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Buckling and Modal Analysis of Composite Plate under Different Orientations

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ABSTRACT

This paper Buckling And Modal Analysis of Composite Materials Under Different Orientation, for those structures, it is required a high natural frequency, high critical buckling load, low weight and high strength etc. Composite materials are full filling these properties. The type of material, Layer orientation, aspect ratio, laminate thickness and boundary conditions are key parameters to determine the natural frequency, deformation and critical buckling load.

A rectangular composite (graphite/epoxy) symmetric laminate plate having 4-layers with clamped boundary conditions are assumed. With the help of ANSYS software, eight laminates (samples) of 10 unit angle varying layup configuration are developed. For each sample, the natural frequency, deformation and critical buckling load and Engineering constants (Effective elastic constants) are calculated using ANSYS software.

1. **INTRODUCTION**

Composite material is a combination of two or more chemically unlike materials with distinct boundaries between them. Such materials have their own specific properties and are usually different from their individual properties. The properties such as strength, resistance to heat, or some other property of composite materials are better than the properties of the individual materials from which there are made. Modern living, demands materials with excellent properties and the specific requirements are increasing day by day.

Introduction to composite materials Composite materials mainly contain two portions, fiber and matrix. The fiber is along section element, made for different materials

Composite materials have the properties like, high strength to low weight ratio, high corrosive resistance, long live and inexpensive to produce. These are improving structures quality of life. Due to these reasons composites are plays a key role in building the aerospace structures, automobiles, ship building, pipelines, and bridges**.**

In eighteen century aluminum material was used for construction of aerospace structures. Later composite materials were developed during the 1960s for their weight savings over aluminum parts. In the end of the nineteenth century composite materials are becoming more important material in aerospace structures. Most of the parts like fairings, spoilers, flight control elements, fuselage and wing structures are made of composites. The primary advantages of composite materials are their high strength, relatively low weight, and corrosion resistance.

like E-glass, carbon fiber and boron etc. The matrix is acts as protective medium, surrounded to fiber element. It is the interface to the fibers and made up of different materials.

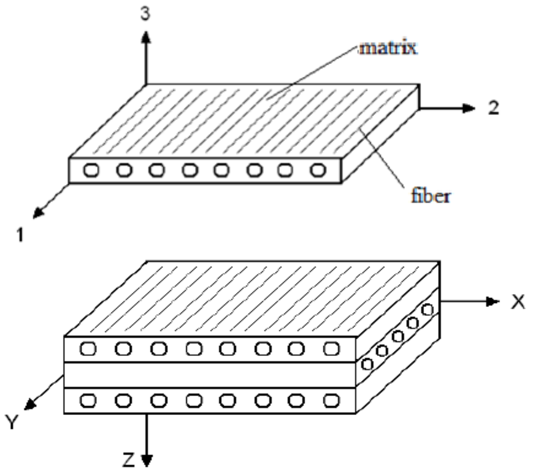


Fig 1.1 : Typical Lamina and Laminate

Fig 1.1 shows the typical lamina and laminate , generally the lamina is represented in local coordinate system(1-2) and laminate represented in global coordinate system(X-Y).

1.1.Fiber and matrix elements

The mechanical properties of fibers dominantly contribute to the overall mechanical properties of the composite. The contribution of the fibers depends on four main factors:

- The basic mechanical properties of the fiber
- The surface interaction of fiber and resin (interface)
- The amount of fibers in the composite (fiber volume fraction)
- The orientation of the fibers in the composite
- The surface interaction of fiber and resin (depending on the degree of bonding between the two).

The amount of fibers in a composite determines the strength and stiffness. As a general rule, the strength and stiffness of a laminate will increase proportional to the amount of fibers. However, above 60-70% fiber volume fraction, the tensile stiffness still increases, while the laminate strength reaches a peak and then slowly decreases. In this situation there is too little resin present to sufficiently hold the fibers together.

The orientation of the fibers in a composite largely contributes to the overall strength. Reinforcing fibers are designed such that, to be loaded along their length, which means that the properties of the composite are highly direction-specific. Commonly used fiber in industry are E-Glass, S-Glass, Aramid and carbon. Other types of fiber are polyester, polyethylene, quartz and boron Fiber. Table 1.1 shows the few fiber types.

1.2. Special Features of Composites

Composites have been designed and manufactured for applications in which high performance and light weight are needed. They offer several advantages over traditional engineering materials as discussed below:

- Provide capabilities for **part integration**. Several metallic components can be replaced by a single composite component.
- Composite structures provide **in-service monitoring** with the help of embedded sensors. This feature is used to monitor fatigue damage in aircraft structures or can be utilized to monitor their sin flow in an RTM (resin transfer molding) process.
- **High specific stiffness** (stiffness-to-density ratio). They offer the stiffness of steel at one fifth the weight and equal the stiffness of aluminium at one half the weights.
- **High specific strength** (strength-to-density ratio). Due to this, airplanes and automobiles move faster and with better fuel efficiency. The specific strength is typically in the range of 3to5 times that of steel and aluminium alloys.
- **Higher fatigue strength** (Endurance limit). Steel and aluminium alloys exhibit good fatigue strength up to about 50% of their static strength. Unidirectional carbon/epoxy composites have good fatigue strength up to almost 90% of their static strength.
- **High corrosion resistance**. Iron and aluminum corrode in the presence of water and air and require special coatings

and alloying. Because the outer surface of composites is formed by plastics, corrosion and chemical resistance are very good.

- **Increased amount of design flexibility**. For example, the coefficient of thermal expansion (CTE) of composite structures can be made zero by selecting suitable materials and lay-up sequence. Because the CTE for composites is much lower than for metals, composite structures provide good dimensional stability.

Table1.1: Comparison of different fibers

Fiber type	Other names	Commonly used Applications	Properties		Cost
			Good	Bad	
E-glass	-	Moderate	High Electrical resistance, fire resistance and strain at failure.	-	Cheapest
S-glass	R-Glass or T-Glass	Aerospace and Defense industries	Higher tensile strength and stiffness.	-	Moderate
Aramid	Kevlar, Technora or Twaron	Ballistic applications	High specific strength ,Impact resistance, high thermal insulation	Poor resistance to ultraviolet light, low compressive and low flexural strength	Moderate
Carbon	PAN (polycrylonitrile)	-	High flexural strength and modulus, high Fatigue resistance	Low fire-resistance, impact resistance, electrical insulation and thermal insulation Characteristics	Expensive
Boron	-	Space applications	-	-	Most Expensive

- **Net-shape or near-net-shape** parts can be produced with composite materials. This feature eliminates several machining operations and thus reduces process cycle time and cost.
- **Complex parts, appearance, and special contours**, which are sometimes not possible with metals, can be fabricated using composite materials without welding or riveting. This increases reliability and reduces production time.
- **Offers greater feasibility for employing design for manufacturing (DFM) and design for assembly (DFA) techniques**. These techniques help minimize the number of parts in a product and thus reduce assembly

and joining time.

- Noise, vibration, and harshness (NVH) characteristics are better for composite materials than metals. These materials **dampen vibrations** an order of magnitude better than metals. These characteristics are used in a variety of applications, from the leading edge of an airplane to golf clubs.

By utilizing proper design and manufacturing techniques, cost-effective composite part can be manufactured. Composites **offer design freedom by tailoring material properties to meet performance specifications, thus avoiding the over-design of products**. This is achieved by changing the fiber orientation, fiber type, and/or resin systems.

2. FINITE ELEMENT METHOD

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called "shape functions". This will represent the displacement within the element in terms of the displacement at the nodes of the element.

The Finite Element Method is a mathematical tool for solving ordinary and partial differential equations. Because it is a numerical tool, it has the ability to solve the complex problems that can be represented in differential equations form. The applications of FEM are limitless as regards the solution of practical design problems.

FEA has been used routinely in high volume production and manufacturing industries for many years, as to get a product design wrong would be detrimental. For example, if a large manufacturer had to recall one model alone due to a hand brake design fault, they would end up having to replace up to few millions of hand brakes. This will cause a heavier loss to the company.

The finite element method is a very important tool for those involved in engineering design; it is now used routinely to solve problems in the following areas.

- Structural analysis
- Thermal analysis
- Vibrations and Dynamics
- Buckling analysis
- Acoustics
- Fluid flow simulations
- Crash simulations
- Mold flow simulations

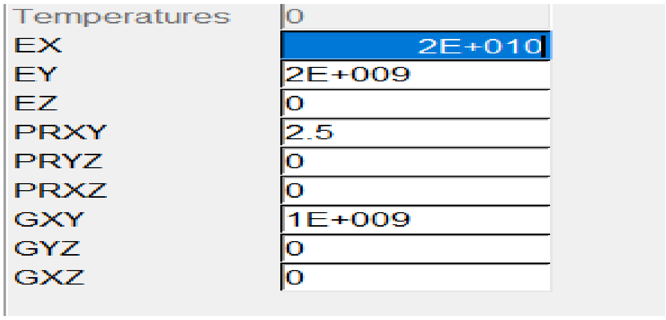
2.1. Available Commercial FEM software packages

- ANSYS (General purpose, PC and workstations)
- SDRC/I-DEAS (Complete CAD/CAM/CAE package)
- NASTRAN (General purpose FEA on mainframes)
- LS-DYNA 3D (Crash/impact simulations)
- ABAQUS (Nonlinear dynamic analysis)
- NISA (A General purpose FEA tool)
- PATRAN (Pre/Post processor)
- HYPERMESH (Pre/post processor)

2.2. Structural Static Analysis:

A static analysis calculates the effects of study loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed, i.e. the loads and the structure's responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis include:

- Externally applied forces and pressures.
- Steady state inertial forces
- Imposed displacement
- Temperatures
- Fluences (for nuclear swelling)



Temperatures	0
EX	2E+010
EY	2E+009
EZ	0
PRXY	2.5
PRYZ	0
PRXZ	0
GXY	1E+009
GYZ	0
GXZ	0

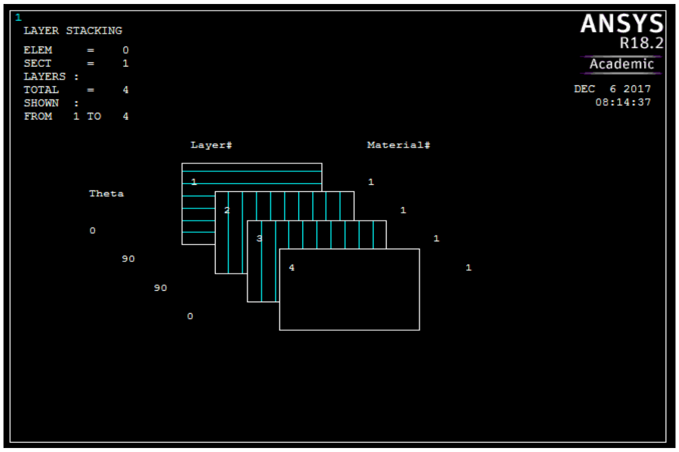


Fig 2.1 . Orientations layers

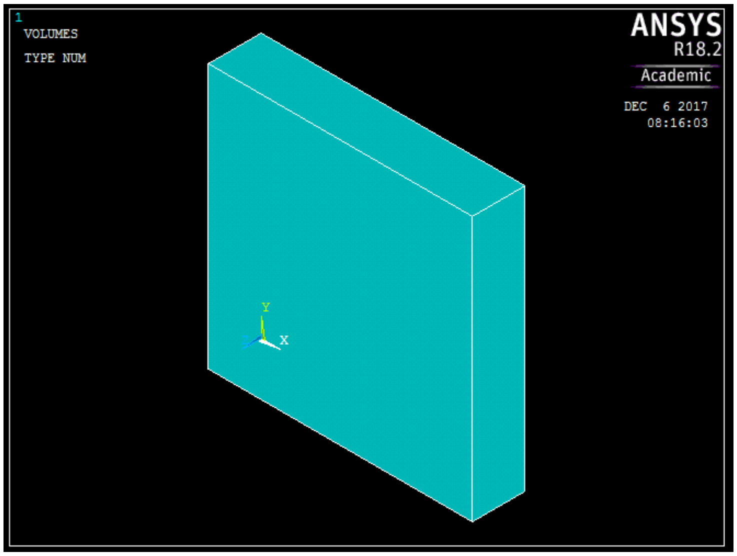


Fig2.2. composite plate

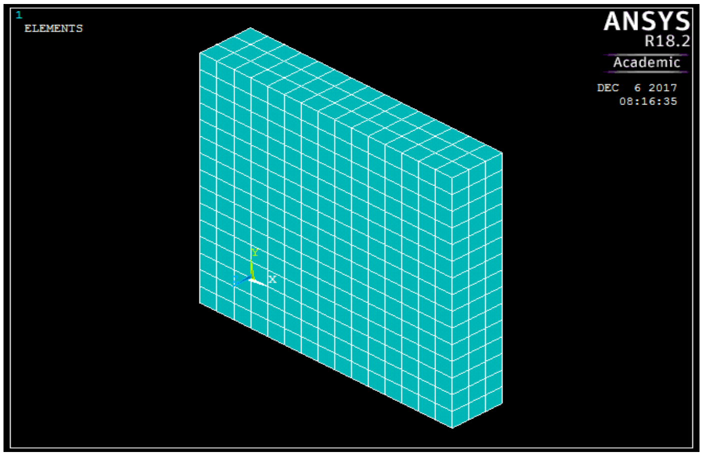
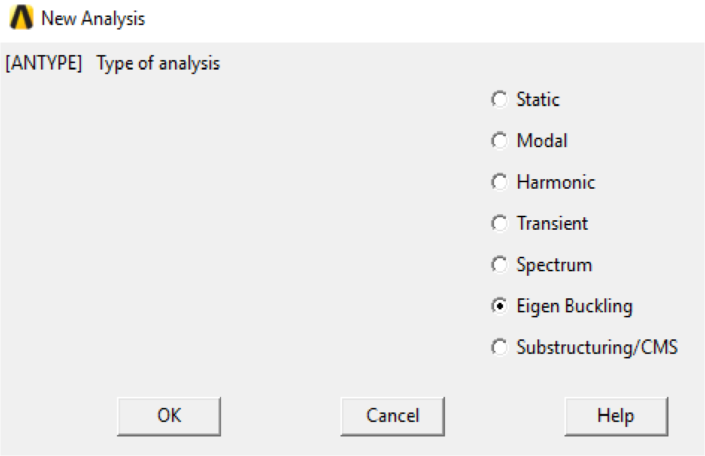


Fig 2.3 Meshing model of composite plate

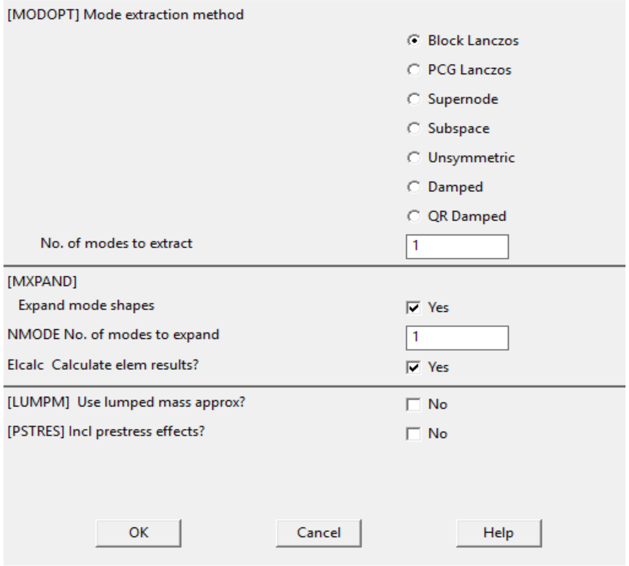


New Analysis

[ANTYPE] Type of analysis

○ Static
○ Modal
○ Harmonic
○ Transient
○ Spectrum
● Eigen Buckling
○ Substructuring/CMS

Fig2.4. Type of analysis



[MODOPT] Mode extraction method

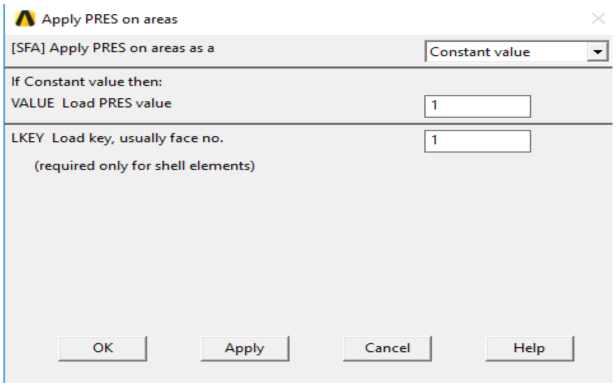
● Block Lanczos
○ PCG Lanczos
○ Supernode
○ Subspace
○ Unsymmetric
○ Damped
○ QR Damped

No. of modes to extract: 1

[MXPAND]
Expand mode shapes ☑ Yes
NMODE No. of modes to expand: 1
Elcalc Calculate elem results? ☑ Yes

[LUMPM] Use lumped mass approx? ☐ No
[PSTRES] Incl prestress effects? ☐ No

Fig2.5. Mode extraction method



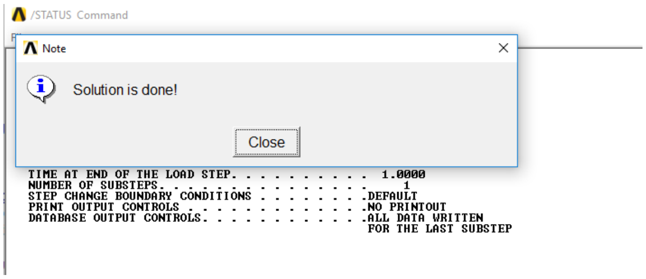
Apply PRES on areas

[SFA] Apply PRES on areas as a: Constant value

If Constant value then:
VALUE Load PRES value: 1

LKEY Load key, usually face no.: 1
(required only for shell elements)

Fig2.6. Apply pressure on area



/STATUS Command

Note

Solution is done!

```
TIME AT END OF THE LOAD STEP. . . . . . . . . .  1.0000
NUMBER OF SUBSTEPS. . . . . . . . . . . . . . .     1
STEP CHANGE BOUNDARY CONDITIONS . . . . . . . .DEFAULT
PRINT OUTPUT CONTROLS . . . . . . . . . . . . .NO PRINTOUT
DATABASE OUTPUT CONTROLS. . . . . . . . . . . .ALL DATA WRITTEN
                                               FOR THE LAST SUBSTEP
```

Fig2.7. Solution is done

3. RESULTS

3.1. ORIENTATION CONFIGURATION OF 0/0/0/0:

FREQUENCY:

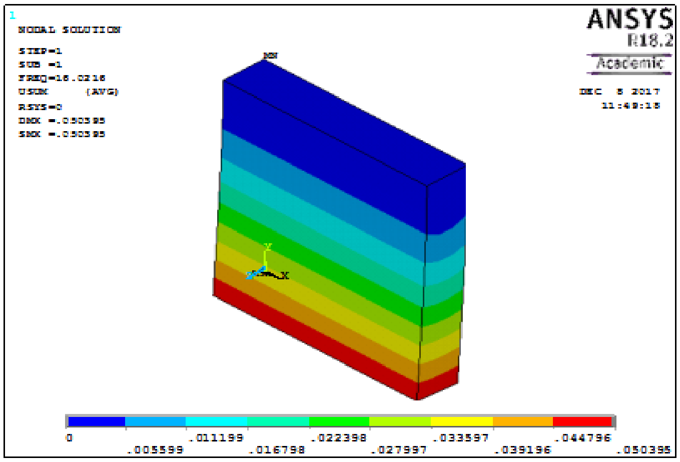


Fig3.1. 0/0/0/0 Frequency

3.1.1. EIGEN BUCKLING:

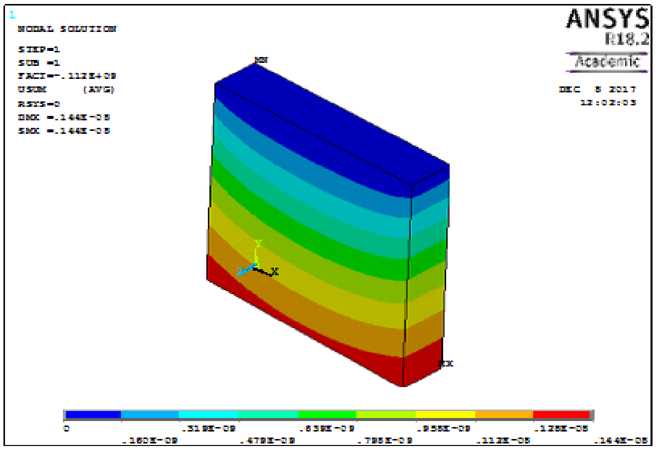


Fig3.2. 0/0/0/0 Eigen buckling

3.2. ORIENTATION CONFIGURATION OF 0/90/90/0:

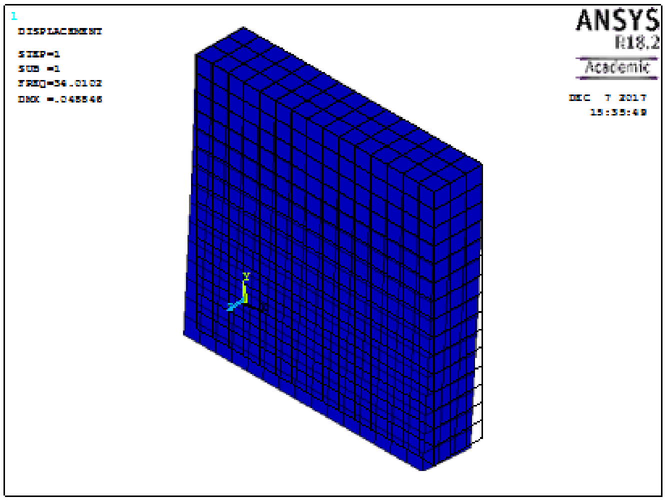


Fig3.3. 0/90/90/0 Frequency

3.2.1. EIGEN BUCKLING:

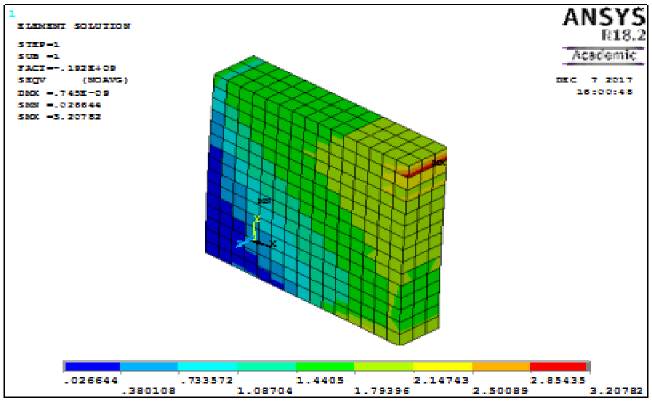


Fig 3.4. 0/90/90/0 Eigen buckling

3.3ORIENTATION CONFIGURATION OF 90/0/0/90:

FREQUENCY:

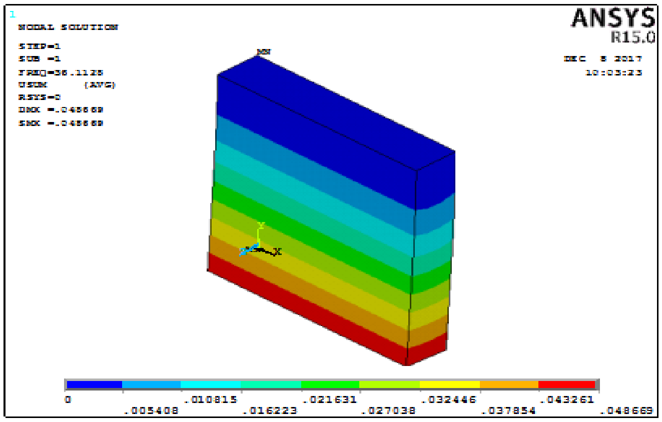


Fig3.5. 90/0/0/90 Frequency

3.3.1. EIGEN BUCKLING:

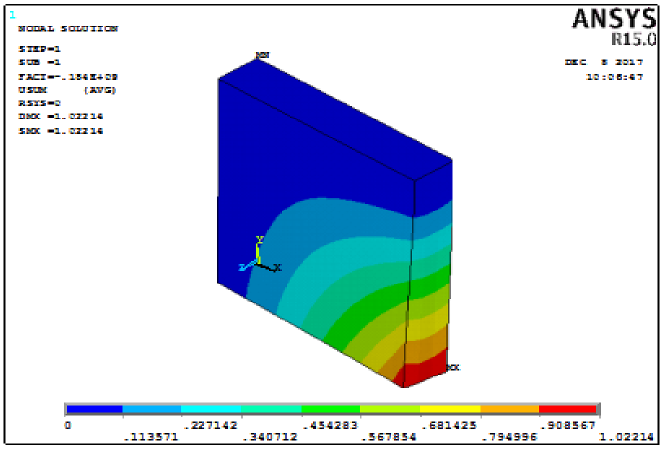


Fig 3.6. 90/0/0/90 Eigen buckling

3.4ORIENTATION CONFIGURATION OF 90/90/90/90:

FREQUENCY:

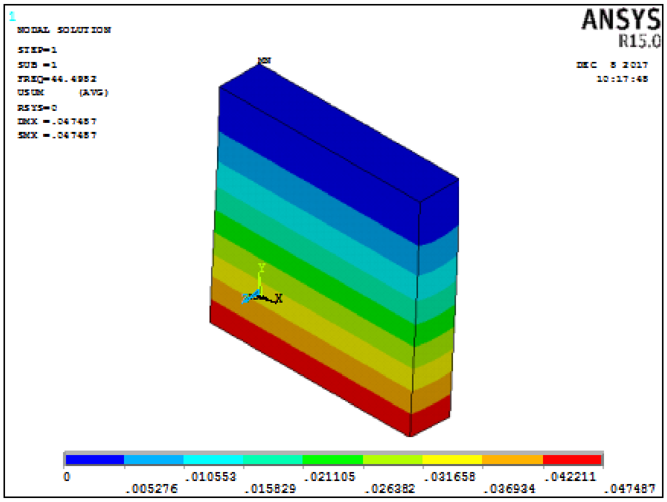


Fig 3.7. 90/90/90/90 Frequency

3.4.1. EIGEN BUCKLING:

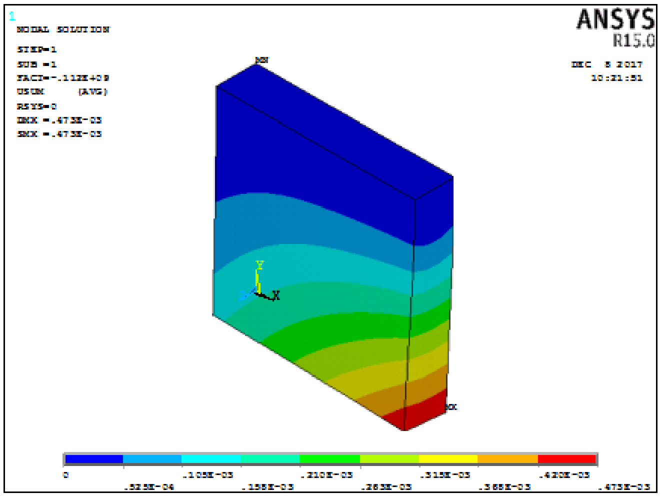


Fig 3.8.90/90/90/90 Eigen buckling

3.5. ORIENTATION CONFIGURATION OF 0/10/10/0:

FREQUENCY:

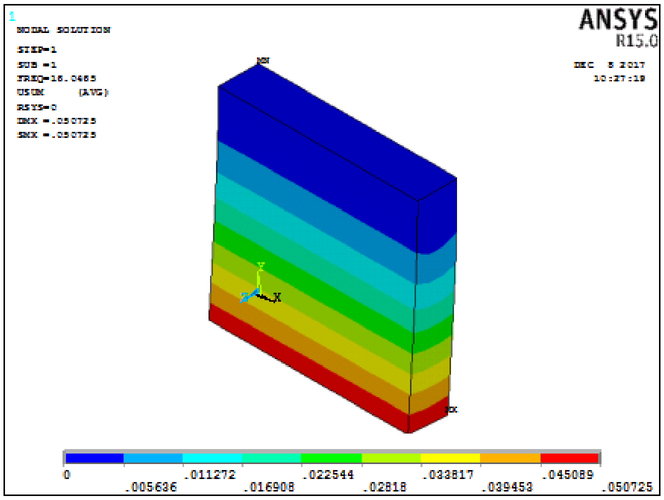


Fig 3.9. 0/10/10/0 Frequency

3.5.1. EIGEN BUCKLING:

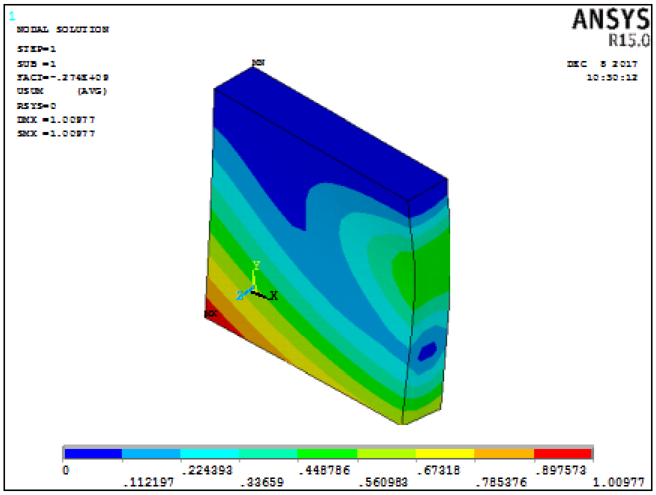


Fig 3.10. 0/10/10/0 Eigen buckling

3.6. ORIENTATION CONFIGURATION OF 0/80/80/0:

FREQUENCY:

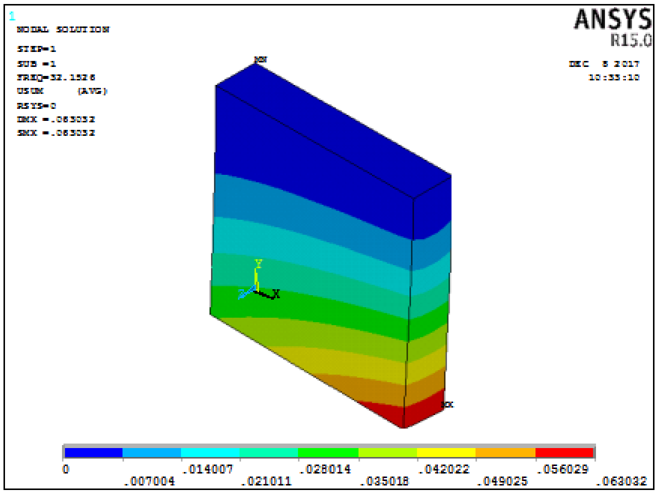


Fig 3.11. 0/80/80/0 Frequency

3.6.1. EIGEN BUCKLING:

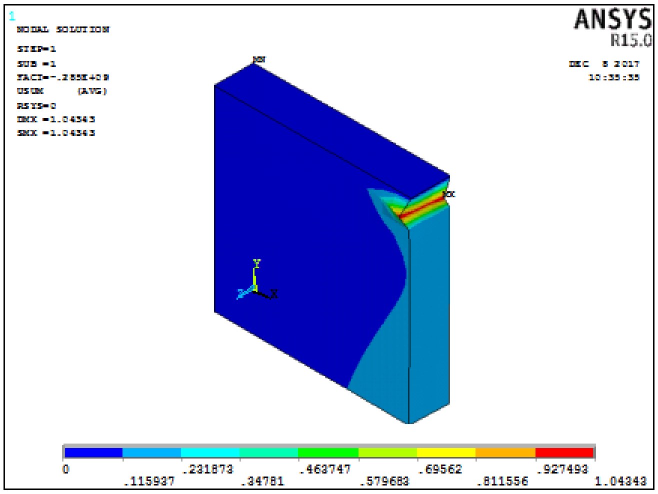


Fig 3.12. 0/80/80/0 Eigen buckling

3.7. ORIENTATION CONFIGURATION OF 90/10/10/90:

FREQUENCY:

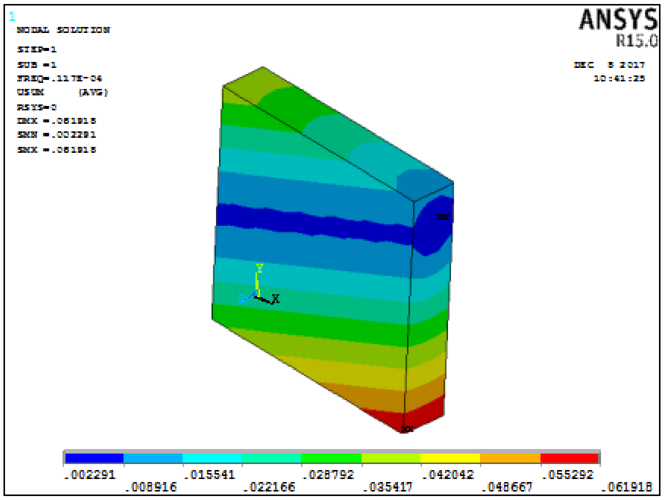


Fig 3.13. 90/10/10/90 Frequency

3.7.1. EIGEN BUCKLING:

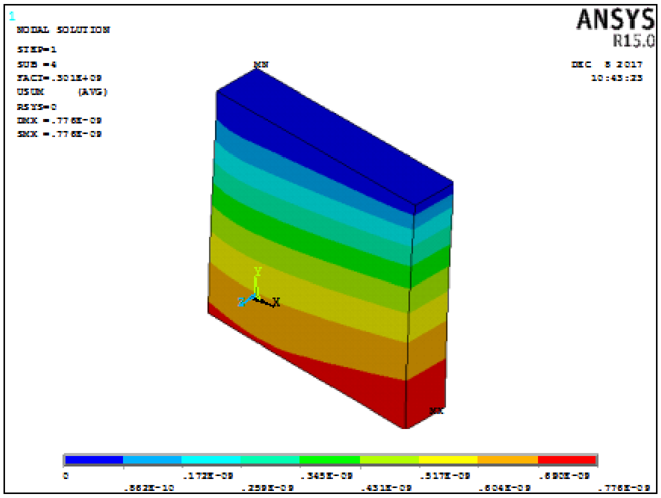


Fig 3.14. 90/10/10/90 Eigen buckling

3.8. ORIENTATION CONFIGURATION OF 90/80/80/90:

FREQUENCY:

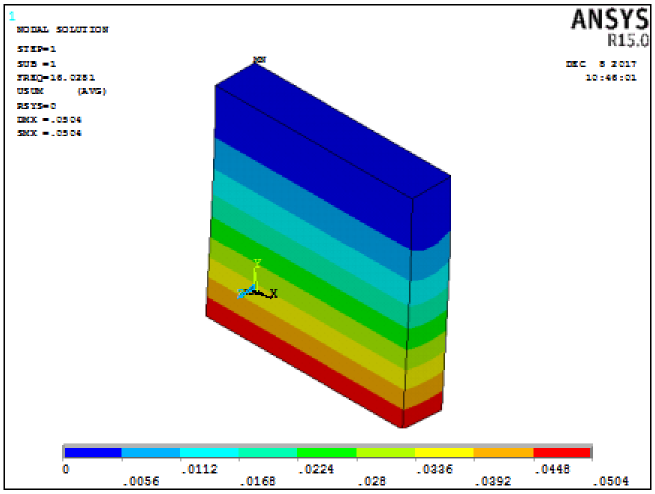


Fig 3.15. 90/80/80/90 Frequency

3.8.1. EIGEN BUCKLING:

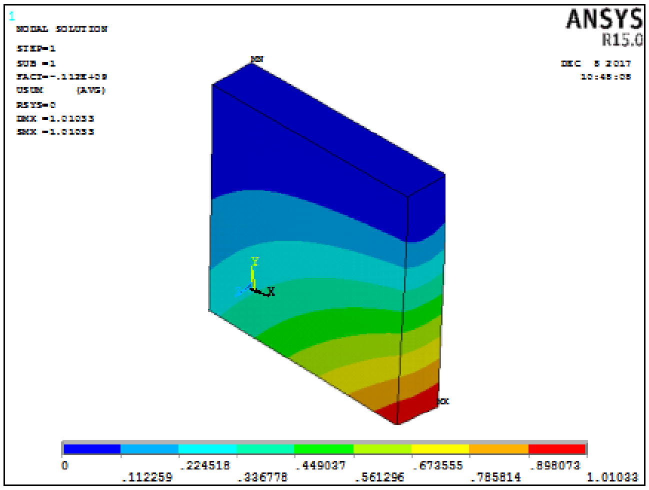


Fig 3.16. 90/80/80/90 Eigen buckling

24. CONCLUSION

Analytical results of Natural frequencies, buckling loads and effective elastic constants of respective samples of a Three layer symmetric graphite/epoxy composite laminate under clamped condition was studied in ANSYS. The natural frequency, buckling load and elastic constants was studied by Modal Analysis on ANSYS simulation of composite design software. The results obtained in simulation software are tabulated with every orientation of layers in composite.

S.NO	ORIENTATION CONFIGURATION	FREQUENCY	DEFORMATION	BUCKLING LOAD
1	0/0/0/0	16.0216	0.050395	0.0244
2	0/90/90/0	34.0102	0.04886	0.0384
3	90/0/0/90	36.1128	0.048669	0.0368
4	90/90/90/90	44.4982	0.047487	0.0224
5	0/10/10/0	16.0465	0.050725	0.0548

6	**0/80/80/0**	**32.1526**	**0.063032**	**0.057**
7	**90/10/10/90**	**0.117E-04**	**0.061918**	**0.0602**
8	**90/80/80/90**	**16.0281**	**0.0504**	**0.0224**

FREQUENCY

90/90/90/90	**44.4982**	**Max**
90/10/10/90	**0.117E-04**	**Min**

considering frequency better orientation is 90/10/10/90, why because considering dynamic analysis this orientation low frequency

DEFORMATION

90/90/90/90	**0.047487**	**Min**
0/80/80/0	**0.063032**	**Max**

considering deformation better orientation is 90/90/90/90, why because less deformation, so strength is more

BUCKLING LOAD

90/90/90/90	**0.0224**	**Min**
90/10/10/90	**0.0602**	**Max**

considering buckling load better orientation is 90/90/90/90, why because less deformation, so load carrying capacity is more

Hence we can conclude that orientation of graphite/epoxy **90/90/90/90** is best orientation.

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