the quantification of damage in percentage for different damage scenarios for cantilever beam case as the damage index (DI) increases with increases in damage severity.

This section presented a method for identification and localization of structural damage is implemented analytically for cantilever beam. The method is focused on RMS values of power spectral density which is most sensitive to damage. The method only requires the RMS values of PSD of the structure before and after damage.

VI. Experimental Damage Identification in Composite Material by Using Modal Assurance Criterion

In this section the effectiveness of using modal assurance criterian and to establish its capability to detect and localize damage. This method is useful in real time damage identification in structures experimentally.

Introduction

The failure of homogeneous materials to withstand the stresses in different engineering applications and the testing with material properties in order to achieve high strengths lead to the discovery of an idea of mixing of materials. Composite material is the combination of two or more materials in order to get better properties than the parent material. Polyester is the center of attraction in polymer matrix composites because of its high strength, durability, low maintenance. The Hemp reinforcement provides high quality natural fibers which are inexpensive and exhibit excellent mechanical properties compared to other natural fibers [28].

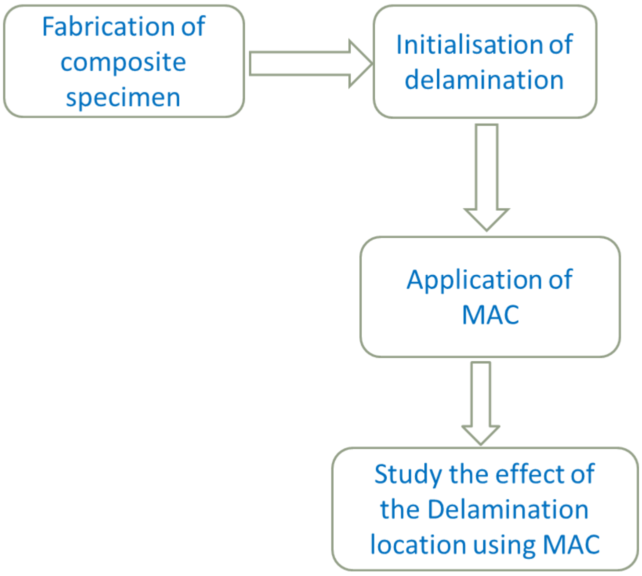


Figure 8. Processes flow chart

Table 3. Specification of specimen

Specimen	Specification
HH1	Specimen without Damage
HD1	Specimen with Damage size of 20mm x 20m at the center
HD2	Specimen with Damage size of 15mm x 15mm at the center
HD3	Specimen with Damage size of 10mm x 10mm at the center
EDGE HOLE	Specimen with Damage size of 20mm x 10mm at the edge
2 LAYERS	Specimen with Damage size of 10mm x 10mm in 2 layers
3 LAYERS	Specimen with Damage size of 10mm x 10mm in 3 layers
BOTTOM HOLE	Specimen with Damage size of 20mm x 10mm at the edge
BIG HOLE	Specimen with Damage size of 30mm x 30mm at the center

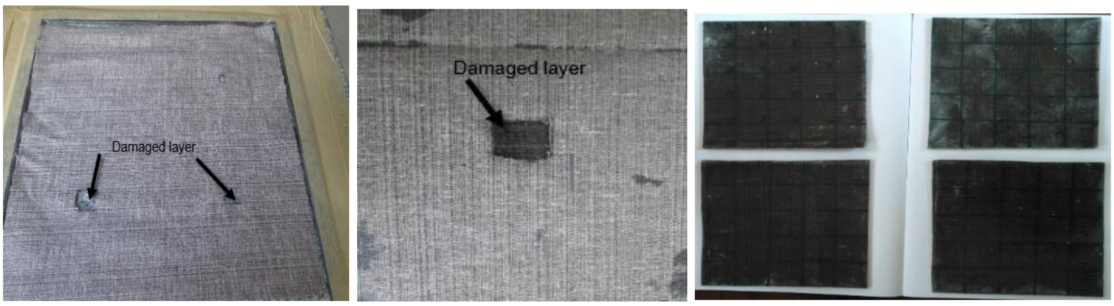


Figure 9. Test specimen

Experimental Modal Analysis

Damping is characterized as a decrease in the plentifulness of a swaying subsequently of vitality being depleted from the framework to defeat frictional or other resistive strengths. Damping test was carried out to find out the natural frequency, damping and the mode shapes of the specimen it causes a lessening in the adequacy of an electrical or mechanical wave.

Modular testing is the type of vibration testing of a question whereby the common (modular) frequencies, modular masses, modular damping proportions and mode states of the protest under test are resolved. A modular test comprises of an obtaining stage and an examination stage. The total procedure is frequently alluded to as a Modal Analysis or Experimental Modal Analysis.

There are a few approaches to do modular testing yet affect pound testing and shaker (vibration analyser) testing are typical. In both cases vitality is provided to the framework with known recurrence content. Where basic resonances happen there will be an intensification of the reaction, obviously found in the reaction spectra. Utilizing the reaction spectra and compel spectra, an exchange capacity can be obtained. The exchange capacity (or recurrence reaction work (FRF)) is regularly bending fitted to gauge the modular parameters[29].

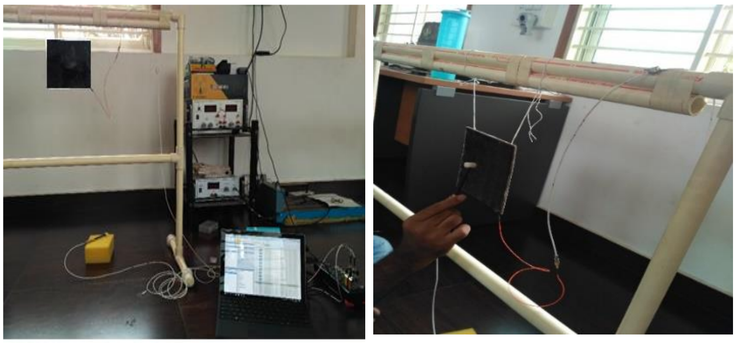


Figure 9. Instruments for Modal Analysis   Figure 10. Experimental modal analysis setup

Figure 11. Dynamic Signal Analyser

Table 4. Specification of dynamic signal analyzer [30]

Perticulars	Details
Number of channels	8
Inputs	Voltage, bridge(IEPE, temperature with adapters)
ADC type	24 bit sigma delta with anti-aliasing filter
Sampling rate	Simultaneous 200kS/sec sampling rate
Input type	Differential
Input ranges	$\pm$10V,$\pm 1V, \pm 100mV, \pm 10mV$
Sensor supply	12V, 400mA sensor supply $\pm 5V$ $\pm$ 0.1 % bridge sensor supply
Overvoltage protection	$\pm$ 70 V input protection
Dynamic range	107dB@$\pm$ 10V range
DC accuracy 10V range **1 V range** **100mV range** **10mV range**	0.05% of value +1mV 0.05% of value +0.2mV 0.05% of value +0.1mV 0.05% of value +0.1mV
Input impedance	20MΩ 47pF(differential), 10MΩ 33pF(common mode)
CMRR	$> 80dB$
Maximum common mode voltage	$\pm 13\ V$
Signal to noise **0.1 k S/s to 51.2k S/s** **51.2 k S/s to 102.4k S/s** **102.4 k S/s to 200k S/s**	 105dB 100dB 75dB
Channel-to-channel Phase Mismatch	$< 0.1\ deg@5kHz$
Phase-to-phase Mismatch	-0.6deg@1kHz

The dynamic signal analyser the information from measuring instrument and hammer and are going to be given to the software package. It's Associate in Nursing eight channeled structure during which the primary 2 channels square measure connected to the hammer and measuring instrument. This can be accountable to research the info from measuring instrument and may tend to the software package[30].

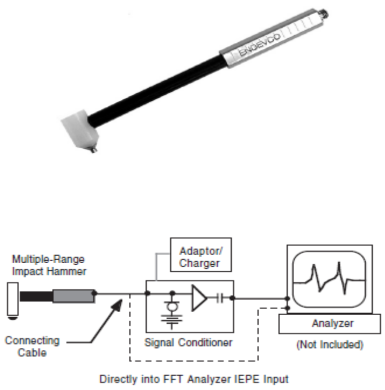


Figure 12. Hammer

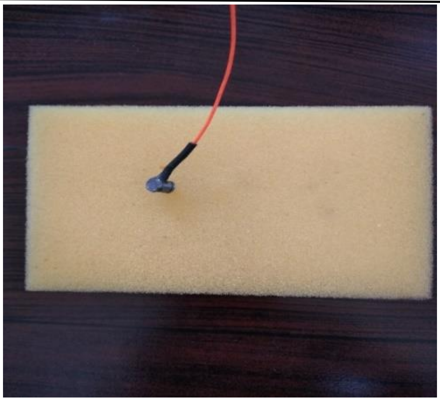


Figure 13. Accelerometer

The Hammer performance specifications conform to ISA-RP-37.2 (1964) and are typical values, referenced at +75˚F (+24˚C), 4 mA, and 100 Hz, unless otherwise noted. Calibration data, traceable to National Institute of Standards and Technology (NIST), is supplied [31].

Accelerometer shown in figure 13 may be a device that measures the acceleration of a body in its own instant rest frame. Sensitive accelerometers square measure used for mechanical phenomenon steering purpose in aircrafts and missiles. This helps in detection and observance the vibrations associate degree measuring system acts as a damped mass on a spring. Once the measuring system is subjected to associate degree acceleration, the mass is displaced to the purpose that the spring is in a position to accelerate the mass at identical rate because the casing. The displacement is then measured to provide the acceleration.

Modal Assurance Criterion

The Modal Assurance Criterion (MAC) is an essential tool in modal analysis. Its use to perform the pairing between two sets of modal vectors is now widespread. The great success of the MAC has fostered the emergence of numerous derivative criteria designed to deal with more specific situations.

However a rigorous treatment of the advanced case still looks to be lacking. Such things square measure comparatively frequent and occur for systems that don't totally go with the classical assumptions of structural dynamics. The analysis is of the aero elastic behavior of aircraft may be a typical example of such a state of affairs. The MAC has been used as a Mode hope correlation constant to quantify the accuracy of identified mode shapes. MAC values are calculated from equation 2 and equation 3 represents that, if modal frequencies are same then Eigen vectors for undamaged specimen $\{\psi_X\}$ and damaged specimen $\{\psi_A\}$ will remain same then the MAC(X,A) is equal to unity [32].

$$MAC(X,A) = \frac{\left|\{\psi_X\}^T\{\psi_A\}\right|^2}{\left(\{\psi_X\}^T\{\psi_X\}\right)\left(\{\psi_A\}^T\{\psi_A\}\right)} \tag{2}$$

Or

$$\{\psi_X\} = \{\psi_A\} \Rightarrow MAC(A,X) = MAC(X,A) = 1 \tag{3}$$

Results and Discussion

First the undamaged specimen is considered and the experimental values of natural frequencies for first nine modes obtained by using the modal analysis for free free conditions. Table 2 shows the first nine natural frequencies for undamaged specimen and specimen listed in table 1.

Table 5. Frequencies of 9 modes for all specimen

Mode shape	Frequency for HH1 Hz	Frequency for HD1 Hz	Frequency for HD2 Hz	Frequency for HD3 Hz	Frequency for 10mm Edge Hole Specimen Hz	Frequency for Damage 10mm x 10mm in 2 layers	Frequency for Damage 10mm x 10mm in 3 layers	Frequency for Damage size of 20mm x 10mm at the edge	Frequency for Damage size of 20mm x 10mm at the edge
1	179	186	184	180	183	183	196	185	216
2	287	393	289	364	396	380	315	288	337
3	368	494	371	474	515	489	399	383	426
4	469	890	488	858	610	655	519	483	568
5	863	948	924	923	937	881	632	516	1050
6	1460	1008	982	1110	1020	1040	953	863	1100
7	1570	1160	1130	1460	1570	1150	1210	934	1590
8	1780	1510	1500	1730	1570	1360	1580	1030	1760
9	1870	1820	1830	1830	1580	1530	1610	1180	1769

The Modal Assurance Criterion (MAC) plots obtained from experimentally from DEWEsoft software from the phenomenon by equations 1 and 2 are shown in figures from 9 to 17.

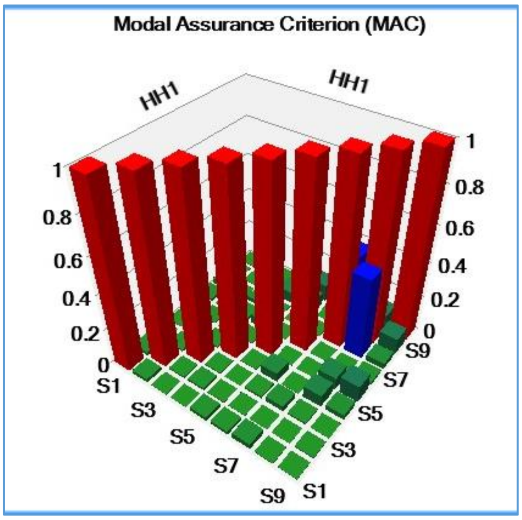
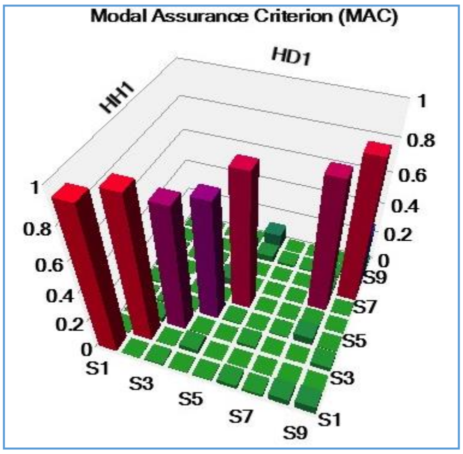


Figure 14. MAC plot for Undamaged and Undamaged specimen (HH1)

The figure 14 shows the MAC plot for the specimen without damage. It shows that along the diagonal MAC is unity due to Eigen vectors are same showing red colored solid cuboids.



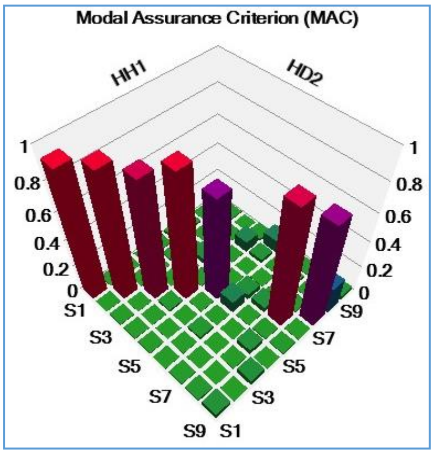


Figure 15. MAC plot for HH1 and HD1 Figure 16. MAC plot for HH1 and HD2

The figure 15 shows the MAC plot for the specimen without Damage (HH1) and Specimen with Damage size of 20mm x 20mm at the centre (HD1). It shows that along the diagonal MAC is unity due to Eigen vectors are same showing red colored solid cuboids for modes 1,2,5,7,8 and 9. The MAC value for modes 3,4 is around 0.8 and for mode 6 is zero. When comparing the figure 14 and figure 15 it is observed that MAC values are sensitive to damage along the diagonals.

The figure 16 shows the MAC plot for the specimen without damage (HH1) and Specimen with damage size of 15mm x 15mm at the center (HD2). It shows that along the diagonal MAC is unity due to Eigen vectors are same showing red colored solid cuboids for modes 1,2,3,4, 6 and 7.

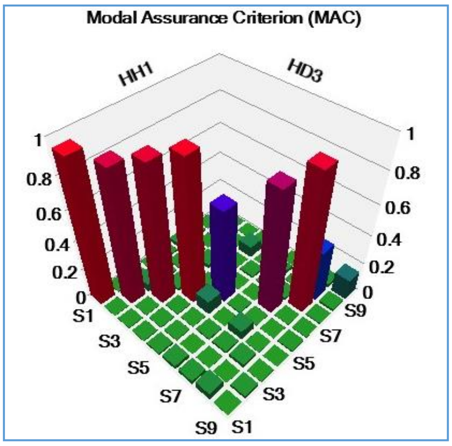


Figure 17. MAC plot for HH1 and HD3

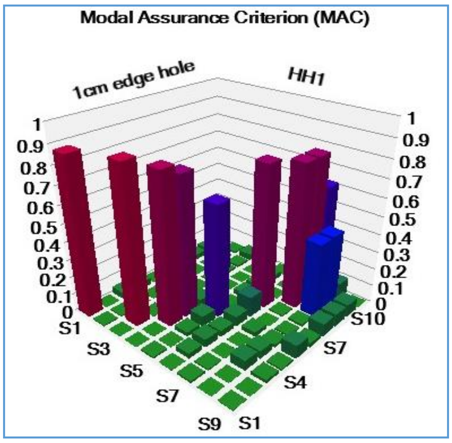


Figure 18. Comparison of undamaged specimen and Damage specimen edge hole

The MAC value for modes 5, 9 and 7 is around 0.8 and for mode 6 is zero. When comparing the figure 14 and figure 16 it is observed that MAC values are sensitive to Damage along the diagonals. The figure 17 shows the MAC plot for the specimen without Damage (HH1) and Specimen with damage size of 10mm x 10mm at the center (HD3). It shows that along the diagonal MAC is unity due to Eigen vectors are same showing red colored solid cuboids for modes 1,2,3,4 8 and 7. The MAC value for mode 7 is around 0.8 and for mode 5 is 0.6, for mode 8 and 9 is 0.4. When comparing the figure 14 and figure 17 and figure 18 it is observed that MAC values are sensitive to damage along the diagonals.

The observations are inferred from above work that, the Modal analysis of square plate for PMC is carried out in detail experimentally. The first four fundamental frequencies of square plate were found. The dynamical behaviour of composite depends on head by structures and type of fibers, on the other hand by physical characteristics such as density, thickness and manufacturing process. And, also the modal assurance criterion shows consistency of MAC results determined from different cases of modal frequency after calculating Eigen Vectors. Inconsistency of MAC results determined from different cases of modal frequency after calculating Eigen Vectors is observed due to presence of damage

VII. Numerical and experimental evaluation of spatial wavelet method for damage detection in isotropic beam structures

This section discuses about existing structural damage identification methods based on dynamic characteristics of structures are examined and new method of damage identification in beam structures based on continuous wavelet transform is presented and compared.

Introduction

The present work includes the study of existing damage identification based on using only the modal data and development of a new method of damage identification based on wavelet transform. All the factors affecting the proposed method of Wavelet based damage identification is investigated in detail. The efficiency of the method is investigated primarily in terms of the spatial input used, choices of wavelets and scales. Numerical as well as experimental study is done on a simple structural beam model.

Methodology

The Fourier analysis consists in transforming a signal from the time or space domain to the frequency domain. The Fourier transform is used to extract the modal information (natural frequencies and vibration modes), or it is used to calculate the FRF from a transient time signal. The theory of the Fourier transform is very well established, and it is a quick and easy tool to find the frequency components in a signal. The disadvantage of the Fourier analysis is that the time or space information is lost in the transformation, and it is not possible to determine when or where a local event occurs, which is necessary in damage identification.

In order to overcome this drawback, wavelet analysis has been considered recently for structural identification and damage detection. Wavelet analysis may be viewed as an extension of the traditional Fourier transform with a window adjustable in location and size. The advantage of wavelet analysis lies in its capacity to examine local information with a ‘‘zoom lens having an adjustable focus’’ to provide multiple levels of details and approximations of the original signal.

Continuous wavelet transforms (CWT)

The Continuous Wavelet Transform (CWT) is defined as the sum over all time of the signal function of time or space (infinite) multiplied by a scaled, shifted version of a wavelet function ψ. For a spatial signal,

$$Wf(u,s)=\int_{-\infty}^{\infty} f(x)\psi(u,s,x)dx \tag{4}$$

Where, *f(x)* is the spatial input signal, and *x* being the spatial coordinate. The results of the CWT are wavelet coefficients *Wf(u,s)* that are a function of the scale *s* and position *u*. Since the input is spatial signal the wavelet transform is called Spatial Wavelet Transform. In case of damage identification in beam structures, the input signal may be mode shape, modal strain energy or the forced vibration data, where x is length of beam or node (element) number.

To perform the CWT, a basic wavelet function must be selected from the existing wavelet families. The basic wavelet function, known as the "mother wavelet" ψ(x) is dilated by a value *s* and translated by the parameter *u*.

The dilation (expansion or compression) and the translation yield a set of basis functions defined as

$$\psi(s,u,x)=\frac{1}{\sqrt{s}}\psi\left(\frac{x-u}{s}\right) \tag{5}$$

The translation parameter, *u*, indicates the space (or time) position of the relocated wavelet window in the wavelet transform. Shifting the wavelet window along the space (or time) axis implies examining the signal *f(x)* in the neighborhood of the current window location. The scale parameter, *s*, indicates the width of the wavelet window.

The wavelets coefficients are defined in equation indicate how similar is the function *f(x)* being analyzed to the wavelet function $\psi(s,u,x)$

In terms of a selected mother wavelet function ψ(x), the continuous wavelet transform of a signal *f (x)* is defined as [33]

$$Wf(s,u)=\frac{1}{\sqrt{s}}\int_{-\infty}^{\infty} f(x)\psi\left(\frac{x-u}{s}\right)dx \tag{6}$$

The wavelet transform can detect and characterize transients (caused due to damage) in a spatial signal with zooming procedure across scales. The wavelet coefficients measures the variation of *f(x)* in a neighborhood of *u* whose size is proportional to *s*. Sharp transients create large amplitude wavelet coefficients. Thus high wavelet coefficients *Wf(u,s)* at a particular point on the spatial signal detects and locates the damage (Level I and II identification) [34]

Vanishing moments

If a wavelet has N vanishing moments it is blind to polynomial up to order N-1. This is expressed mathematically as

$$\int_{-\infty}^{+\infty} x^n \psi(x)dx = 0 \qquad \text{For } n = 0, 1\ldots \text{N-1} \tag{4}$$

A way to obtain a wavelet with N vanishing moments is to take the N[th] derivative of the smooth function $\phi(x)$, called the scaling function.

$$\begin{aligned}\frac{1}{\sqrt{s}}\int_{-\infty}^{+\infty} f(x)\psi\left(\frac{x-b}{s}\right)dx &= \frac{(-s)^N}{\sqrt{s}}\int_{-\infty}^{+\infty} f(x)\left(\frac{d^N}{dx^N}\phi\left(\frac{x-b}{s}\right)\right)dx \\ &= \frac{(-s)^N}{\sqrt{s}}\int_{-\infty}^{+\infty}\left(\frac{d^N}{dx^N}f(x)\right)\phi\left(\frac{x-b}{s}\right)dx\end{aligned} \tag{5}$$

The wavelet transform of *f(x)* with a mother wavelet having N vanishing moments is a smoothened version of the N[th] derivative of *f(x)* at various scales [16].

This clearly shows the importance of choosing an appropriate mother wavelet to analyze a spatially distributed signal for identification of damage. A wavelet with one vanishing moment will derive properties from signal *f(x)* that are related to first derivative of the signal. This similarly happens for higher order derivatives. Thus, to extract relevant information corresponding to a particular derivative of input signal the selection of vanishing moments for mother wavelet should be done accordingly. It has been proved that the minimum number of vanishing moments required to identify damage using the mode shapes as input to wavelet transform is two [35].

Selection of mother wavelet

Higher vanishing moments has the advantage of being able to measure Hoelder exponent of high order. On the other hand, if the wavelet has higher vanishing moments, localization worsens because support length increases. Daubechies [33] proved that if a wavelet has n vanishing moments, its support length must be at least 2n-1. Therefore a compromise between number of vanishing moments and adequate localization should be accomplished.

Selection of scales

A high value of scale corresponds to big wavelets, so that low spatial-frequency components can be looked through, while a low level of scale corresponds to small wavelet suitable for the analysis of high frequency components [16]. Since local perturbation in spatial signal caused due to presence of damage is high frequency component, it is desirable to use lower values of scales. Another important advantage of CWT as compared to discrete wavelet transform is the redundancy of information provided for analysis. This suggests that wavelet coefficients can be estimated for any given value of scale.

Damage identification based on wavelet transform is carried out utilizing the special properties of CWT, discussed previously. Damage detection and localization is done by observing high wavelet coefficients in scale-translation plane and quantification is done by estimating Hoelder exponent and intensity factor at the damaged location. Next chapter presents damage simulations on a simple numerical beam model and identification of damage using CWT, and also experimental verification of the proposed method.

Damage identification procedure

The present wavelet based damage identification procedure is as follows. The input to the continuous wavelet transform is the spatial signal which can be displacement mode shape or the strain energy measurement. The spatial signal is convolved with mother wavelet (e.g., Complex Gaussian Wavelets) for different wavelet scales to get a matrix of wavelet coefficients. The number of rows and column of the coefficient matrix are respectively equal to the size of spatial signal and the number of wavelet scales. Damage can be detected and located by plotting a 3-D graph of wavelet coefficients in scale-translation (Node/element number or length of beam) plane. Any point of high wavelet coefficients on the translation axis, indicate damage and the position of the same helps in locating the damage. The same procedure can be repeated for different damage severity.

Numerical Simulation

For numerical simulations, Inconal625 beam with square cross section of dimensions 1000mm x 20mm x 20mm with young’s modulus of 207.5 GPa and density of 8440 kg/m^3 is used for modeling and modal analysis is performed in ANSYS 11.0. The element type used for modeling the beam model is 2D-elastic beam. The length of beam is divided into 2000 elements as each element length is equal to 0.5 mm. Damage is simulated at the 900th element which is at 450mm from left end as shown in Figure 19.

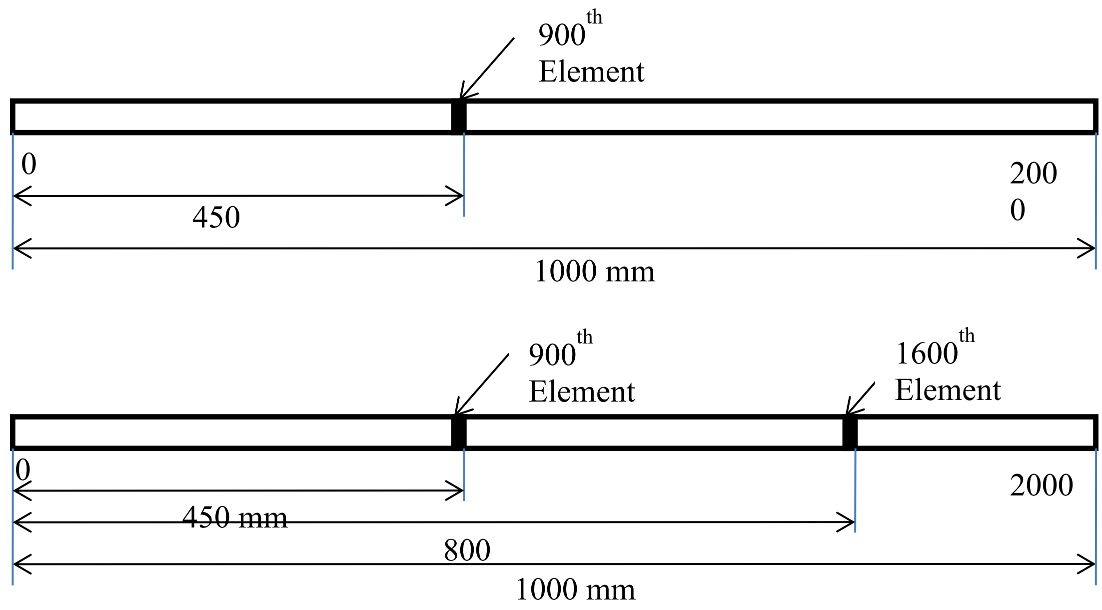


Figure 19. Beam model and Damage geometry

The damage (young's modulus) was varied from 90% to 0.1% for different damage cases. The beam is free-free at both the ends. In the present study damage is simulated by reducing the young's modulus (E) of a desired element which reduces the stiffness of the member.

Modal Analysis

Numerical modal analysis is carried out in ANSYS 11.0 to get first three natural frequencies and displacement mode shape for all damage cases and tabulated in Table 6. To better visualize the shift in natural frequency due to damage from the natural frequency of undamaged beam, a plot of normalized natural frequency for first three modes with different damage cases is shown in Figure 20

Table 6. First three natural frequencies for undamaged and all damage case

Damage case (% reduction in E)			Natural Frequencies (Hz)		
			Mode 1	Mode 2	Mode 3
Undamaged			101.73	280.13	548.46
Single Element Damage	Case 1	90	101.18	279.94	546.73
	Case 2	60	101.63	280.10	548.17
	Case 3	40	101.68	280.12	548.33
	Case 4	20	101.71	280.13	548.41
	Case 5	10	101.78	280.15	548.64
	Case 6	5	101.84	280.45	549.08
	Case 7	2	101.84	280.45	549.08
	Case 8	1	101.84	280.45	549.08
	Case 9	0.5	101.73	280.13	548.46
	Case 10	0.1	101.73	280.13	548.46
Double Element Damage		90	101.09	279.01	544.00

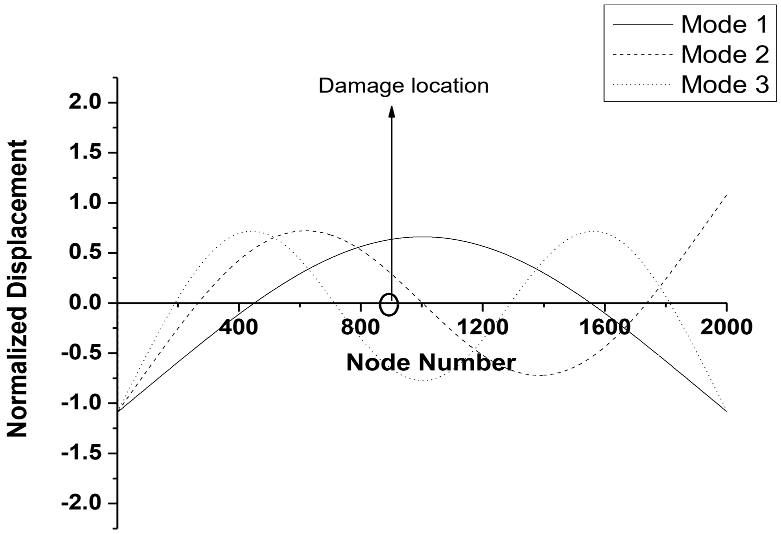


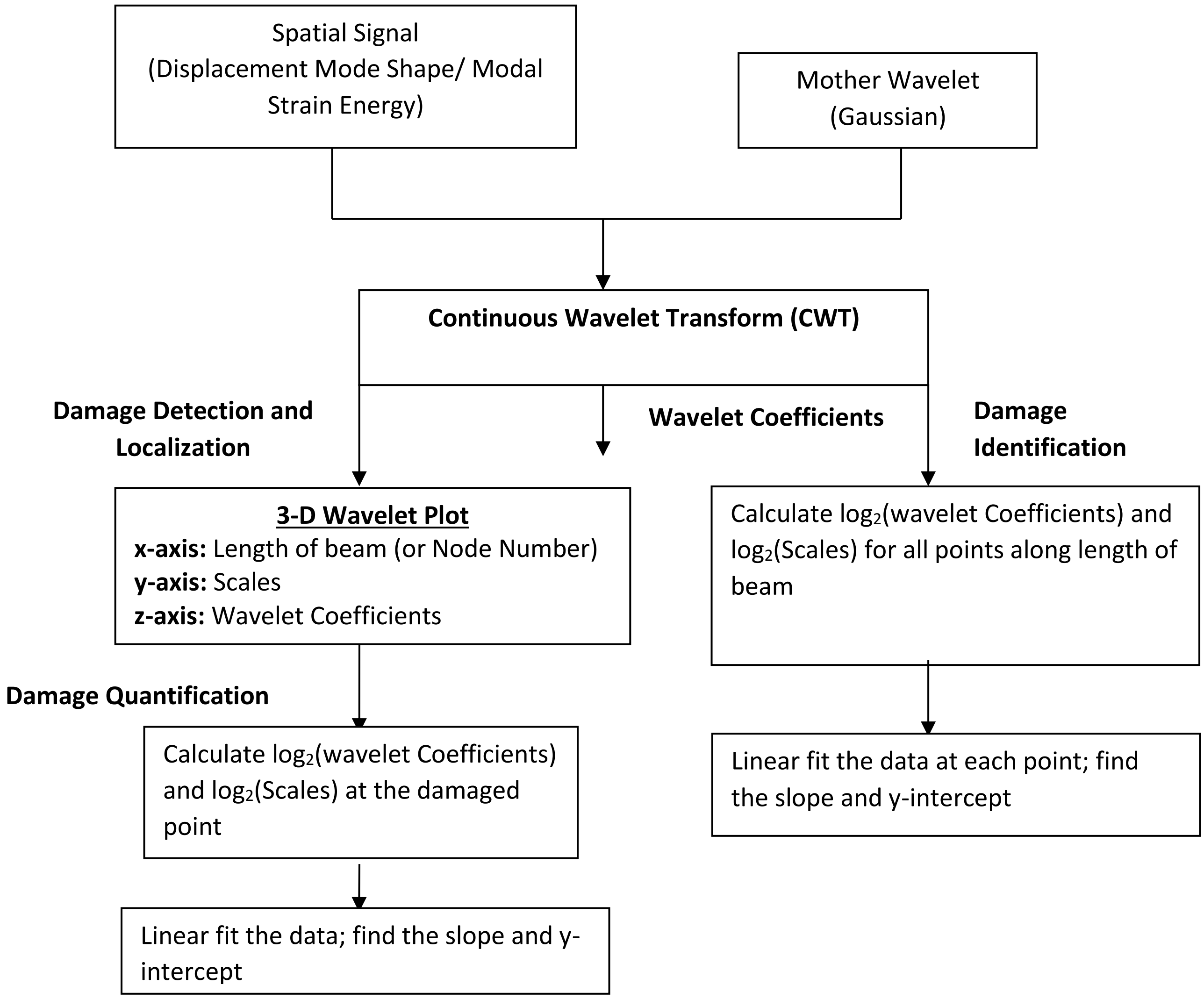
Figure 20. Effect of damage on natural frequencies of first three mode shapes

The natural frequency for different damage cases corresponding to particular mode is normalized with respect to undamaged natural frequency. It is observed that the shift for first mode is more compared to second and third. This is due to anti-node of first mode very close to damage location. The shift is minimum for second mode due to presence of node of mode near the damaged 900th element as shown in Figure 20.

The Spatial signal (fundamental mode shapes/ modal strain energy) from damaged beam is wavelet transformed using Wavelet toolbox available in MATLAB 2012 version. After some experimentation it is found that scales of 8 to 32 provided better results. The mother wavelet selected is Gaussian wavelet with four vanishing moments. The resulting wavelet coefficients are used in damage identification

Methodology or Approach adopted in the execution of the work

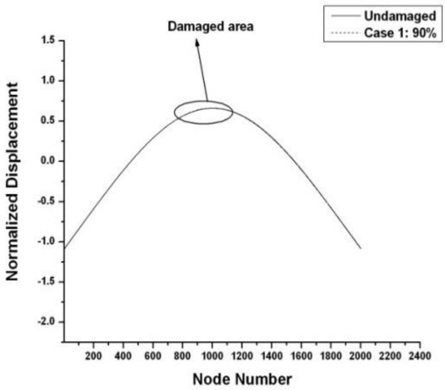
The methodology of for the achievement of defined objectives is as follows:

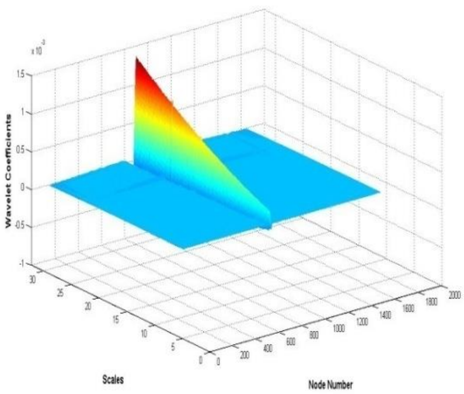


Results and discussion

In this section the resultsfrom numerical simulation are shown and discussed.

Case 1: Single damage location



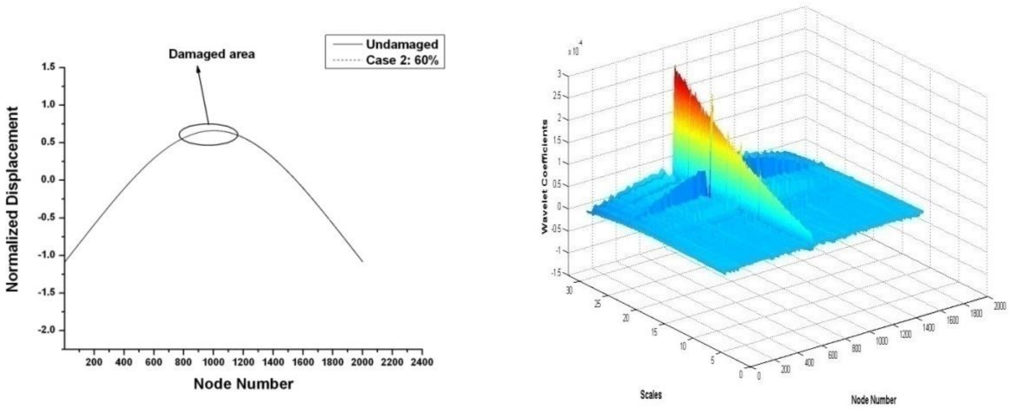


(a) (b)

Figure 21. Damage case 1 (a) Fundamental mode shape (b) 3-D Wavelet plot in Scale-translation plane

Figure 21(a) shows the plot of displacement mode shape for undamaged and damaged beam with damage severity equal to Case1 with which it is practically impossible to locate damage. The mode shape obtained from damaged beam is wavelet transformed using Gaussian wavelet and the resulting wavelet coefficients are plotted in scale-translation plane as shown in Figure 21(b). It is observed clearly in the three dimensional plot at node 900 change in wavelet coefficients occur with respect to adjacent element, indicative of damage.

Similar plots for the damage cases 2 and 3 are shown in Figure 22 and Figure 23 respectively. It is observed that from Figure 22 (a) for case 2 the mode shapes corresponding to undamaged and damaged beam are identical and locating damage becomes impossible. But when the mode shape from damaged beam is wavelet transformed and plotted in scale-translation (node number) plane, damage can be clearly located by high wavelet coefficients at 900th element as shown in Figure 22(b). From Figure 23 (b) observed that the 3-D wavelet plot for case 3, which display considerable value of wavelet coefficients in comparison to value at damaged region. This again is due to the deceased curvature change in mode shape at the damaged region compared to change at the middle of mode shape



(a) (b)

Figure 22. Damage case 2 (a) Fundamental mode shape (b) 3-D Wavelet plot in Scale-translation plane

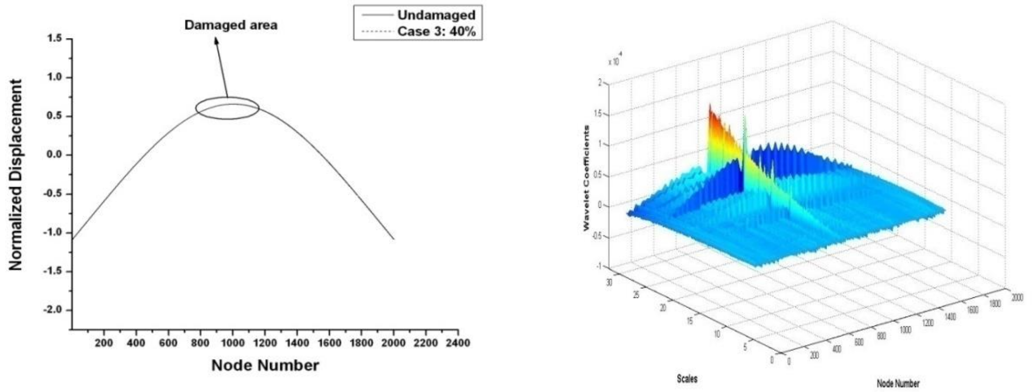
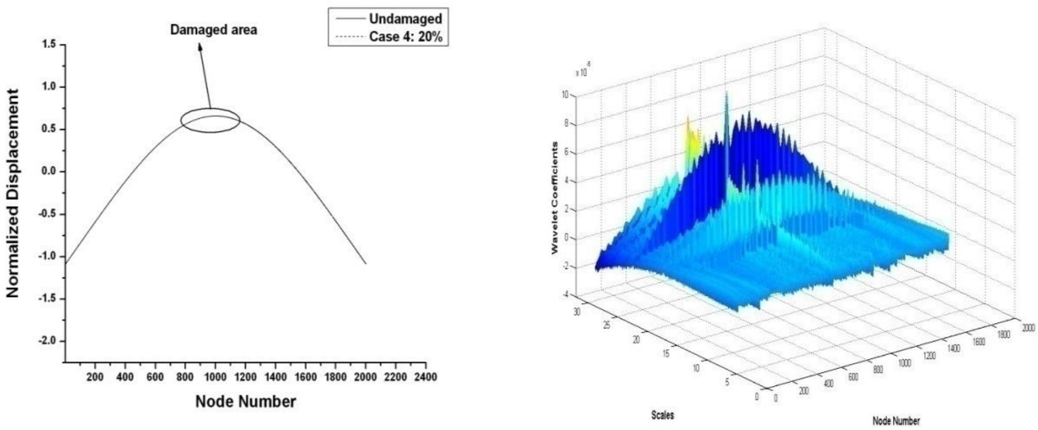
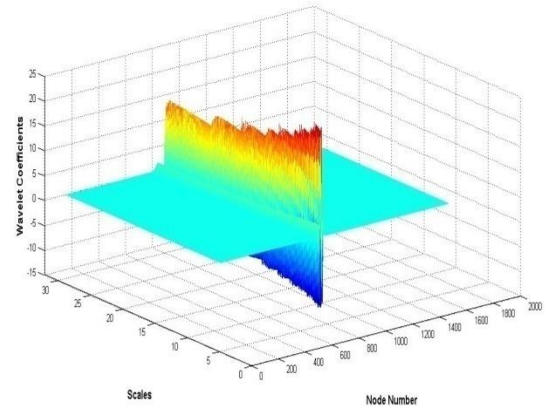


Figure 23. Damage case 3 (a) Fundamental mode shape (b) 3-D Wavelet plot in Scale-translation plane

.



(a) (b)



(c)

Figure 24. Damage case 4 (a) Fundamental mode shape (b) 3-D Wavelet plot in Scale-translation plane (c) 3-D wavelet plot for Fundamental modal strain energy mode shape

Figure 24 (b) shows the 3-D wavelet plot for case 4, which display considerable less value of wavelet coefficients in comparison to value at damaged region. This again is due to the deceased curvature change in mode shape at the damaged region compared to change at the middle of mode shape. It has been found that the method of using displacement mode shape to locate damage is insensitive to below damage case4. Figure 24(b) shows the 3-D wavelet plot for the case 4 where it is practically impossible to locate damage by examining the points of high wavelet coefficients. For lesser value of damage severity the effectiveness of using elemental modal strain energy data (output from ANSYS) as input to wavelet transform is investigated. Since it has been proved that modal strain energy is more sensitive to damage than mode shape [10], using wavelet transform of modal strain energy is much more sensitive for lower level of damage.

Experimental verification

In order to test the feasibility of applying proposed wavelet based damage identification method to experimental data (mode shape), experimental modal analysis is carried out on a simple steel beam with free-free boundary condition. This is particularly necessary because the experimentally obtained mode shape is distorted with noise. Hence the effectiveness of the method with noisy mode shape as input can be investigated.

Experimental modal analysis

For experimentation, a steel beam with rectangular cross section of dimension 700mm x 30mm x 20 mm is considered. The schematic diagram showing the experimental setup is shown in figure 25. The beam is supported by a thin nylon rope with flexible springs to simulate free-free boundary conditions. In order to acquire fundamental mode shape accurately the beam is supported at the nodal points of first mode shape.

A miniature accelerometer (B&K 4344) used to measure the response is firmly fixed near the middle of the beam with a bee wax. The beam is excited by using impact hammer and the resulting data has been acquired by Dynamic Signal Analyzer (ALIGENT-35670A). The acquired signal has been averaged twice in frequency domain. Acquired frequency response functions at different locations from Dynamic Signal Analyzer are given as input to modal analysis software (LMS CADA PC MODAL) to get natural frequencies and mode shape.

The vibration data is acquired at 31 discrete points with a spatial distance of 25.4 mm as shown in figure 26. The damage is artificially introduced by a symmetric wide slot in 13th element (at 304 mm from left end) of the beam as shown in Figure 26, the width (w) of which is 25.4 mm. Experimental mode shapes are measured for three different cases of damage with damage c/h =0.1, 0.15 and 0.2.

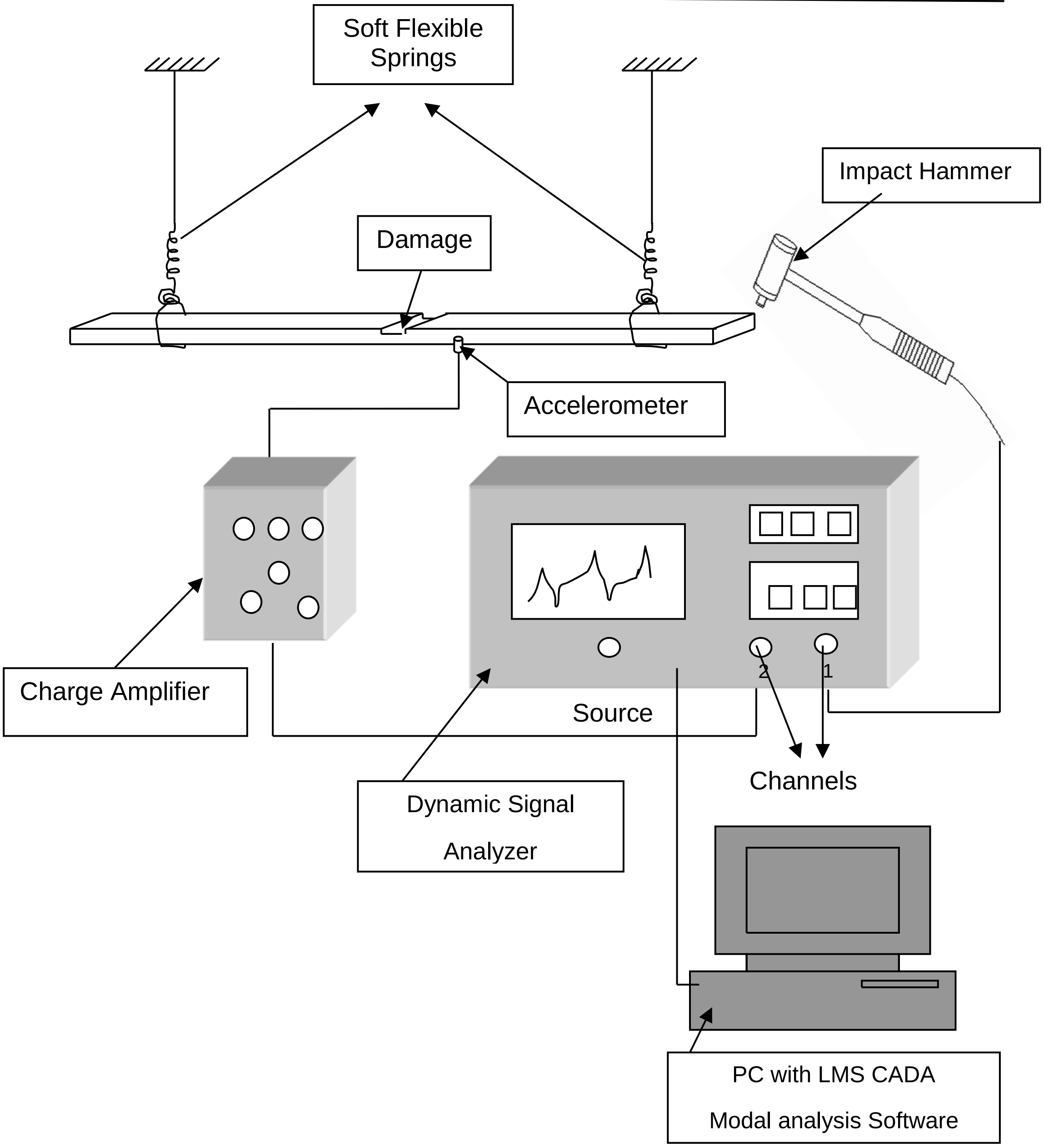


Figure 25. Schematic diagram of experimental set up

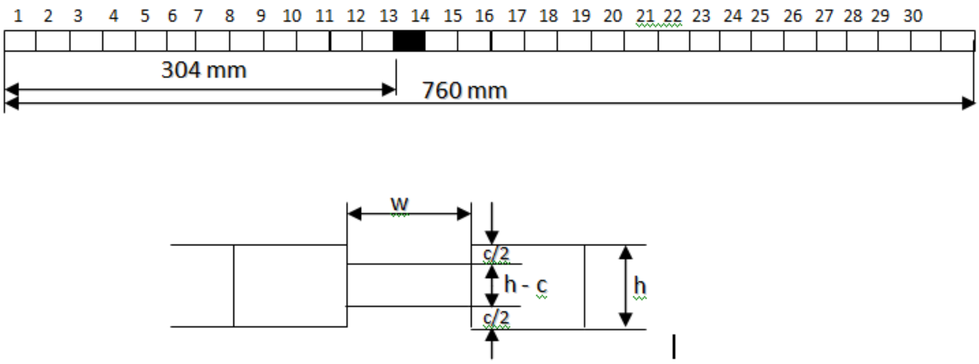


Figure 26. Beam dimension and damage geometry used in experiment

Results and Discussions

First the undamaged beam is considered and the experimental values of natural frequencies are compared to those of numerically results obtained by using the same dimension, material property and boundary condition. Table 2 shows the first four natural frequencies for undamaged beam which shows acceptable differences between the numerical and experimental results.

Table 7. First four natural frequencies of undamaged beam

Mode No	Natural Frequencies (Hz)	
	FEM	Experimental
1	180.88	181.70
2	498.61	498.48
3	977.49	970.02
4	1615.9	1592

Table 7 and figure 27 shows the first four natural frequencies and mode shapes respectively for beam with damage c/h of 0.1 obtained as output from LMS CADA modal analysis software.

Table 8. Comparison of experimentally obtained first four natural frequencies for undamaged and damaged beam

Mode No	Experimental Results	
	Undamaged	damaged, c/h=0.1
1	181.70	179.079
2	498.48	496.201
3	970.02	968.010
4	1592	1579

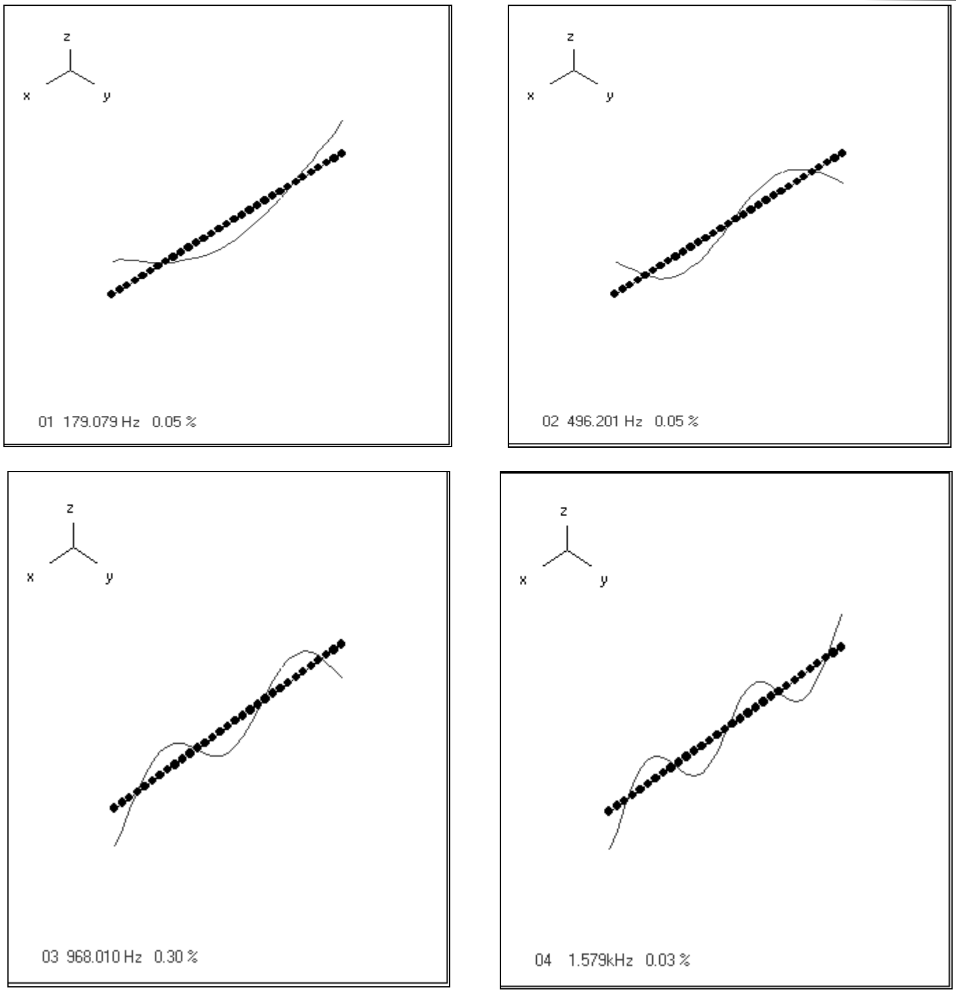


Figure 27. First four mode shapes obtained from LMS CADA modal analysis software

The fundamental mode shape as shown in Figure 28 (a) has 301 spatial sampling points one at each discrete points. Because of sparse sampling, the wavelet transform if implemented directly would detect many points of sampled data as singularities. Therefore, to smooth the transition from one point to another, a cubic spline interpolation has been used to obtain 301 equally spaced points along the length. This mode shape with increased spatial sampling points is wavelet transformed and the 3-D plot of wavelet coefficients is shown in Figure 28 (b). It is found from Figure 28 (b) that, there are high wavelet coefficients at the damaged element (13^{th} element) indicating damage which cannot be observed from Figure 28 (a) that is variation in curve. But there are many points of high wavelet coefficients all along the length giving false indication of damages. This indicates that the measured mode shape signal does not contain the perturbation in curvature caused due to damage, because of which wavelet transform method failed to detect damage correctly.

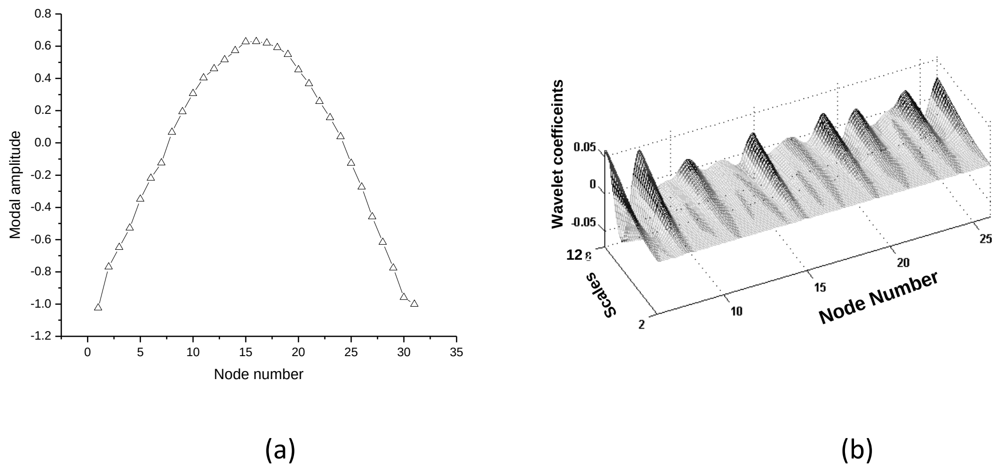


Figure 28. Damage identification with damage c/h=0.1 at 13th element (a) Fundamental mode shape from damaged beam (c/h=0.1) (b) 3-D wavelet plot

Figure 29 (a) shows the experimentally obtained fundamental mode shape for c/h of 0.15 and corresponding wavelet plot is shown in Figure 29 (b). Even though there are many points of high wavelet coefficients other than damaged point, there is high relatively coefficients at the damage element as indicated in Figure 29 (b). To be certain about the presence of damage it is required to observe the decay behavior of wavelet maxima for decreasing scales. The linear variation of wavelet maxima with scales, both in logarithmic axes, is typical for damage. Hence, it is possible to discriminate damage location from other points of noise as shown in Figure 29 (a) and 29 (b).

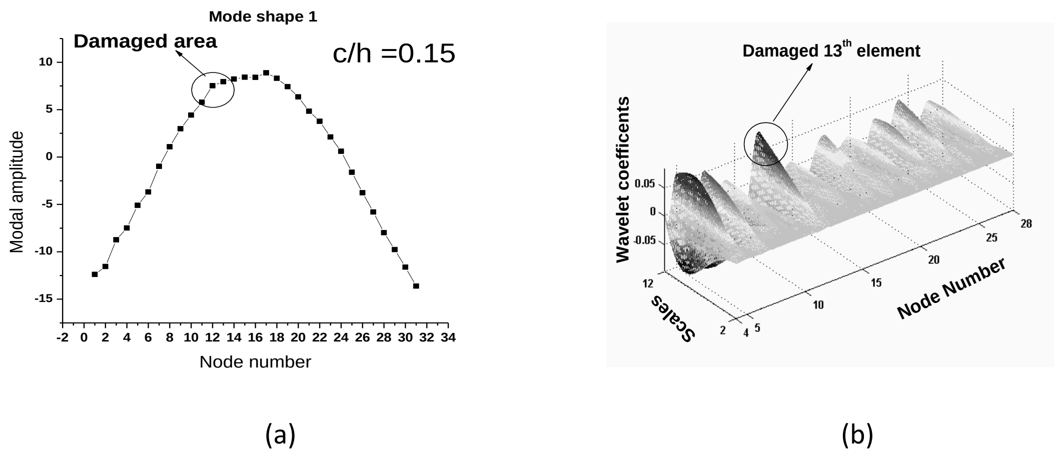


Figure 29. Damage identification with damage c/h=0.15 at 13th element (a) Experimental mode shape (b) 3-D Wavelet plot

It is found that the method is able to correctly locate damage in case of c/h of 0.2 and 0.15 for damage at single element number 13. This method failed to identify damage in case of c/h=0.1 because the mode shape measured did not contain information of damage in terms of changes in curvature at the damage location. Hence the wavelet based damage identification method strongly depends on the measurement methods used to acquire spatial data, the accuracy and the measurement noise. This method is particularly suitable, when the vibration data is obtained from laser vibrometer or optic fiber sensor (non-contact type) which provides data with high accuracy and high spatial density.

The three dimensional wavelets plot has the potential to detect, locate and quantify single as well as multiple damages and also has the capability of pin pointing exact damage location. Some of the important observations drawn based on wavelet transform applied to damage identification in beam structure are given below

1. It is observed that the methods of using change in damaged mode shape with respect to undamaged, as input to wavelet are able to identify single and multiple location (one/two elements in 2000 elements) damage clearly without the use of undamaged (baseline) data.
2. Detailed study showed that the localization and quantification is strongly dependent on following factors: Input used- mode shape, modal strain energy vibration data and Wavelet used and Scales selected
3. The method performed equally in terms of identifying smaller damage than c/h=0.2, when using the damaged mode shape and the difference data as input to wavelet transform.
4. Method based on modal strain energy as input to wavelet transform is more sensitive than using displacement mode shape and is able to locate damage with severity value as small as 0.05 (one element in 2000 elements).
5. Gaussian wavelet with four vanishing moments with scale range of 4 to 32 is found suitable for damage identification using all the different spatial input and for all damage cases.
6. It is observed that the selection of mode shape used (i.e, first, second etc.) depends on the location of damage. It is very difficult to judge which mode is best as the damage location is not known beforehand. But it is concluded that it is sufficient if first few modes are used.

VIII. Damage Detection in Composite Wind Turbine Blade Spar Model by using Spatial Signal Processing

In this section, method of damage identification in structures based on continuous wavelet transform is presented for Composite Wind Turbine Blade Spar model. A three dimensional plot of wavelet coefficients is plotted in scale-translation plane provide necessary detection and localization of structural damage by showing high wavelet coefficients at the damage location. Damage is defined as the reduction in real constants by reducing the layer thickness, numerically simulated by reducing the stiffness of the assumed element. The proposed method is numerically modelled using finite element Composite Wind Turbine Blade Spar model. The results of analysis indicate that the proposed continuous wavelet transform based damage identification method effectively identify single and multiple damage using only the fundamental mode shape. Hence, it is observed that proposed method has the potential to identify damage in structures.

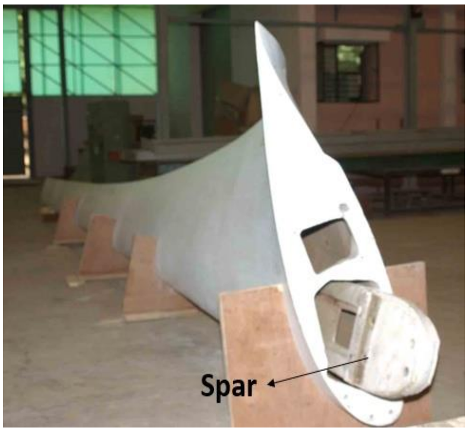
Introduction

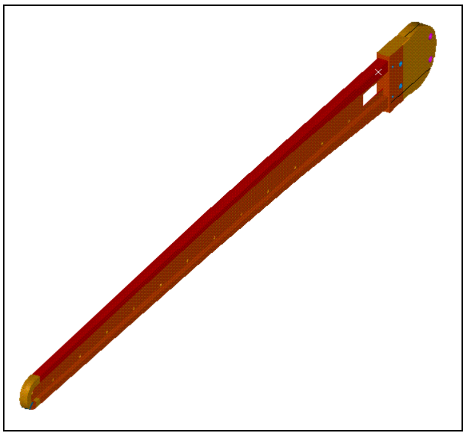
Wind energy is the fastest growing renewable energy worldwide [36] Wind turbines are primerily mechanical devices which produce electrical power [37]. The rotor features blades which capture energy by producing torque from the wind and transferring their power to the hub. Wind turbine blades are made of polymer composite material [38,39]. The turbine rotors are subject to fatigue which leads to deformation of the blades over the course of operation. Common deformations that occur include cracks surface damage structural discontinuity and delamination in composite blades [40, 41]. Non uniform accumulation of ice dirt and moisture manufacturing defects such as imbalance and aerodynamic asymmetry are factors that induce deformations causing the degradation of blades [42, 43]. Monitoring the structural health and condition of wind turbine blades therefore becomes a necessity to help improve reliability

From the extensive studies of damage analysis on wind turbine blade spar it is clear that only few researchers are contributed for small damage identification such as internal damage or delamination. This paper, presents novel method for damage identification in stiffened spar based on wavelet analysis for effective identification of internal damage or delamination in the spar by numerical modal analysis with continuous wavelet transform. The sensitivity of spatial input namely displacement mode shape to damage identification is found to be markedly improved.

Numerical simulation of wind turbine blade spar

Spar is a member of wind turbine blade which is used to couple the hollow blade shell to the rotating hub of the turbine as like in Figure 30(a). It is made-up of Glass Fibers Reinforced with epoxy along the length of the spar. This member is the one which takes up all the load and pressure which is acting on the blade shell.[44, 45]

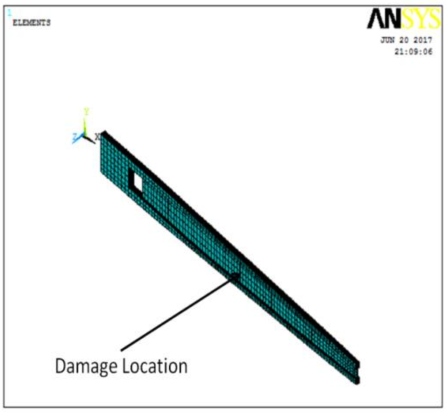




(a) (b)

Figure 30. (a). Real time wind turbine blade spar assembly. (b). CAD model of blade spar.

The spar is made using glass fiber epoxy composite. The cross section of the beam is similar to the I-section. The type of fiber used for the modelling is bi-directional one. The fibers are laid out along the length of the spar. The spar has tapering cross-section along the length. The spar in Figure 30(b) is modelled in solid works a 3D modelling software and it is extracted to Ansys with the help of IGES translator and analysed further for the results. The spar has two sections, rim and web sections. All rim and web sections are made up uni-directional glass fibers. The web section consists of 10 layers of fibers of each 0.6 mm thickness and leads to an overall thickness of 6.5 mm and has a lay-up sequence of 0/90 degree along the spar length. The rim section consists of 68 layers of fibers and each having 0.1 mm thick, the lay-up sequence will be 0^0 along the length of the spar as in Figure 30.a and the boundary conditions for spar shown in figure 30.b.



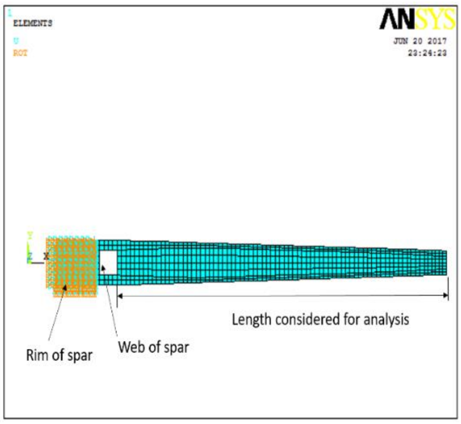


Figure 31. (a) Finite Element Model and Damage location. (b). Boundary condition considered for analysis

In the present work, the models of the angle-ply symmetric layered composite plates with various fiber lamination angles 0/90 were analyzed. The model has been made up with 10 equals the bidirectional composite lamina from the materials: matrix epoxy resin V913 and fibers E−Glass. The values of the lamina engineering constants are given in Table 9. Thicknesses of all laminas are 0.3175 mm.

Table 9. Values of the analysed composite laminate spar

E_1 (GPa)	E_2 (GPa)	E_3 (GPa)	γ_1	γ_2	γ_3	G_1 (GPa)	G_2 (GPa)	G_3 (GPa)
53.78	17.93	17.93	0.25	0.25	0.34	8.96	3.45	8.96

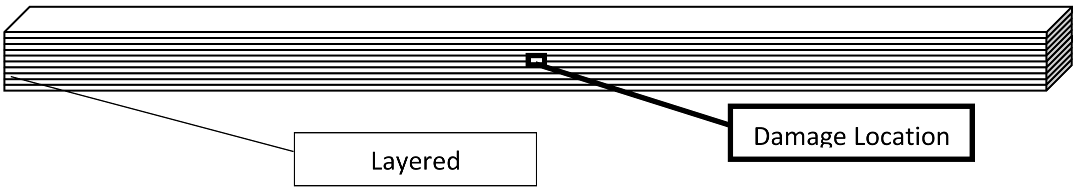


Figure 32. Damage scenario for case 4

The different cases from case 1 to case 6 considered for the present work are shown in table 10. In this work delamination was assumed by reducing stiffness of element from the thickness or reduction of real constants of considered layer shown in figure 31. For case one 90% damage was chosen taking the thickness of layers 1,2,3,4,5,6,7,8,9 was made zero for the element 141 among 300 total elements. Similarly for other cases.

Table 10. Different damage cases with layer number for Spar Model

Damage case (% reduction in E)			Layer Number	Layer Thickness (mm)
Undamaged			1,2,3,4,5,6,7,8,9,10	0.3175
Single Element(141) Damage	Case 1	90	1,2,3,4,5,6,7,8,9	0
	Case 2	60	3,4,5,6,7,8	0
	Case 3	40	4,5,6,7	0
	Case 4	20	5,6	0
	Case 5	10	5	0
	Case 6	5	5	0.15875
Two Element (141,220) Damage	Case 7	60	3,4,5,6,7,8	0

The present wavelet based damage identification procedure as follows. The input to the continuous wavelet transform is the spatial signal which can be displacement mode shape. The spatial signal is convolved with mother wavelet (e.g., Gaussian Wavelets) for wavelet scales to get a matrix of wavelet coefficients. The number of rows and column of the coefficient matrix are respectively equal to the size of spatial signal and the number of wavelet scales. Damage can be detected and located by plotting a 3-D graph of wavelet coefficients in scale-translation (Node/element number or length of beam) plane. Any point of high wavelet coefficients on the translation axis, indicate damage and the position of the same helps in locating the damage. The same procedure can be repeated for different damage severity shown in table 30. The Spatial signal (fundamental mode shapes/ modal strain energy) from damaged beam is wavelet transformed using Wavelet toolbox available in MATLAB 2012. After some trials it is found that scales of 0.01 provided better results. The mother wavelet selected is Gaussian wavelet with two vanishing moments. The resulting wavelet coefficients are used in damage identification. First three natural frequencies for undamaged and all damage cases for Spar Model shown in Table 31, which shows orders decrease in frequencies with respect to increase in damage. The Fundamental mode shape and deformed mode shape Damage case 2 is shown in figure 33.

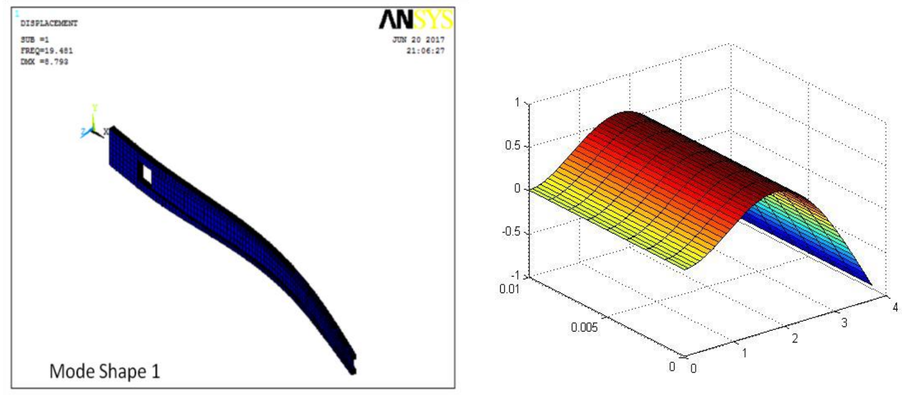


Figure 33. a. Damage case 2 Fundamental deformed mode shape b. Damage case 2 Fundamental mode shape

Table 11. First three natural frequencies for undamaged and all damage cases for Spar Model

Damage case (% reduction in E)			**Natural Frequencies (Hz)**		
			Mode 1	Mode 2	Mode 3
Undamaged			1.0221	2.7752	4.0431
Single Element Damage	Case 1	90	1.0198	2.7748	4.0356
	Case 2	60	1.0198	2.7748	4.0356
	Case 3	40	1.0201	2.7749	4.0370
	Case 4	20	1.0209	2.7750	4.0395
	Case 5	10	1.0214	2.77501	4.0412
	Case 6	5	1.0218	2.7752	4.0421
Two Element (141,220) Damage	Case 7	60	1.0180	2.7654	4.0344

Results and Discussion

In this section results obtained for the different cases from case 1 and case 2 considered for the present work are shown from Figure 33 to Figure 36.

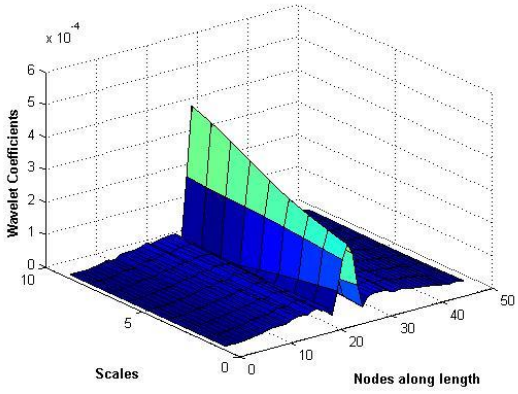


Figure 34. Three dimensional plot of Wavelet coefficients for Case 1

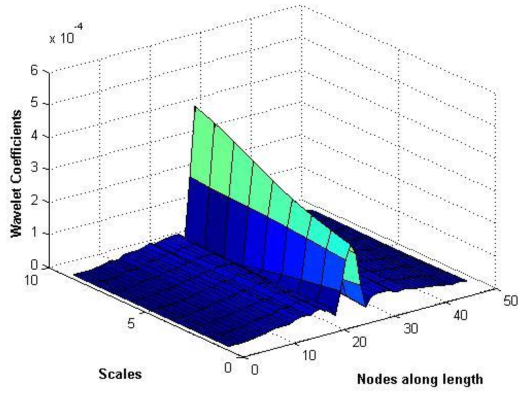


Figure 35. Three dimensional plot of Wavelet coefficients for Case 2

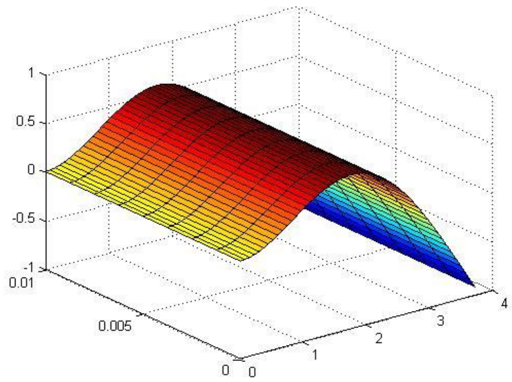


Figure 36. Damage case 7 Fundamental mode shape

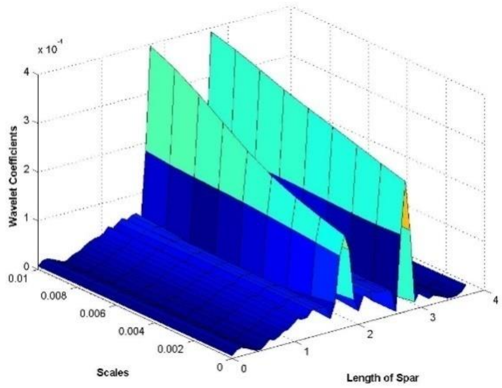


Figure 37. Three dimensional plot of Wavelet coefficients for Case 7

In order to detect the damage position, the mode shape is wavelet transformed using complex Gaussian wavelet with 2 vanishing moment with scale 0.01. Figure 34 to figure 37 shows three dimensional wavelet coefficients plot for different cases of delamination as shown in Table 11. It can be observed that there is a small peak region of high wavelet coefficients with bright area which indicates the existence of damage. So, it can be concluded that as the damage level decreases from 90% damage to 5% damage, the maximum value of wavelet coefficients also decreases at the damage location respectively.

In order to test the feasibility of applying proposed wavelet based damage identification method to numerical simulated data (mode shape), modal analysis is carried out on a stiffened wind blade spar. Hence the effectiveness of the method with mode shape as input is investigated. Three dimensional plots were clearly able to locate single and multiple damage by decrease in amplitude coefficients at the damage location for different damage configurations.

Conclusions

The following conclusions can be drawn from results and discussions of the research work

Conclusion from Section V

- According to the results, the proposed approach not only successfully located the damage for single cases but also for multiple damage scenarios. It is shown that Damage Index (DI) calculated using RMS values of PSD can be effectively used for quantifying damage. It clearly showed that procedure suitable for real application like bridge structures where, in most cases, structures may contain several defects at the same time.

Conclusions from Section VI

- The experimental method represent a non-destructive way used to predict the dynamical behaviour of PMC, in order to design panels and other similar structure used in different application such as automotive and aerospace industries.
- The modal assurance criterion can only indicate consistency of MAC calculated from different modal frequency. Inconsistency of MAC calculated from different modal frequency is observed due to presence of damage

Conclusions from Section VII

- The method has inherent advantage of discriminating the actual damage from other points by examining the variation of wavelet maxima with scales. Thus this method is able to identify damage in presence of noise in measurements.
- The proposed method can be used in real time detection of damage when suitable measuring techniques which are able to pick up the perturbations caused by presence of damage are utilized to obtain mode shape and modal

strain energy. The application of laser vibrometer would enhance the efficiency of the method by providing measurement with high spatial density and accuracy.

Conclusion from Section VIII

- Three dimensional plots were clearly able to locate single and multiple damage by decrease in amplitude coefficients at the damage location for different damage configurations. Through plots conclusions are drawn that this wavelet based damage identification method strongly depends on the measurement methods used to acquire spatial data, the accuracy and the measurement of mode shape displacement.

References

1. Doebling S W., and Farrar C R, (1996) Damage identification and health monitoring of structural and mechanical Systems from changes in their vibration characteristics: A literature review, *Research Rep. No. LA-13070-MS,* ESA-EA, Los Alamos National Laboratory, N.M.

2. Hoon Sohn and Charles R Farrar (2001) Damage diagnosis using time series analysis of vibration signals. Engineering Analysis Group (ESA-EA), M/S P946 Los Alamos National Laboratory, Los Alamos, NM 87545, USA, 446–451.

3. Ren, W.X. and De Roeck G, (2002) Structural damage identification using modal data I: Simulation verification. ASCE Journal of Structural Engineering, 128(1), 87-95.

4. Rytter, A. (1993) Vibration Based Inspection of Civil Engineering Structures. Ph.D Dissertation, Department of Building Technology and Structural Engineering, Aalborg University, Denmark

5. Stubbs, N., and Osegueda, R, (1990) Global non-destructive damage evaluation in solids. Modal Analysis: The International Journal of Analytical and Experimental Modal Analysis, 67-79.

6. Salawu, O.S., and Williams, C, (1993) Structural Damage Detection Using Experimental Modal Analysis–A Comparison of Some Methods. Proc. of 11th International Modal Analysis Conference, 254–260

7. Ren, W.X. and De Roeck G, (2002) Structural damage identification using modal data. I: Simulation verification. ASCE Journal of Structural Engineering, 128(1), 87-95

8. Pandey, A.K., Biswas, M., and Samman, M.M, (1991) Damage detection from changes in curvature mode shape. Journal of sound and vibration 145 (2), 321-332.

9. Salawu, O. S. and Williams C, (1994), "Damage Location Using Mode Shapes," In proc. Of 12th International Modal Analysis Conference, 933 – 939.

10. Chance, J., Tomlinson, G. R., and Worden, K, (1994) A Simplified Approach to the Numerical and Experimental Modeling of the Dynamics of a Cracked Beam. Proc. Of 12th International Modal Analysis Conference, 778–785.

11. Liew, K.M. and Wang, Q, (1998) Application of wavelet theory for crack identification in structures ASCE Journal of Engineering Mechanics, 124 (2): 152–157.

12. Sampaio, R. P., Maia, N. M. and Silva, J. M, (1999) Damage detection using the frequency-response-function curvature method." Journal of Sound and Vibration, 226(5), 1029-1042.

13. Quek, S., Wang, W., Zhang, L., and Ang, K, (2001) Sensitivity analysis of crack detection in beams using wavelet technique. Journal of Mechanical Sciences 43, 2899-2910.

14. Kim, J., Ryu, Y., Cho, H. and Stubbs, N, (2003) Damage identification in beam type structures: frequency-based method vs. mode-shape-based method. Engineering Structures, 25(1): 57-67.

15. Ovanesova, A. and Suarez, L. E, (2004) Applications of wavelet transforms to damage detection in frame structures. Engineering Structures, 26(1): 39-49.

16. Loutridis, S. and Douka, E, and Trochidis, A, (2004) Crack identification in double-cracked beams using wavelet analysis, Journal of Sound and Vibration 277, 1025-1039.

17. Catbas, F. N, M. Gul and J. L. Burkett, (2008) Damage assessment using flexibility and flexibility-based curvature for structural health monitoring, Smart Materials and Structures. 17-015024 (12pp).

18. Edwin Reynders, Guido De Roeck (2010) A local flexibility method for vibration-based damage localization and quantification, Journal of Sound and Vibration 329, 2367–2383.

19. Vimal Mohan, S. Parivallal, K. Kesavan, B. Arunsundaram, A. K. Farvaze Ahmed and K. Ravisankar (2014) Studies on Damage Detection Using Frequency Change Correlation Approach for Health Assessment, Procedia Engineering 86, 503 – 510.

20. Andrzej Katunin, (2015), Nondestructive Damage Assessment of Composite Structures Based on Wavelet Analysis of Modal Curvatures: State-of-the-Art Review and Description of Wavelet-Based Damage Assessment Benchmark, Hindawi Publishing Corporation, Shock and Vibration, Volume 2015, Article ID 735219, 1-19

21. T.-T. - H. Le, N.Point, P.Argoul, G.Cumunel (2016) Structural changes assessment in axial stressed beams through frequencies variation, International Journal of Mechanical Sciences 110 ,41–52.

22. Naresh Jaiswal and Deepak Pande, (2016) Wavelet Transform of Modal Data of Beam in Damage Detection Exercise, Indian Journal of Science and Technology, Vol 9(26), 2-6

23. Burcu Gunes, (2013) Structural health monitoring and damage assessment: A critical review of approaches and methods, International journal of physical science, Vol. 8(34), 1694-1702,

24. Edward, S.S., Powsiri, K., Udaya, B. H., and Gangaroa, V.S, (2002) Non-Baseline Detection of Small Damages from Changes in Strain energy Mode Shapes. Nondestructive Testing and Evaluation, 18(3-4), 91-107.

25. K. Oruganti, (2009) Vibration-Based Analysis Of Damage in Composites, Institute of Materials Engineering Australasia Ltd, Materials Forum Volume 33, 496-503

26. S. Liberatore, G.P. Carman, (2004) Power spectral density analysis fordamage identification and location, Journal of Sound and Vibration 274 761 776

27. Hee-Chang Eun, Dong-Ho Cho1, Young-Jun Ahn1 and Seung-Guk Lee1, (2015) Damage Identification of Truss Structure Using Power Spectral Density Estimation, Advanced Science and Technology Letters, (Architecture and Civil Engineering), Vol.100 pp.61-66

28. N.K Naik , R.Ramasimha, (2001) Estimation of compressive strength of delaminated composite, Composite Structures, Volume 52, Issue 2, , Pages 199-204

29. Prof. Pratibha M Karandikar, Mr.VaishnavVivek, Mr.Dabhade Ganesh, (2016) Experimental Investigation of Crack detection of cantilever beam –FFT Analyser, Pravara rural College of Engineering , Mechanical Engineering Department,Loni University of Pune, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 13, Issue 6, PP 12-17 www.iosrjournals.*org*

30. https://dewesoft.com/products/daq-systems/dewe-43/tech-specs

31. https://datasheets.globalspec.com/ds/225/NationalInstruments/54B6209C-8286-4F69-ACD6-39DC01CAED5B

32. MiroslavPastora, Michal Bindaa, Tomas Hararika, (2012) Modal Assurance Criterion, a Technical University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice, Slovak Republic Procedia Engineering 48 543 – 548

33. Daubechies, I, (1992) Ten Lectures on Wavelets. SIAM, Philadelphia

34. D. Mallikarjuna Reddy et.al.(2012) Damage Detection and Identification in Structures by Spatial Wavelet Based Approach, International Journal of Applied Science and Engineering, 1: 69-87

35. Hong, J.C., Kim, Y. Y., Lee, H.C., and Lee, Y.W, (2002) Damage detection using the Lipschitz exponent estimated by the wavelet transform; application to vibration modes of a beam. International Journal of solids and Structures 39, 1803-1816.

36. MSc CREST Flexible and Distance Learning Series, (2009), The Wind Turbine, in MSc in Renewable Energy Systems Technology Study Notes for Wind 1 2011/12, Loughborough, ,pp. 2–9.

37. D. Wroblewski, (2008) “Wind Turbines,” *Boston University College of Engineering*, Online:http://people.bu.edu/dew11/turbinetypes.htmlhttp://people.bu.edu/dew11/turbinetypes.html

38. K. K. Borum, M. McGugan, and P. Brøndsted, (2006), Condition monitoring of wind turbine blades, in 27th Risø International Symposium on Materials Science: Polymer Composite Materials for Wind Power Turbines, pp. 139–145.

39. J. G. McGowan, R. W. Hyers, K. L. Sullivan, J. F. Manwell, S. V. Nair, B. McNiff, and B. C. Syrett, (2007), A review of materials degradation in utility scale wind turbines, Energy Mater.Mater. Sci. Eng. Energy Syst., vol. 2, no. 1, pp. 41–64.

40. B. Lu, Y. Li, X. Wu, and Z. Yang, (2009), A review of recent advances in wind turbine condition monitoring and fault diagnosis, IEEE Power Electron. Mach. Wind Appl., pp. 1–7.

41. Risø DTU (2010) (National Laboratory for sustainable energy), “Failure modes,”. [Online].Available:http://www.risoe.dtu.dk/research/sustainable_energy/wind_energy/projects/vea_structural_blade_design/failure_modes.aspx?sc_lang=en.

42. A. Ghoshal, M. J. Sundaresan, M. J. Schulz, and P. F. Pai, (2000), Structural health monitoring techniques for wind turbine blades, J. Wind Eng. Ind. Aerodyn., vol. 85, no. 3, pp. 309–324.

43. F. B. Sørensen, L. Lading, P. Sendrup, M. McGugan, P. C. Debel, J. D. O. Kristensen, G. Larsen, A. M. Hansen, J. Rheinlander, J. Rusborg, and D. J. Vestergaard, (2002), Fundamentals for remote structural health monitoring of wind turbine blades - a preproject Risø-R-1336(EN), Riso-R-1336(EN) Report, Denmark,.

44. O. O. Esu, J. A. Flint, and S. J. Watson, (2015), Static Calibration of Microelectromechanical Systems (MEMS) Accelerometers for In-Situ Wind Turbine Blade Condition Monitoring, in Special Topics in Structural Dynamics, Volume 6: Proceedings of the 33rd IMAC, A Conference and Exposition on Structural Dynamics, 2015, R. Allemang, Ed. Springer International Publishing, pp. 91–98.

45. O. O. Esu, S. D. Lloyd, J. A. Flint, and S. J. Watson, (2016), Feasibility of a Fully Autonomous Wireless Monitoring System for a Wind Turbine Blade, in Elsevier Renewable Energy, Volume 97, pp. 89-96.

List of Publications:

International Journals Published:

1. **Shivasharanayya Swamy**, D. Mallikarjuna Reddy, S. Swarnamani, "Application of the Power Spectral Density for Damage Identification and Location in Beam Structures"International Journal of Engineering Research & Technology (IJERT), Volume 3, Issue 17,2015, pp 54-59
2. **Shivasharanayya Swamy**, D Mallikarjuna Reddy, Jaya Prakash G, Damage detection and identification in beam structure using modal data and wavelets, World Journal of Modelling and Simulation, ISSN 1 746-7233, England, UK Vol. 13 (2017) No. 1, pp. 52-65 (Scopus Indexed Journal)
3. **Shivasharanayya Swamy**, D Mallikarjuna Reddy, Delamination Detection in Composite Wind Turbine Blade Spar Model By Using Spatial Signal Processing, International Journal of Mechanical Engineering and Technology (IJMET), Volume 8, Issue 8, August 2017 (Scopus Indexed Journal)
4. **Shivasharanayya Swamy**, D. Mallikarjuna Reddy,"Application of MAC in Delamination Identification for PMC", paper presented ICRRETMCE-2018, which accepted for publication in International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) ISSN(P): 2249-6890; ISSN(E): 2249-8001. (Scopus Indexed Journal)

International Conference Papers Published:

1. **Shivasharanayya Swamy**, D. Mallikarjuna Reddy, S. Swarnamani, "Application of the Power Spectral Density for Damage Identification and Location in Beam Structures" ERAME 2015, **REVA ITM**, 27th and 28th March 2015.
2. **Shivasharanayya Swamy**, D Mallikarjuna Reddy, "Damage Identification in Beam Structures Using Modal Data and Signal Processing ", ICOVP 2015, IIT Guwahati December 14-17, 2015.
3. **Shivasharanayya Swamy**, D. Mallikarjuna Reddy, Crack Identification of a composite beam using wavelet algorithm International NAFEMS conference at Indian Institute of Science (**IISc-Bangalore**), (NAFEMS 3D), Bangalore, August 29-31 2016.

RAJAT S NAVARATHNA
(1DA18ME091)

AXISCADES

ACETL/22-23/IL/ENERGY/BDC/102

May 11, 2022

Mr/Ms. RAJAT S NAVARATHNA
Dr Ambedkar Institute of Technology, Bangalore, India.

Dear RAJAT S NAVARATHNA,

Subject: Internship Letter

With reference to your application, we would like to congratulate you on being selected for internship with AXISCADES Technologies Limited, Bangalore, as per the following terms and conditions

- Your Internship would be for the period of 3 Months with effect from Thursday, 19th May 22
- Department / Function : ENERGY, Bangalore
- Reporting to / Mentor : Mr. Gairik Ghosh
- During this period you will be paid a stipend of **INR 8,000/- (Rupees Eight Thousand only)**
- Your Offer of Full time Employment will follow soon at the end of your Internship, depending on your performance report based on review of your performance by your reporting manager
- Your internship will focus primarily on learning and developing new skills and gaining a deeper understanding of functional concepts through hands-on application / On-the-Job Learning
- The project details and technical platform will be shared with you in due course of your internship
- Either party may terminate this Internship by giving a notice of 1 week to the other side during the period of Internship.

You should report for joining at the following address on your joining date as mentioned above

AXISCADES Technologies Limited
Kirloskar Business Park, 2nd Floor, Hebbal, Bangalore - 560024

Contact Person: **Punith Kumar V**

All of us at AXISCADES Engineering Technologies Limited are excited that you will be joining our team!

Once Again, Congratulations and we look forward to working with you.

Yours sincerely,

For **AXISCADES Technologies Limited,**

Sreedhar Ellentala
Senior Vice President – Human Resource

I have read and understood the above terms and conditions and agree to faithfully accept and abide by the same.

(Signature)

Name:

Date:

PAN Number	
Aadhaar Number	
Passport Number	

SHIVAKUMAR. P. K..
1DA18ME114
9916085671

JSW

28th March, 2022

Dear Graduate Engineer Trainee,

WELCOME TO THE JSW GROUP

With reference to your application and subsequent interview you had with us, we are pleased to offer you the position of **Graduate Engineer Trainee ("GET")** in **'L08T'** grade and your subsequent appointment will be subject to the following terms and conditions:

A. Your training period shall commence from the date of your appointment i.e. 01st June 2022 and will continue for a period of one year. Your initial remuneration as a GET during training period with JSW shall be **Rs. 5.5 lakhs** per annum (**"CTC"**).

B. You shall be eligible for **Rs. 1 lakh ("Retention Bonus")** spread over 2 years, subject to such terms and condition as may be detailed under the Appointment Letter.

C. This offer is valid subject to **your successful Graduation, with a passing score of Min 60% in aggregate.**

D. The location where you shall be posted shall be communicated to you by May, 2022. You are requested to report at the assigned location a day prior to **01st June, 2022.** Your appointment shall be final subject to the following conditions of eligibility:

   a. You having secured at least 60% in your 10th and 12th standard examinations.

   b. You having completed the B. E/ B.Tech course with a First Class (aggregate 60% or equivalent or more and as per University declaration). In case you fail to clear your degree, then the offer shall stand cancelled and revoked.

   c. You having been declared medically fit by a certified medical practitioner and having provided the necessary documents to such effect. In the event of any medical abnormality, your offer will stand cancelled and revoked.

   d. You having cleared all reference checking, background verification and having submitted copies of the following documents at the time of your joining (along with the production of the original documents for verification):

      - All Educational Certificates – S.S.L.C, H.S.C, UG/PG, Additional qualifications (If any)
      - Proof of your Date of Birth
      - PAN Card or any other identity cards issued by the Government
      - 5 Passport size photographs
      - Submission of medical fitness as per the medical tests prescribed by JSW.

E. In the event of you not meeting any of the conditions of eligibility stated above, you shall not be eligible for appointment and the offer of appointment shall stand revoked and withdrawn with immediate effect. In the event of you furnishing any wrong, inaccurate information or suppressing any of the information, your appointment as well as this offer, shall be terminated and revoked with immediate effect.

1DA18ME103
S Vigneshprabhu
9148890956

28th March, 2022

Dear Graduate Engineer Trainee,

WELCOME TO THE JSW GROUP

With reference to your application and subsequent interview you had with us, we are pleased to offer you the position of **Graduate Engineer Trainee ("GET")** in **'L08T'** grade and your subsequent appointment will be subject to the following terms and conditions:

A. Your training period shall commence from the date of your appointment i.e. 01st June 2022 and will continue for a period of one year. Your initial remuneration as a GET during training period with JSW shall be **Rs. 5.5 lakhs** per annum ("CTC").

B. You shall be eligible for **Rs. 1 lakh ("Retention Bonus")** spread over 2 years, subject to such terms and condition as may be detailed under the Appointment Letter.

C. This offer is valid subject to **your successful Graduation, with a passing score of Min 60% in aggregate.**

D. The location where you shall be posted shall be communicated to you by May, 2022. You are requested to report at the assigned location a day prior to **01st June, 2022.** Your appointment shall be final subject to the following conditions of eligibility:

   a. You having secured at least 60% in your 10th and 12th standard examinations.

   b. You having completed the B. E/ B.Tech course with a First Class (aggregate 60% or equivalent or more and as per University declaration). In case you fail to clear your degree, then the offer shall stand cancelled and revoked.

   c. You having been declared medically fit by a certified medical practitioner and having provided the necessary documents to such effect. In the event of any medical abnormality, your offer will stand cancelled and revoked.

   d. You having cleared all reference checking, background verification and having submitted copies of the following documents at the time of your joining (along with the production of the original documents for verification):

      - All Educational Certificates – S.S.L.C, H.S.C, UG/PG, Additional qualifications (If any)
      - Proof of your Date of Birth
      - PAN Card or any other identity cards issued by the Government
      - 5 Passport size photographs
      - Submission of medical fitness as per the medical tests prescribed by JSW.

E. In the event of you not meeting any of the conditions of eligibility stated above, you shall not be eligible for appointment and the offer of appointment shall stand revoked and withdrawn with immediate effect. In the event of you furnishing any wrong, inaccurate information or suppressing any of the information, your appointment as well as this offer, shall be terminated and revoked with immediate effect.

Innominds

Septem

Abhishek Kulkarni
imabhi765@gmail.com
+91 7406161041

Dear Abhishek Kulkarni,

Sub: Letter of Offer

With reference to your application and subsequent discussion you had with us, we are pleased to offer you a position of '**Trainee-Software Engineer**' in our organization.

1. Your CTC (Cost to the Company) will be Rs.3,20,000/- (Rupees Three Lakh Twenty Thousand) per annum inclusive of all allowances, refer to Annexure - I.
2. Your compensation will be revised after 6 Months, subject to completion of your training and performance.
3. You are required to commit a minimum duration of 18 months of service from the dateof your joining with the organization.
4. A detailed appointment letter will be issued upon your joining with the company and upon furnishing the documents as per check list provided in the following page.
5. Your date of joining is on 3rd **September 2021** and your requested to report at10 A.M, Waverock Gachibowli.

Innominds Software SEZ India Private Limited.
BuildingNo.2.1,4thFloor,Waverock,SurveyNo.115,
TSIIC IT / ITES SEZ, Nanakramguda Village,
Serilingampally Mandal, Hyderabad – 500008

We look forward for a long-term association!!!

Thanking you,
Pallavi Garimella
Director – Human Resources

Continued.........

16ME003

Superset ID: 815573

Letter of Intent ("LOI")

Dear Adarsh Warad,

With reference to your interview conducted by us, we are pleased to inform that you have been shortlisted for the position of **Analyst and A4** with **Capgemini Technology Services India Limited.**, (hereinafter referred to as "Capgemini").

In this regard, we are proposing compensation package and benefits, the details of which are set forth in **Annexure 1** to this letter.

The final Employment Offer Letter shall be subject to your successful completion of all curricular requirements as laid down by the University/ Institute for award of the degree/ diploma and the minimum passing percentage/ grade/ rank/ class as determined by Capgemini.

The date of joining and the location of posting will be purely based on business requirements of Capgemini. Capgemini solely reserves the right to make any changes to the date of joining and the location of posting during the course of your training and employment with Capgemini.

Upon joining Capgemini,

1. You are expected to enter into an employment agreement with Capgemini which shall contain details including the scope, terms and conditions of your employment and the contractual obligation with Capgemini.
2. You will be on probation for a period of six months from your date of joining and subject to satisfactory performance your employment will be confirmed (vide written confirmation) at the end of six months.
3. During your probation you may be required to undergo classroom trainings for such duration as deemed necessary by Capgemini and your performance will be evaluated periodically during such training period

Capgemini reserves the right to decide the continuance of your further training and your employment depending on your performance in its opinion.

The terms of this Letter of Intent shall remain confidential and are not to be disclosed to any third party.

You may note that this letter should neither be construed as an offer of employment from Capgemini nor should it in any manner confirm our intent to make you an offer of employment. We may, at any time, at our discretion, revoke this Letter of Intent

16ME022

Infosys
Navigate your next

IRD/3T/1003360890/21-22

January 19, 2022

Ir. Chandan V
ODDAGANJUR VILLAGE AND POST
HINTAMANI TALUK
hikkaballapura-563125
dia

n: +91-8548801456

ear Chandan,

Welcome to Infosys!

oday, the corporate landscape is dynamic and the world ahead is full of possibilities! None of the amazing ings we do at Infosys would be possible without an equally amazing culture, the environment where ideas n flourish and where you are empowered to move forward as far as your ideas will take you.

t Infosys, we assure that your career will never stand still, we will inspire you to build what's next and we ill navigate further, together. Our journey of learnability, values and trusted relationships with our clients ntinue to be the cornerstones of our organization and these values are upheld only because of our people.

e look forward to working with you and wish you success in your career with us.

Varm regards,

ICHARD LOBO
VP and Head Human Resources - Infosys Limited

Signature Not Verified
Digitally signed by Richard Lobo
Date: 2022.01.19 16:33:23 IST
Reason: Digitally Signed
Location: Bangalore

INFOSYS LIMITED
CIN: L85110KA1981PLC013115
44, Infosys Avenue
Electronics City, Hosur Road
Bangalore 560 100, India
T 91 80 2852 0261
F 91 80 2852 0362
askus@infosys.com
www.infosys.com

[11]

wistron

Wistron Infocomm Manufacturing
(India) Private Limited
[illegible]
[illegible]
Kolar Taluk & District,
KARNATAKA – [illegible]
Telephone +91 [illegible]

To

E-Code: MI21020156
Mr. RAVI KUMAR V
Anepura village
Nidaramangala post malur
kolar, Karnataka- 563130.

Date: 08-02-2021

SUB: LETTER OF APPOINTMENT

Dear RAVI KUMAR V,

We are pleased to offer you employment in our company on the following terms and conditions, subject to your acceptance of such terms and conditions:

1) Appointment

a) Your will be designated as an **Trainee Engineer** in the **MLB TE** Department. This designation is subject to successful completion of probation period and assessment of your performance by your reporting manager at the end of the probation period.

a) You will remain in probation for 3 months.

b) The company operates on six days in a week i.e. (from Monday to Saturday). Working hours are subject to company norms. You shall be willing to work in various shifts as defined by management.

c) The date of your appointment will be the same date as joining as per the HR records.

d) At the end of your probation period, you will be appraised by your reporting authority for your performance during the probation period. On the basis of such appraisal, you may be – a) confirmed as a permanent employee in your designation; b) required to serve additional probation period for the purpose of further training and development; c) not confirmed in the position and found unsuitable for this position.

e) You will be based at BANGALORE India but the company may require you to travel to regional operations or may transfer you to other locations as determined necessary by the management.

Your will report directly to Supervisor

2) Duties and Responsibilities

Your duties and responsibilities shall include but not be limited to –

a) Functional responsibilities and roles as assigned to you from time to time by your reporting manager;

b) Customer responsibilities and roles as assigned to you from time to time by your reporting manager or the management;

National Pension Scheme

We offer all our India based employees the option to contribute towards the National Pension Scheme. This is an optional retirement benefit introduced by the Government of India for all its citizens. It enables accumulation of retirement corpus during active employment with add-on tax breaks. Please refer to the Information Sheet at Annexure - IV for more details.

Insurance

You will be eligible to participate in a Group Health Insurance Scheme. You may choose to enhance the coverage with other participatory optional health insurance plans (Platinum, Gold and Silver). You will be covered by default under the Standard Plan which provides you and your family (your spouse and two children up to the age of 22 years) with a cover of **INR 4,00,000** per annum.

You will be covered under the Group Life Insurance Scheme, managed by Infosys Welfare Trust which provides you with a total Life Insurance cover of **INR 62,00,000** of which **INR 32,00,000** is covered towards natural death, and **INR 30,00,000** towards an accidental death. All employees become members of Infosys Welfare Trust, by one-time payment of **INR 250** and fixed monthly contribution of **INR 250**.

The details of the Scheme would be available to you when you join the Company.

Notice period

During the probation period, if your performance is found to be unsatisfactory or if it does not meet the prescribed criteria, your training / employment can be terminated by the Company with one-month notice or salary thereof. On confirmation, you will be required to give three months' notice or salary thereof in case you decide to leave our services, subject to the Company's discretion. Where circumstances make it necessary, the Company will have the discretion to relieve you only at the end of the three months' notice period. Similarly, the Company can terminate your services by giving three months' notice or salary thereof.

In the event you do not successfully complete your training, or you are involved in an act that constitutes misconduct, your training/employment can be terminated by the Company with immediate effect without notice.

Background checks

The Company may, at its discretion conduct background checks prior to or after your expected joining date to validate your identity, the address provided by you, your education details and details of your prior work experience if any, and to conduct any criminal checks. You expressly consent to the Company conducting such background checks. In this connection, you are required to furnish the documents listed in "Offer Annexure for India".

If you fail to submit the necessary documents as required by the Company within the specified time period or if the Company is not satisfied, with the outcome of the background checks, the Company, in its sole discretion, reserves the right to withdraw this Offer without notice and Compensation or to take any appropriate action against you, including, but not limited to termination of your employment.

When a background check raises any concerns regarding any of the details furnished by you and the Company feels the need to further validate such facts, the Company may at its sole discretion, ask you for further information, to substantiate the details that you have earlier provided to the Company, before initiating appropriate action.

Please note that Infosys requires you to furnish a copy of your passport at the time of joining. If you are unable to do so, the Company will initiate a criminal background check.

141 (5)

BE YOURSELF, MAKE A DIFFERENCE.

accenture

10-May-2019

C3379923
UDAY JOSHI
Dr AIT Men's Hostel, Mallathalli, Bengaluru 560056

Dear **UDAY**,

Based on our recent discussions with you, we are pleased to extend you an offer to join Accenture Solutions Private Ltd (hereinafter referred to as 'the Company') in **Bengaluru**. This letter will officially confirm your annual total earning potential and terms of your employment.

Role- **Analytics Associate**
Career Level- **12**
Sublevel - **3**
Talent Segment-**Analytics**
Business Deal-**Non Contact Center**

Your annual total cash compensation will be **INR 364613** and will be structured as per the attached Annexure 1 ' Compensation Details. This will continue to be applicable until further communication on the same. Your annual total earning potential includes:

-Annual fixed compensation of **INR 315000/-**; this includes allowances and statutory benefits and will be structured in accordance with the Company's compensation guidelines. The said amount includes employer's contribution to Provident Fund, as applicable.

-Variable Bonus: You will be eligible to participate in the FY19 (September 2018 to August 2019) Individual Performance Bonus (IPB) Programme. Your indicative pay-out can range from **0%** to **15.75%** of the prorated fixed pay in the FY19, subject to the overall terms and conditions of the IPB, including but not limited to your performance achievements and the Company's performance. The Company may, at any time and in its sole and absolute discretion, amend, suspend, withdraw vary and/or modify any of the terms and conditions of the IPB programme guidelines. The IPB will be paid out subject to you being on the rolls of the Company on the date of disbursement of these payouts and will be prorated based on your tenure in Accenture India and considering the period of leave without pay during the said financial year.

Joining Bonus: You will be paid a joining bonus of INR 75000.The joining bonus is a one-time conditional payment that you will be entitled to only if you (a) join us on or before the date of joining confirmed to you by the recruiter; and (b) are employed with the Company for a period of 18 months from the date on which you join the Company. However, to facilitate your transition into Company, the joining bonus will be paid to you in advance along with the 1st month's salary. In the unlikely event, you choose to leave the Company, or if your services are terminated for any reason whatsoever, other than for redundancy, before the completion of 18 months of employment with the Company, the aforementioned joining bonus will be construed as debt due and will have to be repaid fully by you before your last working day. By signing this Agreement, you authorize the Company to set off the advance amount i.e. the joining bonus due from you against any amounts, salaries, allowance, or any other pecuniary benefit due and payable to you by the Company. However, if the advance amount exceeds the amount due and payable by the Company to you at the time of your exit, the Company shall notify you of the same, and you agree to pay the remaining balance within the notified timelines. In the event you fail to repay the balance of the joining bonus pursuant to the time frame set forth above and it is necessary to take legal action against you to collect such amount, you agree to reimburse the Company for all costs incurred by the Company to collect such amounts, including attorneys' fees and court costs.

On joining you may undergo a training program to acquire the knowledge to enable you to successfully perform to the expectations of the position for which you are being considered for employment. This offer and your employment with the Company are contingent upon you successfully completing the training program as per the satisfaction of the Company. Failing which, the Company may, in its sole discretion, elect to terminate or suspend your employment immediately.

IDA14ME130

ahindra CIE

Mahindra CIE Automotive Ltd
Foundry Division*
Gat 318, Gaon Urse
Taluka Maval, Pune 410 506. India.
www.mahindracie.com

(off)

Date:14-Dec-2018

Mr. SHRIDHAR SURYANOR
T.NO 707072

Appointment as an Apprentice /Trainee

With reference to your application, we are pleased to offer you an appointment as an Apprentice /Trainee for a period of one year with effect from **14-Dec-2018 to 13-Dec-2019.** Your training will automatically come to an end on expiry of the period of one year. The terms and conditions governing this appointment will be as follows:

1. You will be appointed as an Apprentice/Trainee " **EU2T**"as per certified standing orders applicable to the company and given an opportunity to learn various activities, tasks, jobs and assignments as deemed suitable considering your background and qualifications. The program of Training shall be entirely at the discretion of the Company.
2. You shall pay undivided attention to the training given and carry out all the instructions to the satisfaction of your trainer /s and superior/s. During the period of your apprentice training, test and interviews may be conducted to assess your learning.
3. A detailed documented communiqué as regards your responsibilities towards safety, forming part of the terms and conditions of your appointment is enclosed.
4. The training period may be extended or shortened at the discretion of the Management.
5. The continuation of this appointment is subject to your remaining physically and mentally fit. Further it is also subject to your performance in learning and implementing the lessons there from to the satisfactions of your trainer/s superiors.
6. Your appointment may be terminated at any time during the period of training as well without assigning any reasons whatsoever. Either party shall give at least 6 days notice or payment in lieu thereof in the event of termination of this arrangement.
7. The traineeship does not confer on you the status of a permanent employee and therefore, you would not be entitled to benefits, facilities and perquisites extended to permanent employees of the Company.
8. The Company is not bound to offer you employment at the end of the training period. However, in case the Company has any vacancy, it may consider candidature on applications and merits.
9. Incase this training is terminated any time for any reason whatsoever, you shall return Company's property, including your records, notes, drawings, instruments etc., used or obtained during training.
10. You shall keep confidential and prevent divulgence of any information, documents etc. of the Company which might come to your knowledge or possession during the training period and thereafter as well.
11. You shall be governed by the rules and regulations brought about by the Management from time to Time.
12. Hence forth you will be paid stipend as follows.
    a) Stipend of Rs. 9220/- P.M.
    b) HRA Rs : Rs. 461/- P.M
    c) Adhoc Allowance Rs. 500/- P.M
    d) Attendance Incentive
    If one day's absent in a month then Rs. 800/- P.M
    If two day's absent in a month then Rs. 400/- P.M
    If three day's absent in a month then Rs. 200/- P.M
    More than three days absent in a month you will not be eligible for any attendance incentive.

Total Stipend **10981P.M** Considering you will earn full attendance incentive

Mahindra CIE Automotive Ltd. (Formerly Known as Mahindra Forgings Ltd.)
CIN: L27100MH1999PLC121285
Regd. Office: Mahindra Towers, 1st Floor, Dr. G. M. Bhosale Marg, Worli, Mumbai 400 018, India
Tel : +91 22 24901441 Fax: +91 22 24915890 email: mcie.investors@mahindra.com

** The Foundry Division was known as Mahindra Hinoday Industries Ltd and same was merged into Mahindra CIE Automotive Limited.*

QUEST

BORN TO ENGINEER

IDA14ME059

OFFER OF EMPLOYMENT

QI-HR9247/18

November 20, 2018

Mr. Lokesh K,
1771,4th Cross,Prakashnagar,
Bangalore- 560021

USN:- IDA14ME059

Dear Lokesh,

Further to our discussions, we are pleased to offer you an employment on following terms and conditions:

1. Commencement and Duration

1..1 Your employment will commence with effective from **November 26, 2018**.

1..2 The Employer reserves the right to amend the term of employment should it be deemed necessary. Any such amendment shall be shared / communicated / provided by Employer to you in writing.

2. Role Details

2.1 You will be appointed as, **Trainee Engineer** this role is evaluated at **1E** in the QuEST's grading structure. In this role you shall report to **Senior Lead Engineer**.

2.2 You will be expected to work from the following QuEST Office Bangalore, However this is subject to change as necessary for this role. You may at any time be required to work at another location on a temporary or permanent basis dependent upon the requirements of the role with as much notice as reasonably possible.

3. Remuneration

3.1 You will receive an **Annual Total Gross Salary (TGS) INR 260000/- (Rupees Two lakh Sixty Thousand Only)**,taxes as applicable. Details of remuneration are as given in Annexure – I.

3.2 Employer will deduct from the total remuneration such amounts as are required to be deducted as source under the Income Tax Act or any other law for the time being in force in India.

3.3 You will be paid monthly in arrears by bank transfer to the nominated Bank Account on the last working day/banking day of each month, unless advised otherwise.

4. Benefits

4.1 *Annual Leave*: You will be eligible for Annual Leave as per the Employer's Leave Policy, the policy however can be modified time to time at Employer's discretion.

4.2 *Holidays*: You are entitled to Public Holidays applicable at India every year at the regular rate of pay. If placed at a customer site you must follow holidays observed by customer.

IDAISME429

ntact

w.linkedin.com/in/pavan-kumar-
j-85460215a (LinkedIn)

p Skills

TIA

GRAPHICS

PAVAN KUMAR M G

assistant system engineer trainee @ Tata consultancy services

Bengaluru, Karnataka, India

Experience

Tata Consultancy Services Limited
Assistant system engineer trainee
January 2019 - Present
Bengaluru Area, India

Education

Dr. Ambedkar Institute Of Technology
Bachelor of Engineering, Mechanical Engineering · (2015 - 2018)

Siddaganga Institute of Technology, Tumkur
(An Autonomous Institute Affiliated to Visvesvaraya Technological University, Recognized by AICTE & Accredited by NBA, New Delhi)
Department of Industrial Engineering & Management
Ph: Direct: +91-816-2214045, Fax: +91-816-2282994.
E-mail: gvpshankar@sit.ac.in, **Mobile:+91-98454-30739**

Ref. No.BOS/15-16/Appointment

Date: 15-07-2015

To,

Dr. T. N. Raju
Associate Professor
Dept. of Mechanical Engineering
Dr. A.I.T.,
Bengaluru

Sir/Madam,

Sub: Appointment as Member of Board of Studies - reg.

I am happy to inform you that you have been appointed as a member of Board of studies of I.E.M. department, S.I.T., for a period of TWO academic years starting from 2015-16., and it is my pleasure to invite you to participate in the board meeting, scheduled to be held on 25-07-2015, at 9.00 a.m.

I request you to accept our invitation and oblige.

Yours Sincerely

Chairman
B.O.S and B.O.E of IEM
S.I.T.-Tumkur

Invitation for Chairing a Session at ICRDME-2022

icrdme_2022@sit.ac.in
to Me
17 Jun, 3:20 pm

Dear Sir,

Greetings of the day

We at the Dept of Mechanical Engineering are organizing International Conference on Recent Trends in Mechanical Engineering (ICRDME-2022) on 24th and 25th June 2022. The conference has received excellent response with more than 250 research papers.

In this regard, I am elated to invite you to chair a session for evaluating the research carried out by the delegates and provide your valuable feedback for young researchers on 6/24/2022 at 1:30 - 3:00 PM Indian Standard Time.

Kindly drop me a line to confirm your acceptance

Dr. H S Shivashankar

Convener

ICRDME - 2022

Siddaganga Institute of Technology

Ph-9901245082

1:55 PM

Thank you for Chairing Sessions at ICRDME-2022

icrdme_2022@sit.ac.in
to Me
14 Sep, 12:20 pm

Dear Dr SATHISH S

With a highest of gratitude, I am writing this mail for the support extended by you towards successfully organizing INCRDME-2022.

I hereby acknowledge your meticulous review and valuable feedback during the conference sessions.

Further, I am thankful for taking time out of your packed schedule in chairing these sessions.

I hope you found the sessions were organised well, kindly drop feedback, regarding the same.

I hope you will continue your support all future activities of SIT, Tumkur. Kindly download the certificate for chairing the session from the below link.

https://drive.google.com/uc?id=1SDW3dwz9Gn2sMd4e6PCx4iVCzZ4OwAal&export=download

Once again, thank you for supporting ICRDME-2022.

Kindly

Dr. H S Shivashankar

Delete Archive Move Forward More