

Intelligent Sensor Technologies for Predictive Maintenance and Structural Health Monitoring Using ANSYS WORKBENCH

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Abstract: By examining the intelligent sensor technologies to enhance predictive maintenance and structural health monitoring (SHM) significantly improving safety, efficiency, and reliability. These advanced sensor systems—comprising fibre optic sensors, piezoelectric sensors, MEMS (Micro- Electric-Mechanical Systems), and smart sensors — enable real-time monitoring of critical parameters such as strain, temperature, vibration, and pressure across various aircraft components. By using ANSYS WORKBENCH a flat plate with crack and without crack is designed and static structural analysis and modal analysis is performed so that the frequencies are compared to detect the failure. The sensors can detect changes in strain, fatigue and other stress indicators that may compromise structural safety.

Keywords: Intelligent Sensors, Structural Health Monitoring, Predictive Maintenance, FEA, Static, Modal Analysis, ANSYS.

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I. INTRODUCTION

➤ Structural Health Monitoring:

Structural health monitoring (SHM) is like having a check-up for buildings and bridges or any structure. Just as we go to the doctor to make sure, we're healthy, SHM uses technology to keep an eye on the condition of our structures. With sensors placed on these structures, engineers can track things like cracks, vibrations, or any shifts that might happen over time. This way, they can catch potential problems early, ensuring that everything stays safe and sound. It's all about being proactive and making sure our infrastructure remains reliable for everyone who uses it, helping to prevent accidents and costly repairs down the line.

➤ Predictive Maintenance:

Predictive maintenance is like having a smart assistant for your machines. Instead of waiting for something to break down and dealing with unexpected repairs, this approach uses data and technology to keep an eye on equipment health. It helps predict when something might fail, allowing you to fix it before it causes any problems.

➤ Intelligent Sensors:

Sensors used in structural health monitoring (SHM) are like the senses of a building or bridge. They help the structure feel what's going on around it and share that information with us. These sensors can pick up on things like stress, vibrations, and temperature changes, giving engineers a clear picture of how well a structure is holding up.

➤ Types of Intelligent Sensors: Accelerometer:

An accelerometer is an electromechanical device that measures acceleration forces in one or multiple directions. These forces can be static, like gravity, or dynamic, such as vibrations from a truck crossing a bridge. Accelerometers are used in various fields, from smartphones to civil infrastructure. In structural monitoring, accelerometers help in real-time monitoring of changes in structural dynamic characteristics due to damage or changes in performance. Multi-axis accelerometers detect the magnitude and direction of acceleration. They are widely used in construction to control the dynamic behaviour of structures over short or long periods. Measuring and recording the

dynamic behaviour of structures is crucial for evaluating their safety and viability, with dynamic loads originating from various sources like impact loads, construction work, traffic loads, and earthquakes. Accelerometers: Think of these as the ears of a structure. They pick up vibrations and movements, like how a building swags during strong winds or earthquakes.

➤ *Piezoelectric Accelerometer*

A piezoelectric accelerometer is an accelerometer that employs the piezoelectric effect of certain materials (e.g. quartz) to generate electric charge in response to applied mechanical stress. This type of vibration transducers offer a very wide frequency and dynamic range. Piezoelectric devices are widely used in different industries, environments and applications, allowing to measure dynamic changes in mechanical variables including acceleration, shock and vibration.

➤ *Strain Gauges:*

These sensors are like the skin of a structure, measuring how much it stretches or bends under pressure. They help us see if a bridge or beam is handling its load properly.

➤ *Fibre Optic Sensors:*

Fibre optic sensors (FOS) are now widely recognised as an efficient and effective means of SHM. They are ideal for real-time monitoring of the structure's health since they can measure parameters such as strain, temperature, vibration, and displacement. FOS has essential benefits because of its high sensitivity, immunity to electromagnetic interference, and the possibility of local and global monitoring.

➤ *Microelectromechanical Devices:*

Microelectromechanical (MEMS) Devices Microelectromechanical systems (MEMS) technology has revolutionised structural health monitoring (SHM) by offering compact, efficient, and cost-effective solutions for predicting and measuring vibrations in civil structures. MEMS devices consist of tiny mechanical and electrical components integrated into a single microchip, allowing for precise sensing and analysis of structural vibrations. One of the key advantages of MEMS technology in SHM is its ability to predict and detect increases in structural vibration levels.

➤ *Introduction to ANSYS:*

ANSYS is the standard FEA tool within the Mechanical Engineering Department and also used in Civil, Aeronautical and Electrical Engineering. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs.

➤ *Steps in Finite Element Analysis: Discretization*

- Formulation of properties to each element and concern nodes.
- Assemble all elements for structure
- Give input such as load , forces , etc based on type of analysis means structural, thermal etc.
- Solve simultaneous line algebraic equations. Display the results in the form of graphs.

The finite element method is a numerical analysis technique for obtaining approximate solutions to a wide range of engineering problems.

II. METHODOLOGY

If we look at how accelerometers are used in structural health monitoring, think about a tall building in a bustling city. When strong winds blow, an accelerometer placed in the building continuously tracks how much it sways. If it picks up on unusual vibrations or excessive movement, it can immediately alert engineers. This way, they can quickly check if everything is okay or if any repairs are needed, keeping everyone inside safe and sound.

A real-time example of a piezoelectric accelerometer that many people might relate to is in car safety systems. Imagine you're driving, and suddenly, you have to slam on the brakes or you're involved in a collision. Inside your car, there's a tiny piezoelectric accelerometer that quickly senses that sudden change in motion.

When it detects the rapid stop or impact, it instantly sends a signal to the airbag system, making the airbags deploy in just milliseconds. Engineers use tiltmeters to keep an eye on how much the building is tilting. If the tiltmeter notices that the building is leaning more than it should, it sends a warning to the engineers. This way, they can check things out and make sure everything is safe.

III. DESIGNING & ANALYSIS

We have designed the FLAT PLATE with and without CRACK with the following dimensions: Length:100m; Breadth:40m; Thickness:1m; The following figure shows the development of the design in the ANSYS WORKBENCH.

➤ *Isometric View of FLAT PLATE without Crack*

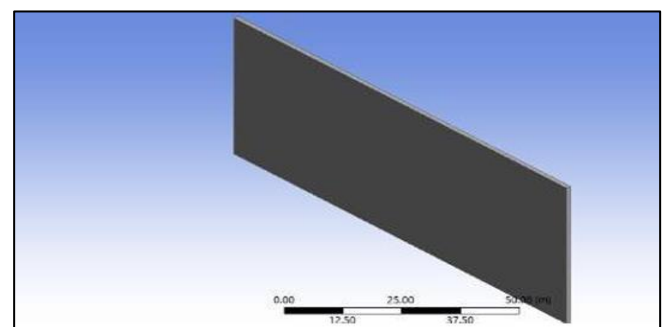


Fig 1 Model in ANSYS

➤ *Isometric View of FLAT PLATE with Crack*

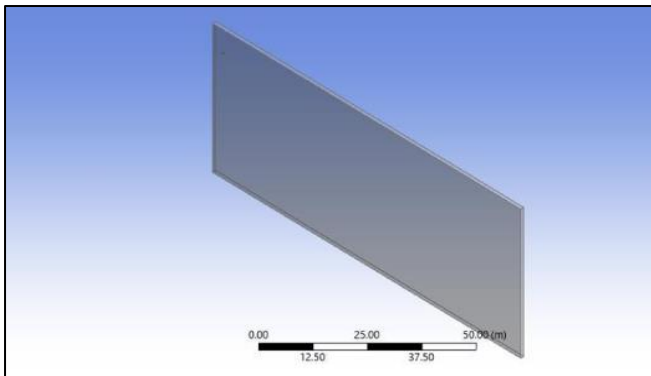


Fig 2 Fat Plate with Crack

The dimensions are same for flat plate with and without crack.

The crack dimensions are Length:0.2m; Breadth:0.1m; Thickness:1m;

➤ *Crack Insertion*

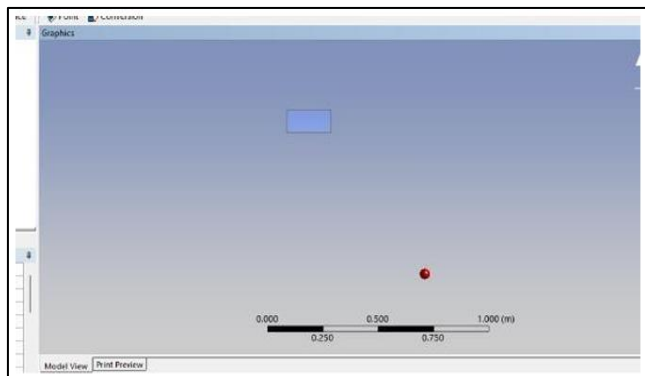


Fig 3 Crack Insertion

The flat plate is designed and simulated in ANSYS WORKBENCH. The analysis by Static Structural is used in order to calculate deformation and stresses in it and Modal analysis is used to calculate the frequency changes in the flat plate with and without crack. For meshing, the geometry is opened in Mechanical model, and performed meshing with sizing 0.6m

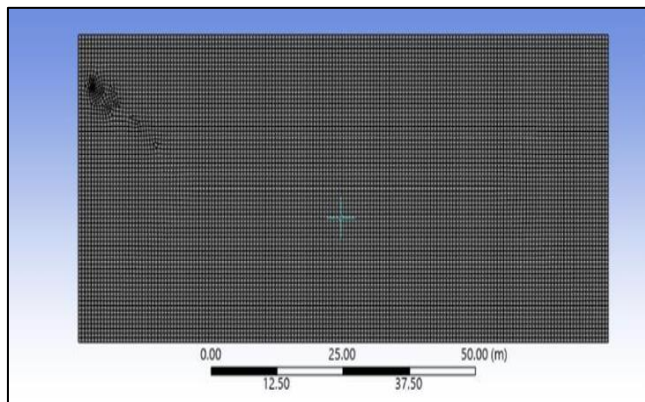


Fig 4 Meshed Model with Crack in ANSYS

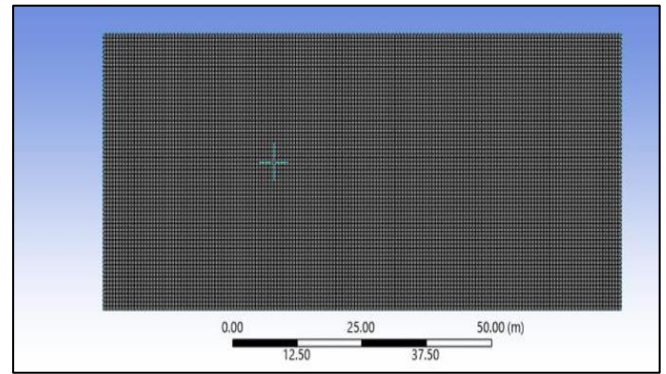


Fig 5 Meshed Model without Crack in ANSYS

➤ *Materials Used:*

In this project, We have been used structural steel for analysis. The used material data is default. which is there in ansys engineering data.

➤ *Analysis for Flat Plate without Crack:*

➤ *Static, Structural Analysis:*

In static structural analysis we should assign fixed support and force to the flat plate such that the deformations, stresses and strains are observed.

Variations of different parameters such as Total deformation, Von-misses Strain and Von-misses Stresses has been observed .the design load condition i.e 100N

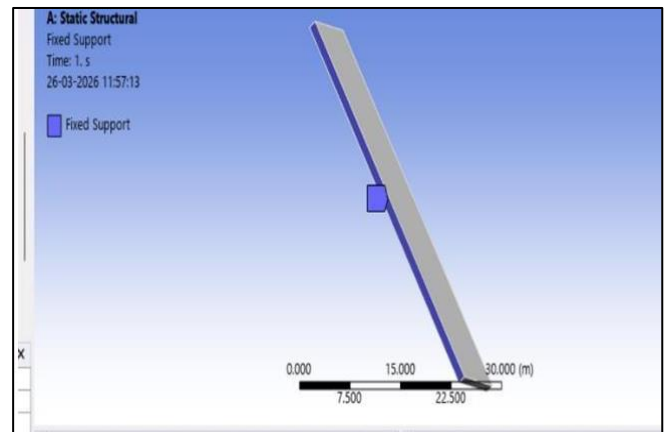


Fig 6 Fixed Support

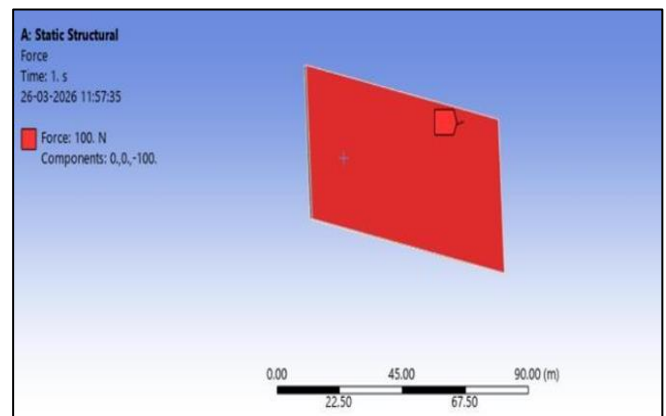


Fig 7 Force Applied

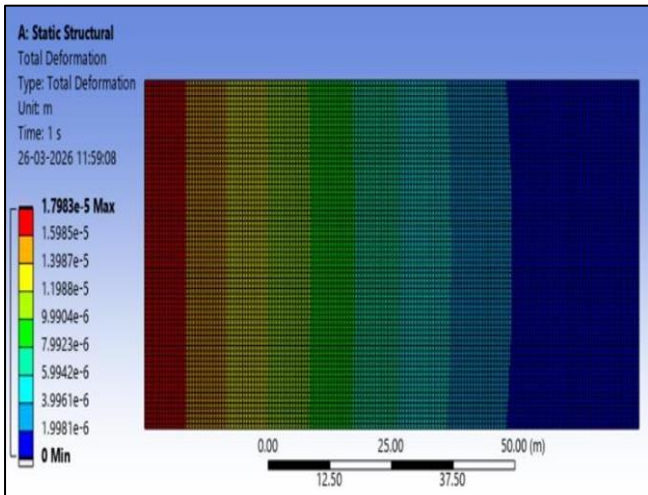


Fig 8 Total Deformation

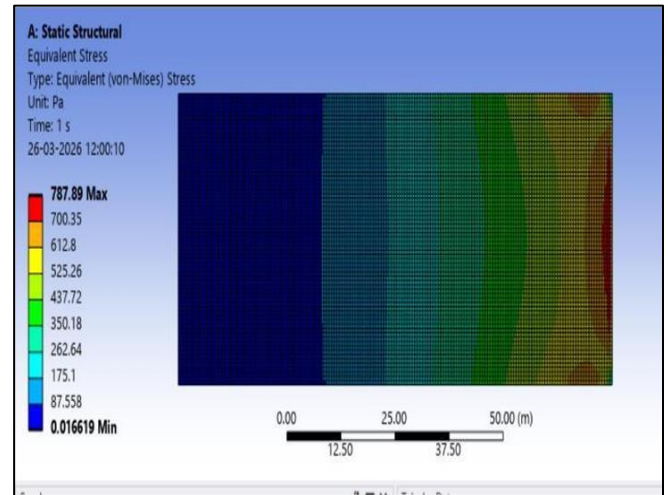


Fig 11 Equivalent Strain

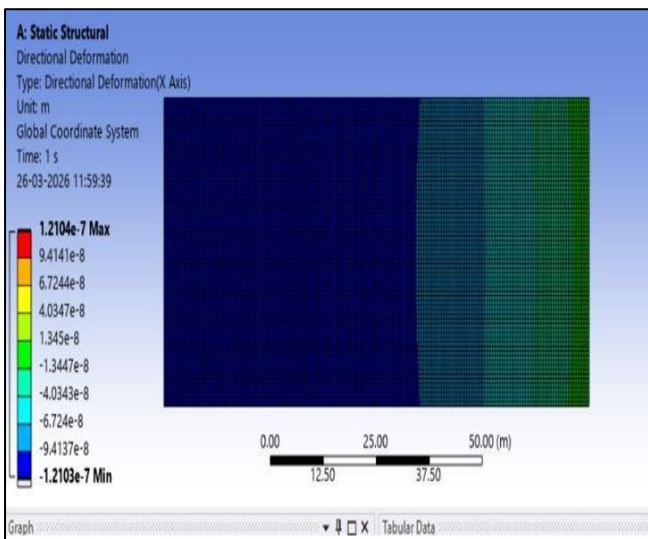


Fig 9 Directional Deformation

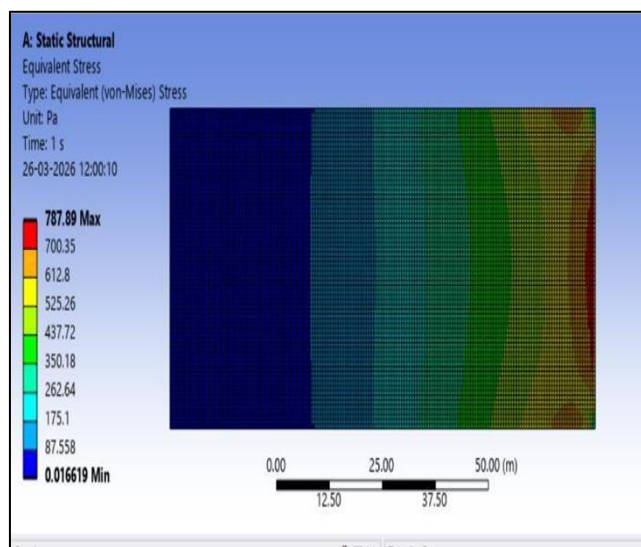


Fig 10 Equivalent Stress

➤ *Modal Analysis:*

In modal analysis we performed modal analysis to determine the mode shapes, vibrations and frequencies. The number of mode shapes are 6. So that we got 6 total deformations and frequencies.

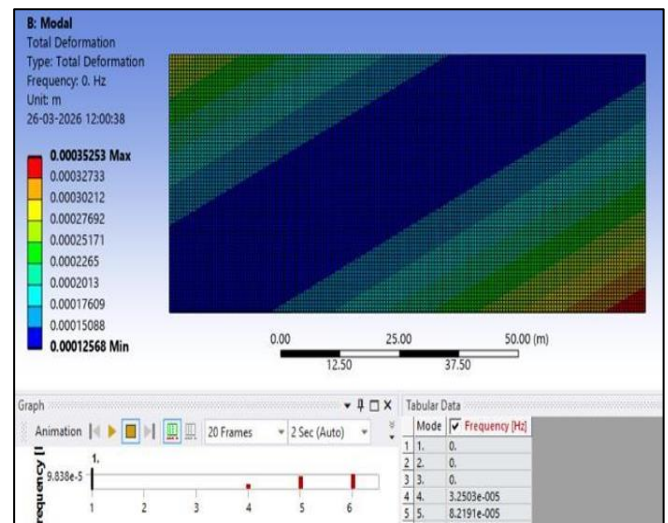


Fig 12 Mode Shape 1

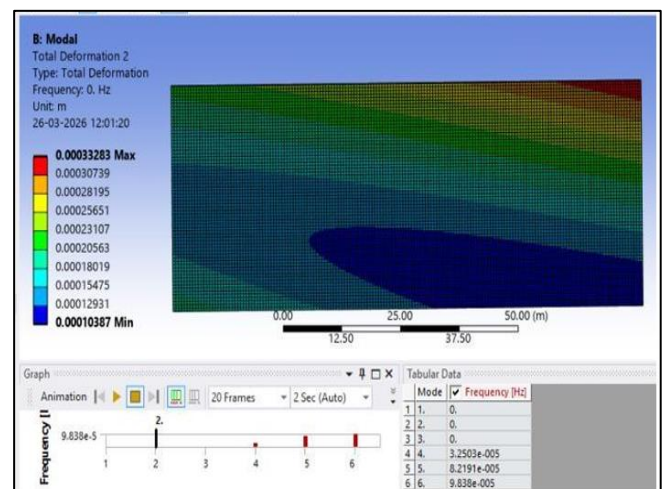


Fig 13 Mode Shape 2

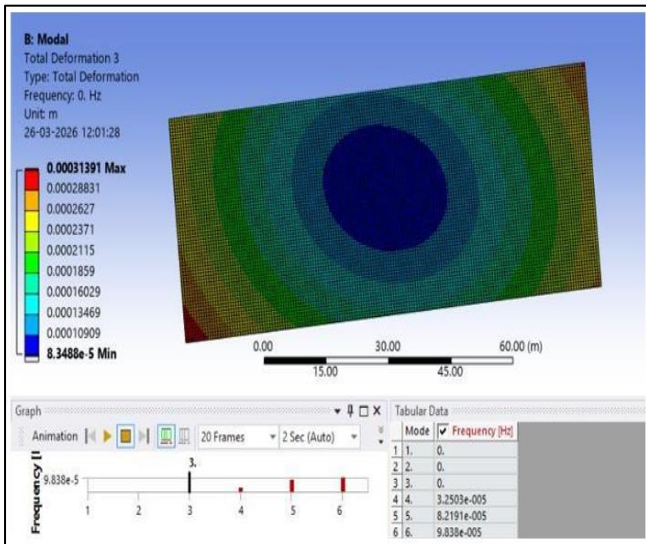


Fig14 Mode Shape 3

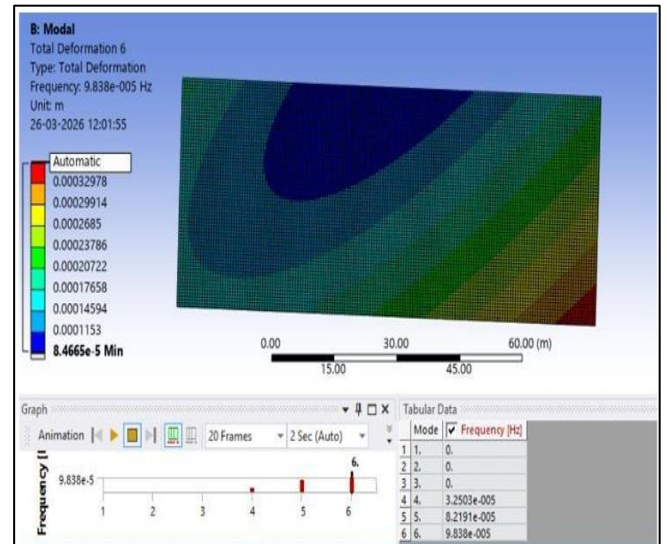


Fig 17 Mode Shape 6

Frequencies observed in modal analysis for flat plate without crack are:

Table 1 Frequencies

Mode No	Frequency (Hz) –without Crack
1	0
2	0
3	0
4	3.2503e-005
5	8.2191e-005
6	9.838e-005

➤ Analysis of Flat Plate without Crack:

➤ Static Structural Analysis:

The analysis is similar to the flat plate with crack.

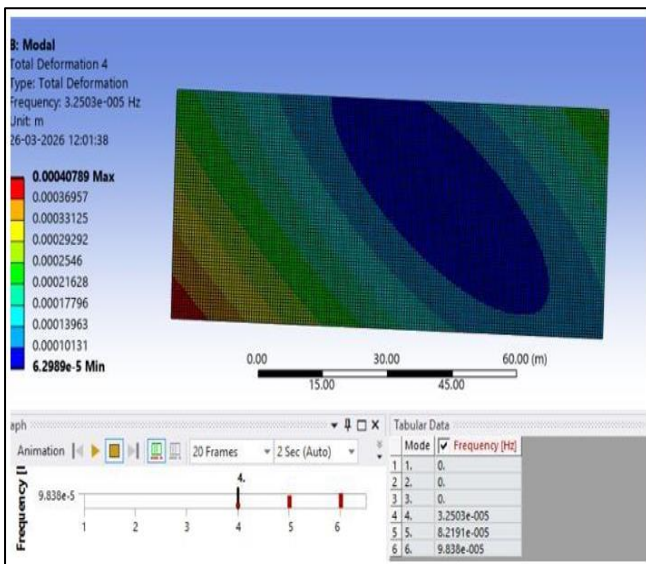


Fig 15 Mode Shape 4

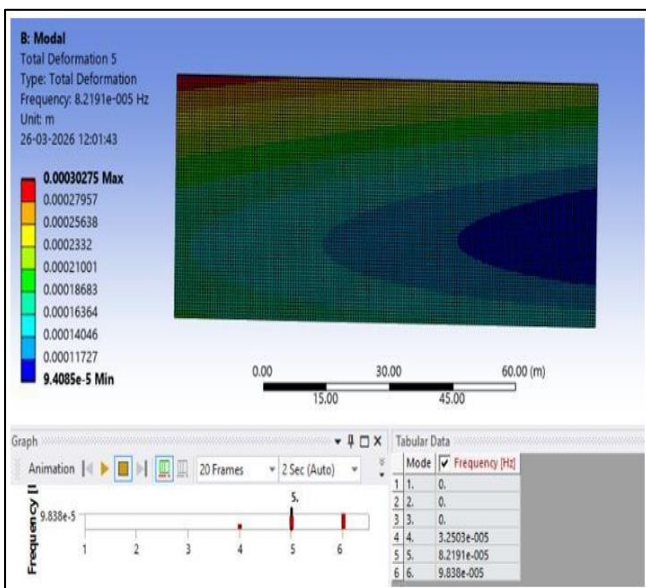


Fig 16 Mode Shape 5

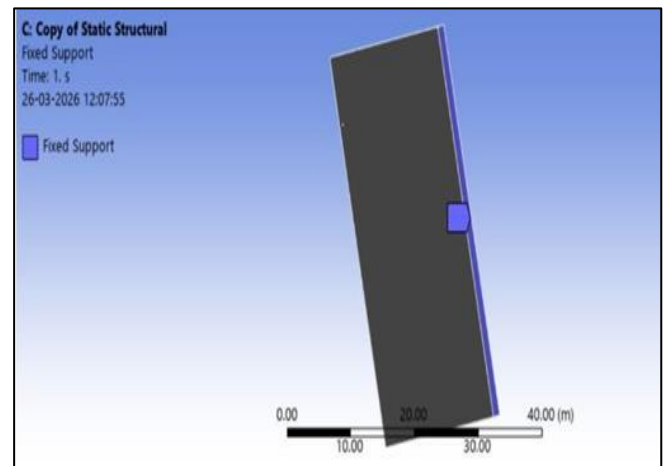


Fig 18 Fixed Support

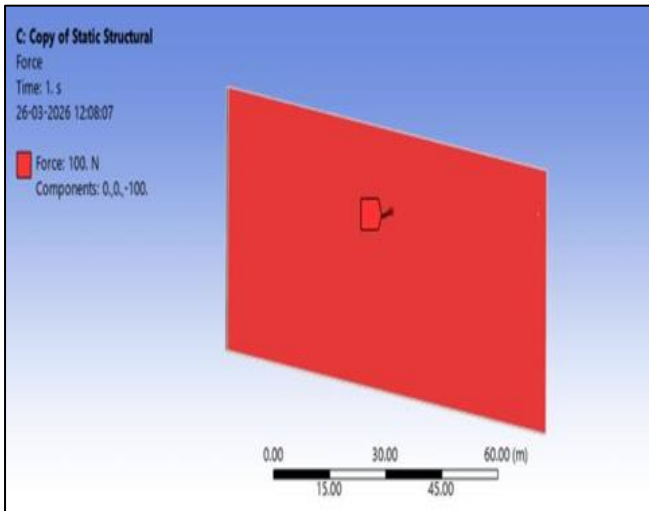


Fig 19 Force

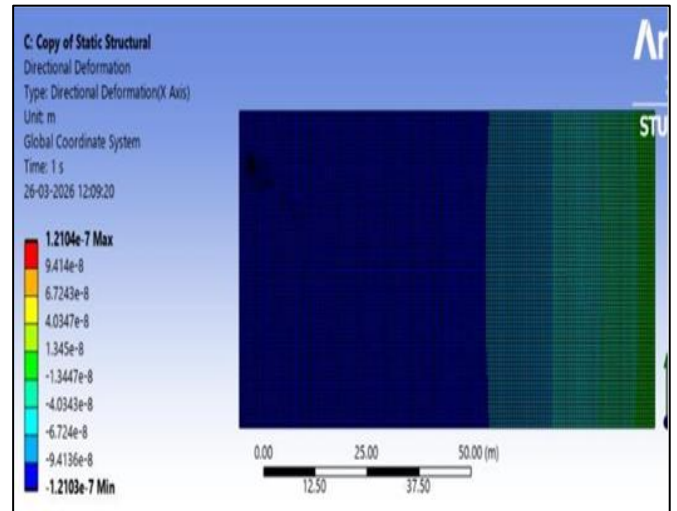


Fig 22 Equivalent Stress

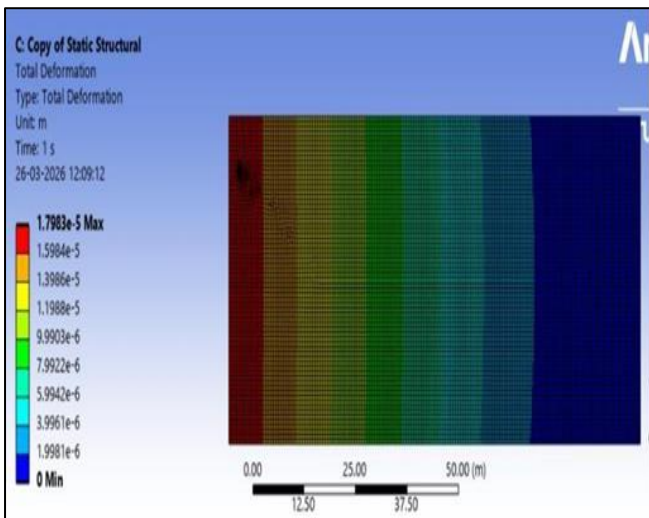


Fig 20 Total Deformation

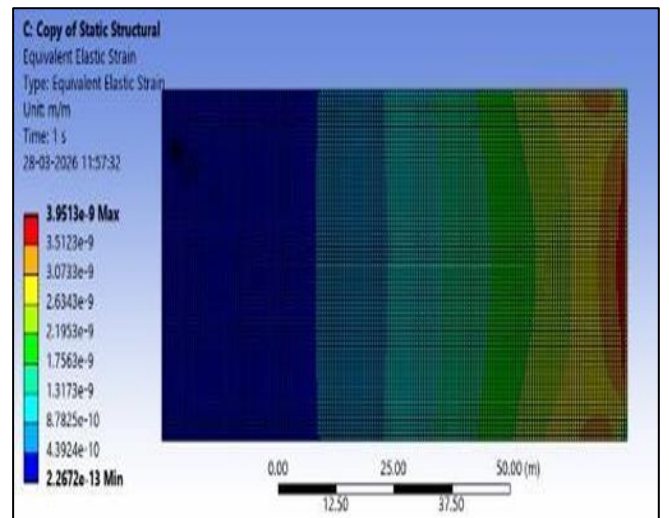


Fig 23 Equivalent Strain

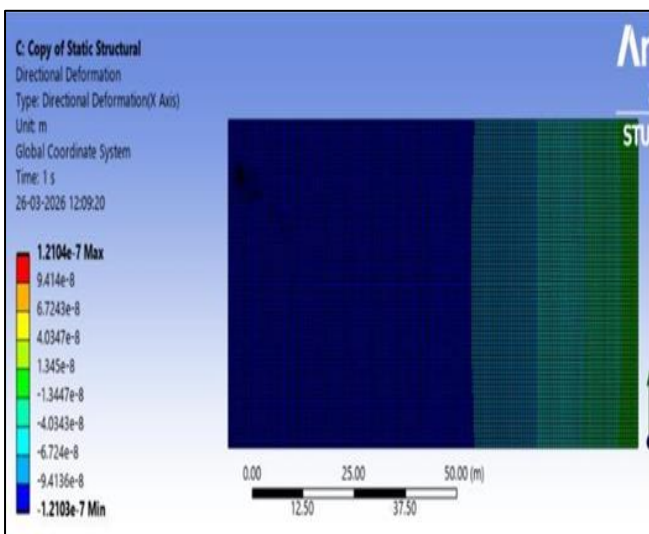


Fig 21 Directional Deformation

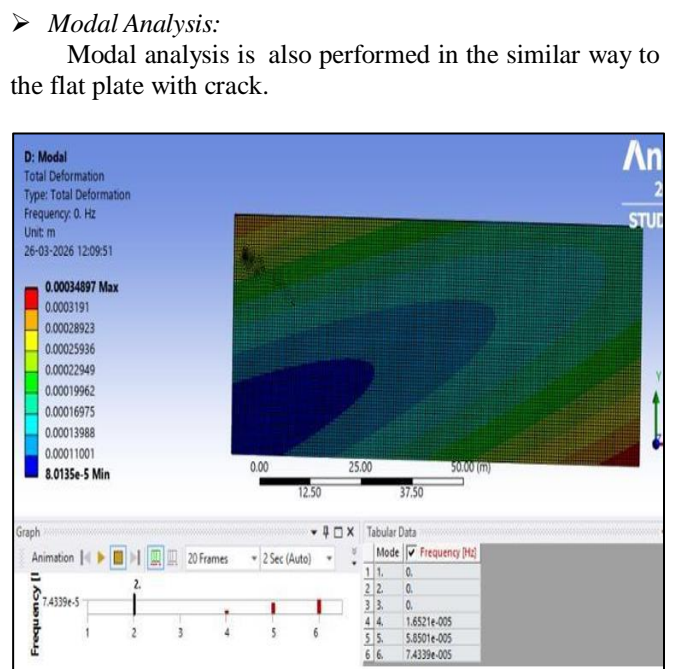


Fig 24 Mode Shape 1

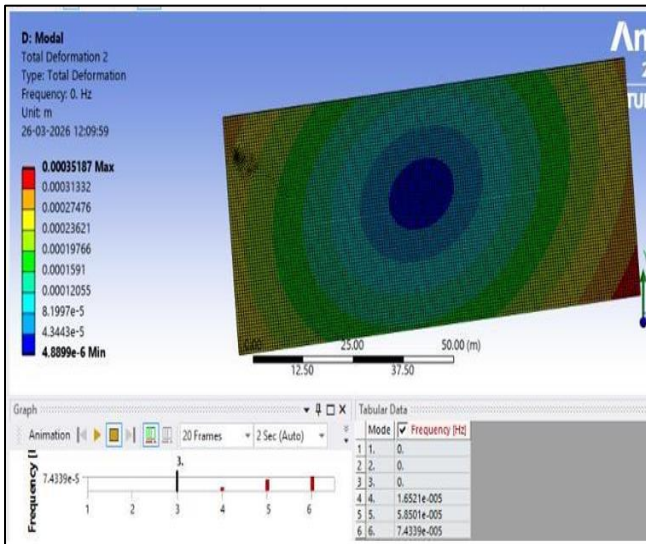


Fig 25 Mode Shape 2

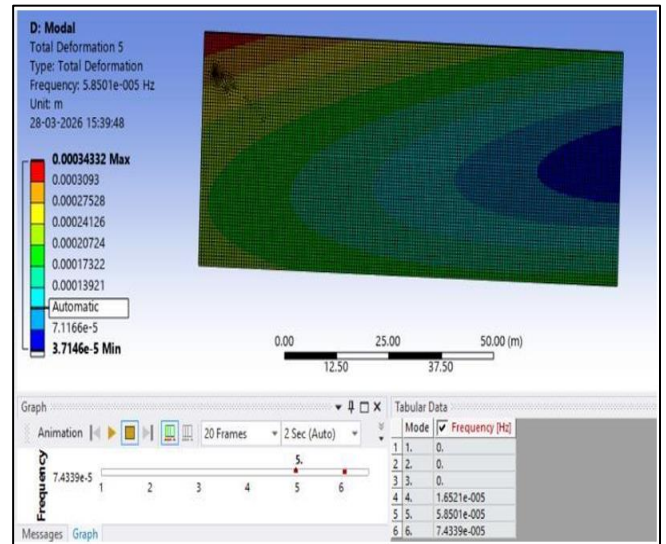


Fig 28 Mode Shape 5

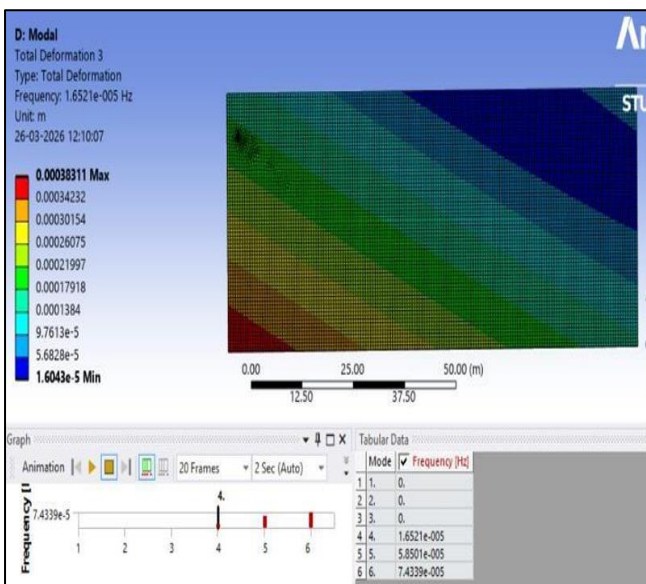


Fig 26 Mode Shape 3

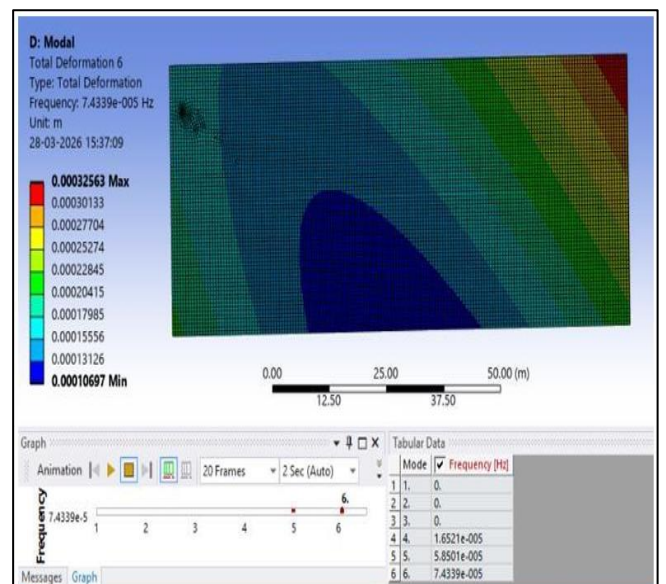


Fig 29 Mode Shape 6

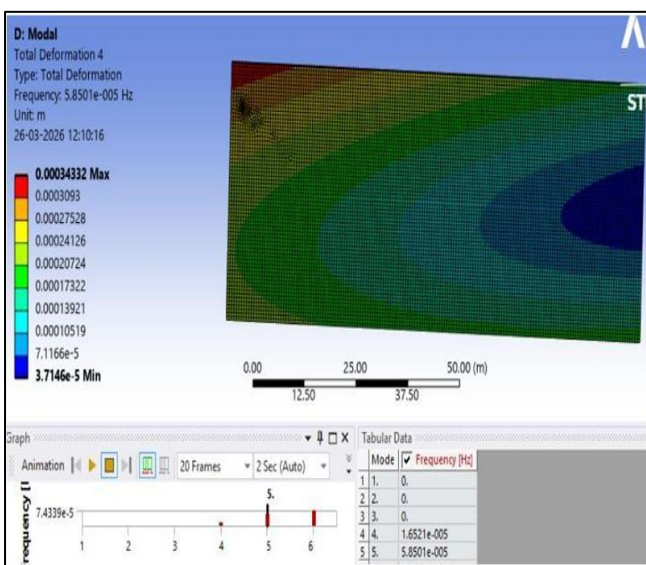


Fig 27 Mode Shape 4

Frequencies Observed in Modal Analysis for Flat Plate without Crack are:

Table 2 Frequencies of Flat Plate with Crack

Mode No	Frequency (Hz) –with Crack
1	0
2	0
3	0
4	1.6521e-005
5	5.8501e-005
6	7.4339e-005

IV. RESULTS AND DISCUSSIONS

The presence of a crack significantly alters the structural and dynamic behaviour of the flat plate by increasing stress concentration, deformation, and reducing natural frequencies, making the structure more prone to failure. The crack introduces a weak zone, causing localized stress concentration increasing failure risk.

Table 3 Comparing Frequencies

Mode No	Frequency (Hz)–without Crack	Frequency (Hz)– with Crack
1	0	0
2	0	0
3	0	0
4	3.2503e-005	1.6521e-005
5	8.2191e-005	5.8501e-005
6	9.838e-005	7.4339e-005

V. CONCLUSIONS

The analysis shows that a flat plate without crack has uniform stress distribution, smooth deformation, and higher natural frequencies, indicating stable behavior. In contrast, the cracked plate exhibits stress concentration, increased deformation, and reduced stiffness. These changes highlight the importance of Structural Health Monitoring (SHM) and predictive maintenance to detect damage early. SHM helps ensure safety and reliability by identifying cracks before failure occurs. Future work can include advanced crack analysis using fracture mechanics and different loading or material conditions. Implementing Structural Health Monitoring (SHM) and predictive maintenance can enable early crack detection and improve structural safety and reliability.

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