A STUDY ON DYNAMIC BEHAVIOR OF COMPOSITE BEAMS WITH VARIABLE CROSS SECTION

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***ABSTRACT:** A simple finite element formulation, accounting for variation of the material properties through the beam thickness and the shift in the physically neutral surface, is derived and employed in the study. The exact variation of the cross-sectional profile is employed in evaluation of the element stiffness and mass matrices. The dynamic response of the beam is computed with the aid of the implicit Newmark method. The numerical results show that the derived finite element formulation is capable to assess accurately the dynamic characteristics of the beam by using just several elements. The effect of the moving speed, material inhomogeneity and section profile on the dynamic behavior of the beams is investigated. The present study deals with experimental investigation on free vibration of laminated composite beam and compared with the numerical predictions using finite element method (FEM) in ANSYS environment. A program is also developed in MATLAB environment to study effects of different parameters. The scope of the present work is to investigate and understand the effect of different parameters including cross sectional shape on modal parameters like modal frequency, mode shapes.*

***Keyword:** ANSYS, FEM, Dynamic response, Beam, Stiffness*

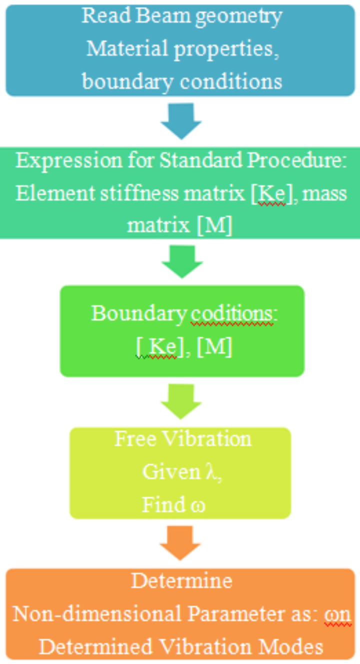
I. INTRODUCTION

In this research, Finite element models for different boundary conditions are constructed using the commercial finite element software package ANSYS to support and verify the dynamic measurements. Initial FRP (Fibre Reinforced Polymer) composite channel section and box section beams were created. Furthermore, the FEM results of the beams are compared to the experimental solution for understanding of the relationship between the FE results. The natural frequencies and mode shapes of the composite beam are obtained after performing modal analysis which the author contribution to this area of research.

II. PURPOSE AND OBJECTIVES OF STUDY

The main objective of this thesis is to study and compare the numerical and experimental result of free vibration analysis of composite Fibre Reinforced Polymer (FRP) beam. The present investigation mainly focuses on the study of vibration of industry driven woven fiber glass/epoxy composite beams. A first order shear deformation theory based on finite element model is developed for studying the free vibration, The influence of shape of the beams, boundary conditions, number of layers, fiber orientations and aspect ratio on the free vibration of composite beams are investigated experimentally also examined numerically.

Flow Chart of Program



III. EXPERIMENTAL PROGRAMME

This chapter deals with the details of the experimental works conducted on the static analysis and free vibration of industry driven woven roving composite beams. Therefore composite beams are fabricated for the aforementioned experimental work and the material properties are found out by tensile test as per ASTM D3039/ D3039M (2008) guidelines to characterize the composite beams. The experimental results are compared with the analytical or numerical predictions. The experimental work performed is categorized in three sections as follows:

- Static analysis
- Determination of material constants
- Vibration study
-

Experimental programme for vibration study Fabrication of specimens

The fabrication procedure for preparation of the composite beams of channel section and box section in case of vibration study was bit difficult. Artificial metal moulds were fabricated to maintain the shape. Specimens are fabricated by hand layup technique and cured under room temperature.

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The laminate consisted of eight layers of identically 0- 90° oriented woven fibers to maintain thickness of the beam as 5mm. Beams are fabricated by maintaining constant moment of inertia and uniform cross sectional area with uniform length of 400mm in order to evaluate the shape Effect. After completion of all the layers, again aplastic sheet was covered on the top of last ply by applying polyvinyl alcohol inside thesheet as releasing agent. Again one flat ply board and a heavy flat metal rigid platformwas kept at the top of the beams for compressing purpose. The plates were left for aminimum of 48 hours before being transported and cut to exact shape for testing. All the specimens are tested for free vibration analysis. The geometrical dimensions (i.e.length, breadth, and thickness), ply orientations of the fabricated beams are shown in Table-4.2. All the specimens described in Table 4.2 were tested for its vibration characteristics. To study the effect of boundary condition on the natural frequency of fabricated beams, the beams were tested for three different boundary conditions (B.C) i.e. for cantilever, Fixed-Fixed, Free-Free. For different boundary conditions, one iron frame was used.


Figure 4.4: glass/epoxy composite specimen fabricated with different shapes

Sections	Height H(m)	Width B(m)	Weight (kg)	Area (m^2)
box	0.04	0.03	0.31	4.5
channel	0.04	0.03	0.32	5.3

Table 4.2 Properties of composite beam specimen

Equipments for vibration test

In order to achieve the right combination of material properties and service performance, the dynamic behavior is the main point to be considered. To avoid the typical problems caused by vibrations, it is important to determine the natural frequency of the structure and the modal shapes to reinforce the most flexible regions or to locate the right positions where weight should be reduced or damping should be increased. The fundamental frequency is a key parameter. The natural frequencies are sensitive to the orthotropic properties of composite plates and design-tailoring tools may help in controlling this fundamental frequency. Due to the advancement in computer aided data acquisition systems and instrumentation, experimental modal analysis or free vibration analysis has become an extremely important tool in the hand of an experimentalist. The apparatus which are used in free vibration test are

- Modal hammer (type 2302-5)
- Accelerometer (type 4507)
- FFT Analyzer (Bruel Kajer FFT analyzer type .3560)
- Notebook with PULSE software.
- Specimens to be tested

The apparatus which is used in the vibration test are shown in Figure 4.7 to Figure 4.10.



Figure 4.7: Modal Impact Hammer(type 2302-5)
Figure 4.8: Accelerometer (4507)



Figure 4.9: Bruel & Kajer FFT analyzer
Figure 4.10: Display unit

PROCEDURE FOR FREE VIBRATION TEST

The setup and the procedure for the free vibration test are described sequentially as given below. The test specimens were fitted properly to the iron frame. The connections of FFT analyzer, laptop, transducers, modal hammer, and cables to the system were done. The pulse lab shop version-10.0 software key was inserted into the port of the computer. The beams were excited in a selected point by means of small impact with an impact hammer (Model 2302-5) for cantilever, Fixed-Fixed and Free-Free boundary condition. The input signals were captured by a force transducer, fixed on the hammer. The resulting vibrations of the specimens on the selected point were sensed by an accelerometer. The accelerometer (B&K, Type 4507) was mounted on the specimen by means of bees wax. The signal was then processed by the FFT Analyzer and the frequency spectrum was also obtained. Both input and output signals are investigated by means of spectrum analyzer (Bruel & kajer) and resulting frequency response functions are transmitted to a computer for modal parameter extraction. The output from the analyzer was displayed on the analyzer screen by using pulse software. Various forms of frequency response functions (FRF) were directly measured. However, the present work represents only the natural frequencies of the beams. For FRF, at each singular point the modal hammer was struck five times and the average value of the response was displayed on the screen of the display unit. At the time of striking with a modal hammer to the points on the specimen precaution were taken for making the stroke to be perpendicular to the surface of the beams. Then by moving the cursor to the peaks of the FRF graph the frequencies are measured.

Procedure in Modelling ANSYS

There are major and sub important steps in ANSYS model, pre-processing, solution stage and post-processing stage.

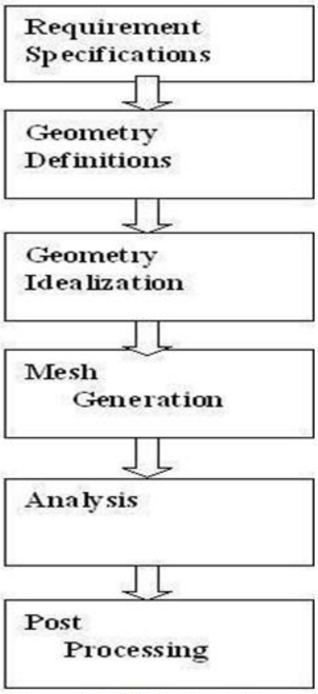


Figure 6.1: FE-Analysis Steps

Requirement Specification

This step is done in pre-processing in ANSYS. In this work the beam element model used knowwas SHELL93 and it was specification at the pre-processing stage. The SHELL93 element is applicable to this model for the structural meshing and boundary condition applications.

Geometry Definition	Values
Thickness	3.57e-4m
Young modulus	1.46e9
Density	1660
Width	0.05m
Length of the beam	0.40m
Poisson Ratio	0.3

Table 5.1:Input data for Modelling of the beam

The parameter specified in the table above indicated that only vertical direction analysis wascarried on the beam. This is applicable to the modal analysis experiment in the previous section.

Idealization Specification

This is sub-stepping procedure in model context represents a 3D shell definition. This model is optimized for rapid FEM analysis and is composed of 2D geometry, beam surface model. It iseasy to locate and calculate the numerical position in shell geometry; beam shell model can be defined of the 3D definition. The analysis type is defined as modal

Mesh Generation

The generation of a mesh on the idealized geometry is done through meshed model. The meshing depend on the configuration for the model, the general rules are carried out by setting a density for the mesh. In this application, loads and boundary conditions are added in the input file. The solver input file consists of mesh elements, nodes and load cases. The input file is generated from the application containing mesh elements, nodes and boundary conditions are added to the file.

Analysis

This is a stage where solution was conducted. It was the step to pre-processing and different stages of analysis took place. The load is applied to edges of beam, this was easier to implement in SHELL model. And the other entire complex algorithm in FEM solved.

Post-processing

At this stage the results of analysis are obtained numerically and graphically.

Result analysis Discussion

In this chapter the results obtained from ANSYS 12 software package are used for the numerical results given below, the procedure to obtained the results on ANSYS given on the chapter 5 and Experimental procedure for the experimental results are given in chapter 4. The ANSYS program must be first verified in order to ensure the subsequent analyses are free of error. Therefore the result obtained from the analysis is compared with available results of references. Natural frequencies obtained from experimental and ANSYS are listed in tables and thoseresults comparing with the available results of references for thecomposite laminated beam with different boundary conditions. And mode shapes are presented by graphs for different boundary conditions.

Comparison with Previous Studies

In order to check the accuracy of the present analysis, the case considered in Kisa (2004) is adopted here for Isotropic beam and the case considered in Li Jun (2008) is adopted for Composite beam. To find out the natural frequencies and mode shapes of beam, finite element solution program done by ANSYS.

Vibration analysis studies of isotropic beam

Length, L = 0.2m,
Breadth , b= 0.0078m
Depth, d= 0.025m,
E= 216.19e9 Nm-2 V= 0.28, P = 7.85×10^3.
Cantilever boundary condition considered.

Natural frequencies	Present study	Kisa (1998)
1^{s} Mode	1038.21	1037.01
2^{nd} mode	6506.89	6458.34
3^{rd} mode	18229.11	17960.54
4^{th} mode	35780.05	34995.429

Table 6.1: First three non-dimensional frequencies of isotropic beam

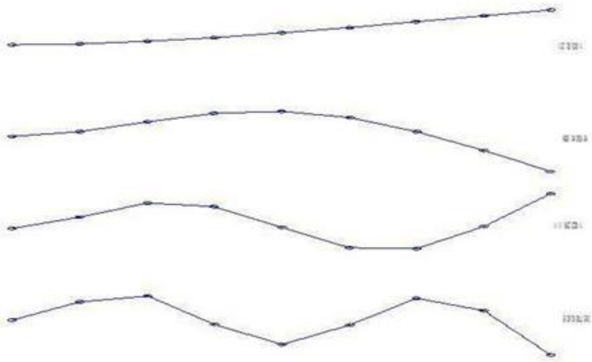


Figure 6.1 : 1^{st} four natural frequency mode shapes

Vibration analysis studies of Composite beam

Modulus of elasticity, E_{11} =144.80 Pa

E_{22} = 9.65 Pa

Modulus of rigidity, G_{12} = 4.14 pa

G_{13} = 3.45 pa

Poisson's Ratio,

ν_{12} =

0.3 Mass density, ρ =

1389.23kg/m3 Length, L

=

0.381m,

Height, h =

25.4*10^-3 m,

Breadth, b =

25.4*10^-3 m

Both Cantiliver and Fixed boundary condition is considerd

	Clamp -Clamp		Clamp -Free	
Natural frequencies	Present study	Jun,Honhxing (2009)	Present study	Jun,Honhxing (2009)
1^{st} Mode	637.74	638.5	105.37	105.39
2^{nd} mode	1656.41	1657.3	636.71	637.67
3^{rd} mode	3032.19	3034.0	1696.94	1698.0
4^{th} Mode	4663.51	4661.2	2391.11	2392.3
5^{th} Mode	4780.74	4784.6	3119.27	3121.0

Table 6.2 Comparison of Natural frequencies (Hz) of [30/50/30/50] composite beam

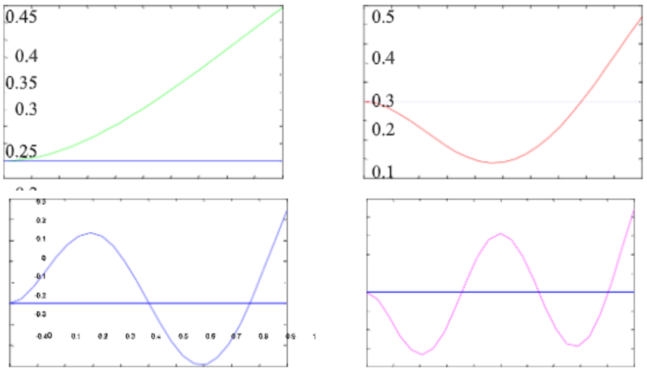


Figure 6.2: Four natural frequency mode shapes of composite beams

Experimental and Numerical Results

Numerical (FEM) and experimental results of frequencies of vibration for [0/0]8s woven fiber Glass/Epoxy composite beams are obtained for different boundary conditions. The boundary conditions considered for the present numerical analysis as well as experimental work are - cantilever, Fixed-Fixed, simply supported.

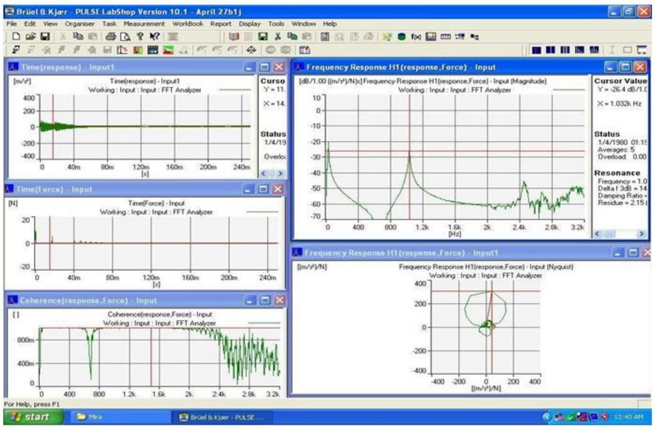
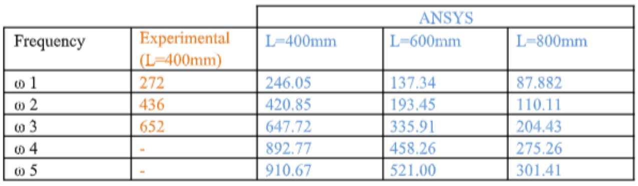


Figure 6.3: The different peaks of FRF shows the different modes of vibrations and the coherence

Fixed-Fixed Boundary Condition

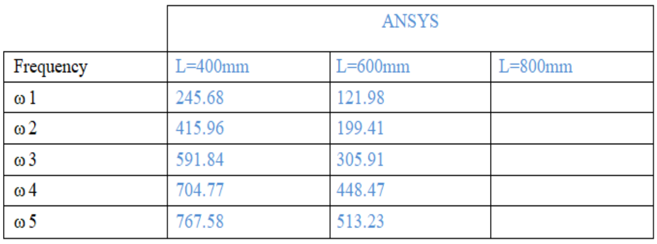
Channel section; fixed-fixed; 8 layers



Frequency	Experimental (L=400mm)	ANSYS L=400mm	L=600mm	L=800mm
ω 1	272	246.05	137.34	87.882
ω 2	436	420.85	193.45	110.11
ω 3	652	647.72	335.91	204.43
ω 4	-	892.77	458.26	275.26
ω 5	-	910.67	521.00	301.41

Table 6.3: First five non-dimensional frequencies of composite channel section of 8 layers with Fixed-Fixed Boundary condition

Channel section; fixed-fixed ; 6 layers



Frequency	ANSYS L=400mm	L=600mm	L=800mm
ω 1	245.68	121.98	
ω 2	415.96	199.41	
ω 3	591.84	305.91	
ω 4	704.77	448.47	
ω 5	767.58	513.23	

Table 6.4: First five non-dimensional frequencies of composite channel section of 6 layers with Fixed-Fixed Boundary condition

Graphical Analysis Results

Effect of Boundary Condition

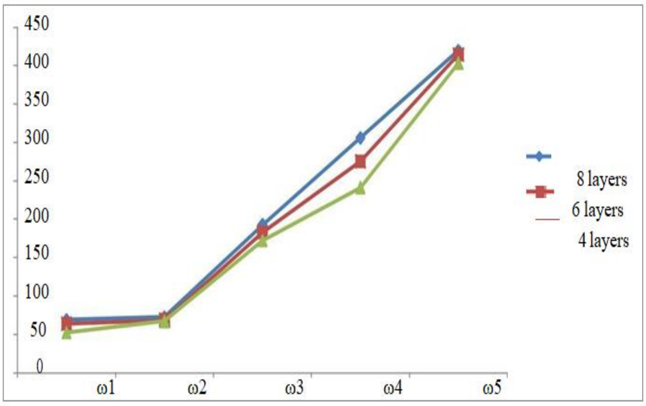


Figure 6.5 Effect of layers on free vibration of a cantilever channel section. The natural frequency increases with increases in no. of layers.

4.4.3 Effect of Length

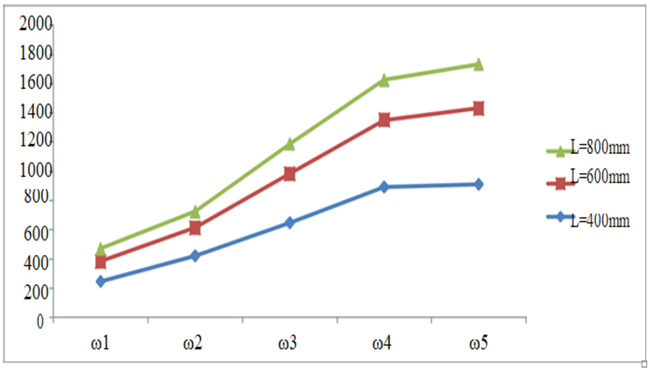


Figure 6.6 Effect of length on free vibration of a Fixed-Fixed channel section. The natural frequency decreases with increases in length of the beam.

4.4.4 Effect of Length

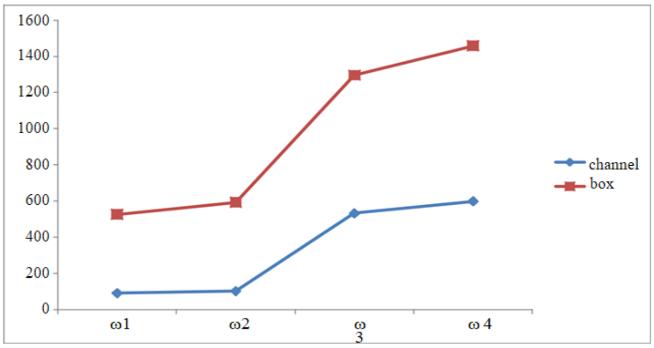
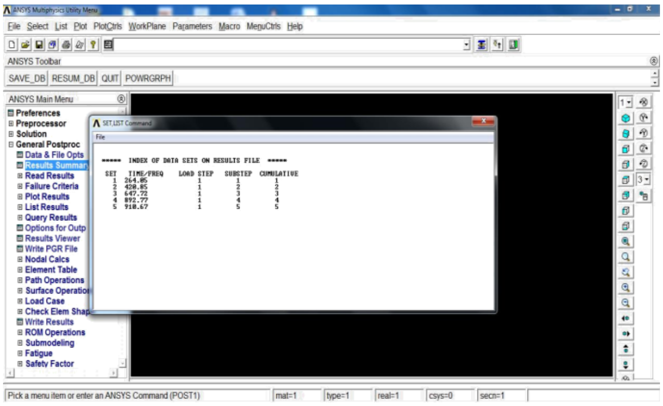


Figure 6.7: effect of Shape on free vibration of a box section. The natural frequency is minimum for cantilever and maximum for fixed beam



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 *****  INDEX OF DATA SETS ON RESULTS FILE  *****

  SET   TIME/FREQ    LOAD STEP   SUBSTEP  CUMULATIVE
    1   264.05           1          1          1
    2   420.85           1          2          2
    3   647.72           1          3          3
    4   892.77           1          4          4
    5   910.67           1          5          5
```

Pick a menu item or enter an ANSYS Command (POST1) | mat=1 | type=1 | real=1 | csys=0 | secn=1

Figure 6.8: Modal analysis of a 8 layer channel beam at fixed-fixed boundary condition by Ansys

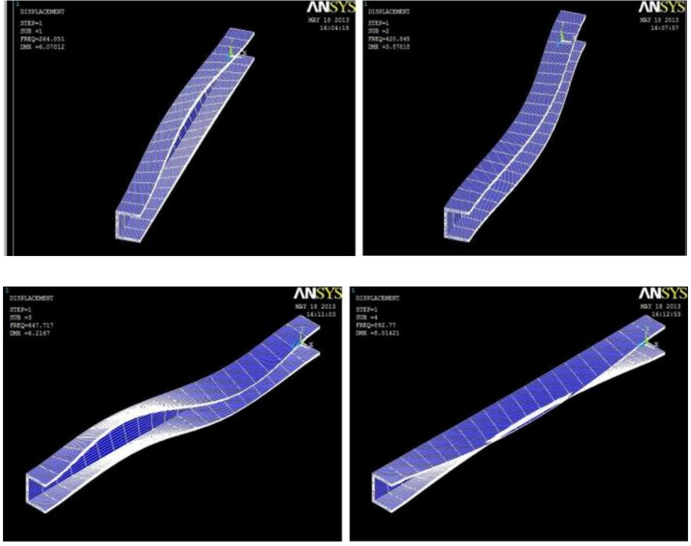

Figure 6.9: Four natural frequency mode shapes of a 8 layer channel beam at fixed-fixed boundary condition by Ansys

V. CONCLUSION

The following conclusions can be made from the present investigations of the box and channel shaped composite beam finite element. This element is versatile and can be used for static and dynamic analysis of a composite or isotropic beam.

- The dynamic behavior of nonuniform FGM Euler-Bernoulli beams subjected to multiple moving

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forces has been studied by using the finite element method. The material properties of the beams are assumed to vary in the thickness direction by a power law function.

- The exact variation of the section profile was used in evaluation of the element formulation. The dynamic response of the beam was computed with the aid of the implicit Newmark method.
- It is found that natural frequency is minimum for clamped –free supported beam and maximum for clamped-clamped supported beam.
- Mode shape was plotted for differently supported laminated beam with the help of ANSYS to get exact idea of mode shape. Vibration analysis of laminated composite beam was also done on ANSYSto get natural frequency and same trend of natural frequency was found to be repeated.
- There is a good agreement between the experimental and numerical results.
- Dynamic behavior of planar curved Timoshenko beams on viscoelastic Pasternak foundations having rectangular composite cross-section is investigated via the mixed finite element method. The warping effect of composite cross-section of curved beam is considered. The rocking influence is also considered in viscoelastic foundation model.
- We assumed different examples and it is found that natural frequencies increase with the value of E1 increases.
- It is found that natural frequencies decrease with the increase of beam length

SCOPE OF FUTURE WORK

- An analytical formulation can be derived for modelling the behaviour of laminated composite beams with integrated piezoelectric sensor and actuator. Analytical solution for active vibration control and suppression of smart laminated composite beams can be found. The governing equation should be based on the first-order shear deformation theory .
- The dynamic response of an unsymmetrical orthotropic laminated composite beam, subjected to moving loads, can be derived. The study should be including the effects of transverse shear deformation, rotary and higher-order inertia. And also we can provide more number of degree of freedom about 10 to 20 and then should be analyzed by higher order shear deformation theory.
- The free vibration characteristics of laminated composite cylindrical and spherical shells can be analyzed by the first-order shear deformation theory and a meshless global collocation method based on thin plate spline radial basis function.
- An algorithm based on the finite element method (FEM) can be developed to study the dynamic response of composite laminated beams subjected to the moving oscillator. The first order shear deformation theory (FSDT) should be assumed for the beam model.
- The damping behavior of laminated sandwich composite beam inserted with a visco elastic layer can be derived.
- Static and dynamic stability of composite beams with cracks, delaminations under hygrothermal condition

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