Structural Health Monitoring of Wind Turbine Blade

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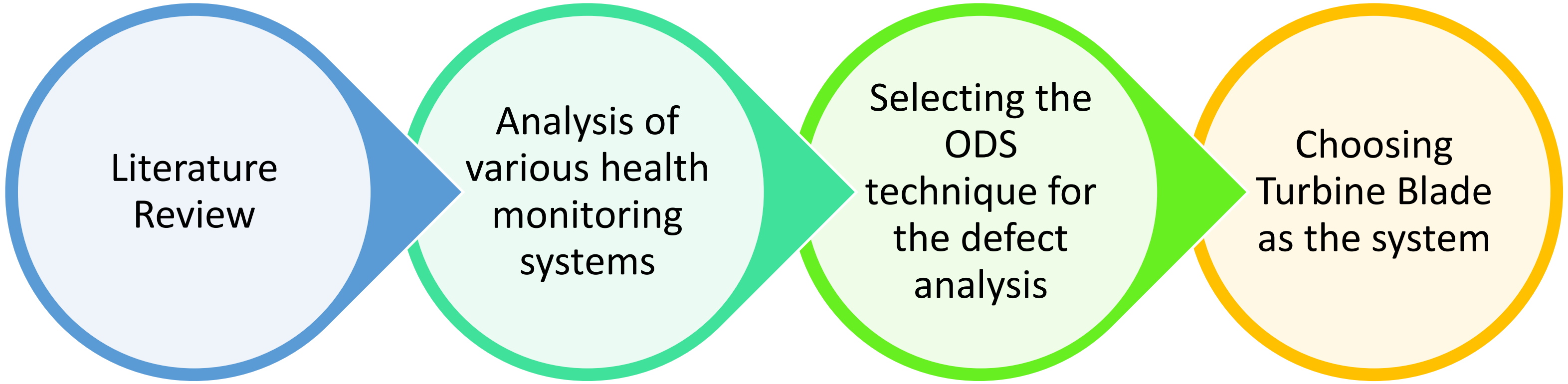
Contents

Problem Definition



<u>To determine the early detection of longitudinal cracks & establishing benchmarks for severity of their propagation at the trailing edge of the Wind Turbine blade</u>

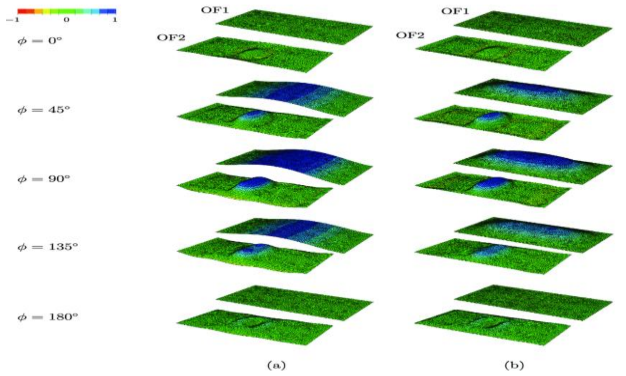
Abstract & Background

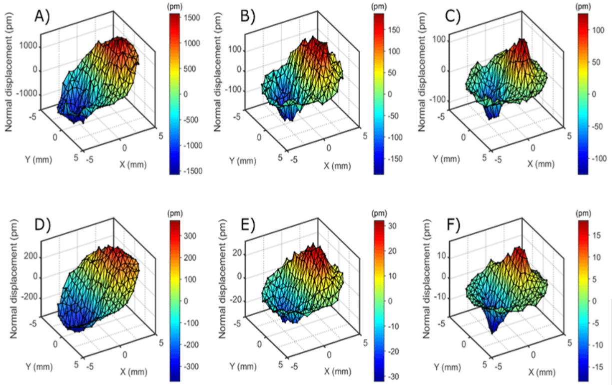
- Damage detection using vibration signals is a nondestructive testing method that utilizes global information about a structure.

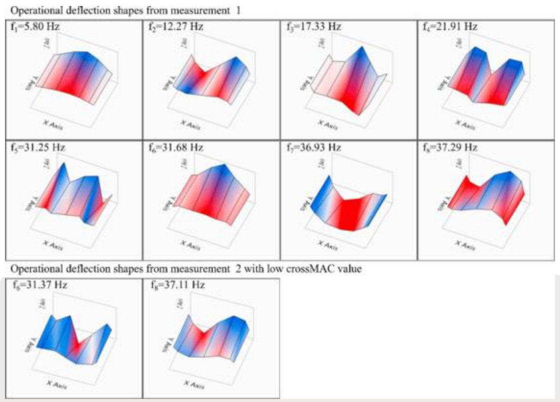
- Any damage to a structure can alter its physical properties, which causes changes in the natural frequency, damping, and other modal parameters of the material.

- Modal shapes and natural frequencies are often used for damage detection in structures due to the inexact measurement of mode damping.

Operational Deflection Shape(ODS) to visualize the vibration pattern of a machine or structure as influenced by its own operating forces.







Analysis on Turbine Blade Failures

Longitudinal Cracks

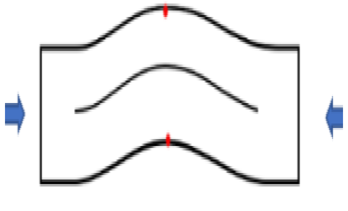
- The longitudinal crack at the trailing edge of the tip is mainly due to a reduction in the thickness of the shell, resulting in a crack formation due to change in stiffness of the blade.

Transverse Cracks

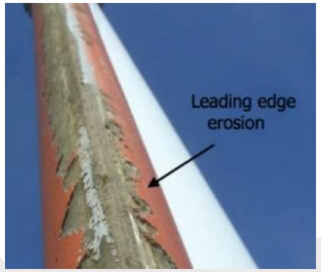
- It occurs mainly when one side of the blade needs to be polished in order to eliminate the asymmetry between the two shells of the blade during the manufacturing process, which leads to a reduction in glass fiber on one side, and this kind of crack occurs under the high load or stall of the blade.

Others

- Corrosion
- Damage due to lightning
- Delamination



Global Buckling Mode



Assumptions & Model Stratification

1)Blade Material is Orthotropic

2)Cross-Section<<Length of the Blade ->Slender

3)The blade is considered as a continuous system

4) 3 Degree of freedom system is considered

5)The cracks considered for analysis are present on trailing edge only & has been modelled as triangular geometries

6)First 20 Modes are considered for the analysis

7) The thermal effects are neglected & vibrations induced due the same are also neglected

Equation Formulations

The vibration equation of a structure with multiple degrees of freedom (MDOF) can be expressed as:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = 0$$

The Natural Frequencies of the System Determined as:

$$|A - \omega^2 I| = 0 \qquad \text{where, } A = [M]^{-1}[K]$$

In case of System Subjected to excitation force:

$$[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} = \mathrm{f(t)}$$

In case of Harmonic excitation the equation becomes:

$$(K - i\omega C - \omega^2 M)xe^{i\omega t} = fe^{i\omega t}$$

Equation Formulations

The FEM Elemental Equations for Solid187(10 noded) element with 3 Degrees of Freedom is given as:

$$[M]_{30\times30}\{\ddot{X}\}_{30X1} + [C]_{30\times30}\{\dot{X}\}_{30\times1} + [K]_{30\times30}\{X\}_{30\times1} = \{F_i^e\}$$

On Assembling for 633 Nodes the Equation Obtained are as follows:

$$[M]_{1899\times1899}\{\ddot{X}\}_{1899X1} + [C]_{1899\times1899}\{\dot{X}\}_{1899\times1} + [K]_{1899\times1899}\{X\}_{1899X1} = \{F_i\}_{1899X1}$$

Thus solving the above equation give the response of the system at different frequencies of applied excitation force.

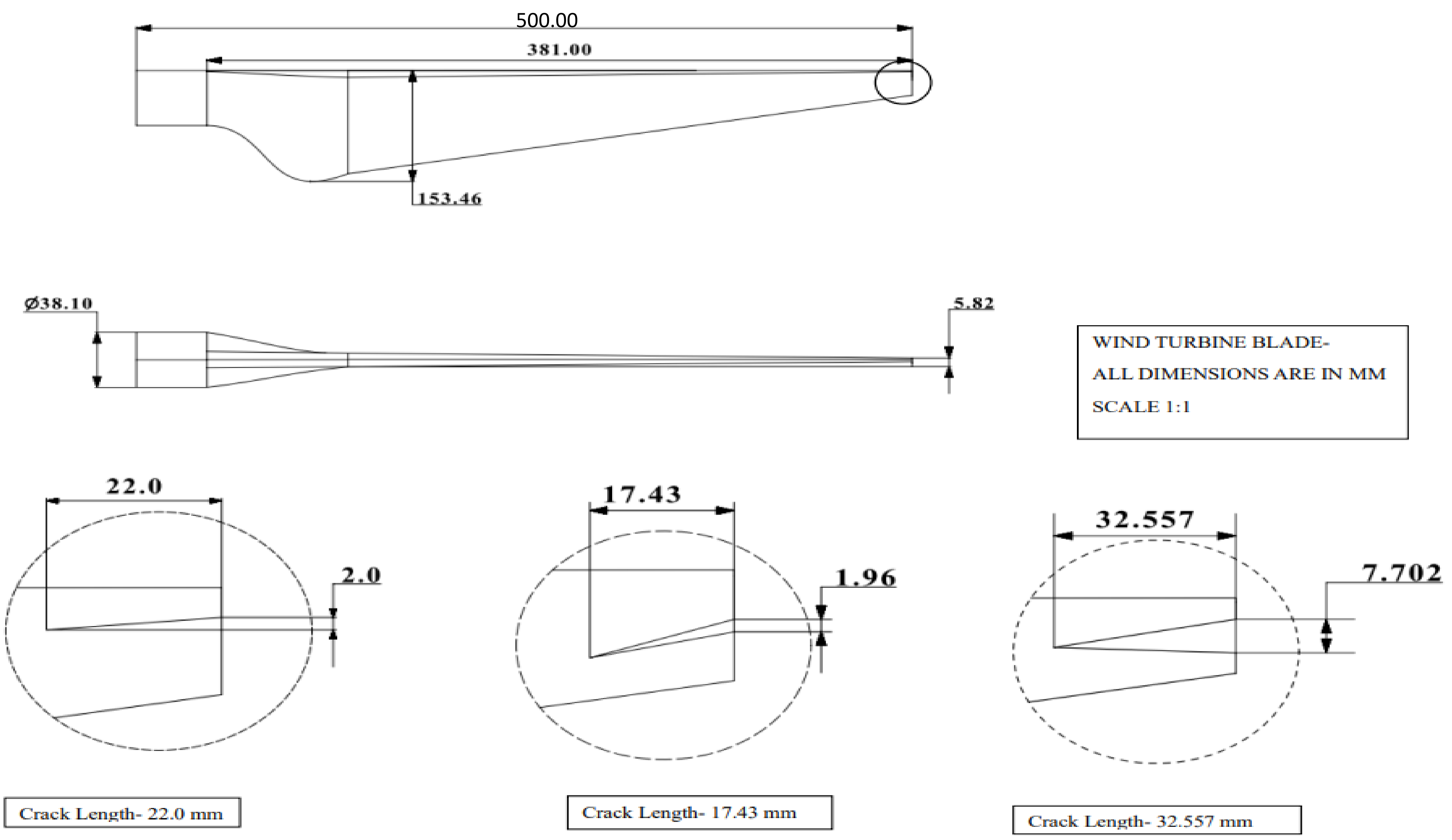
System Specifications

Material Specifications	
Material	Glass Fibre
Material Behaviour	Orthotropic
Ex	4.26*E10 Pa
Ey	1.65*E10 Pa
Ez	1.65*E10 Pa
Poisson's Ratio	0.3
Material Density	1950 kg/m^3
Damping Ratio	0.3
Blade Specifications	
Blade Length	500mm
Blade Maximum Width	153.5mm
Blade thickness	6mm

Process Flow

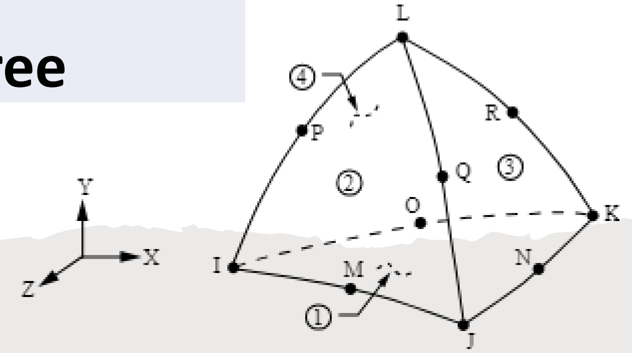
CAD model of the turbine Blade in Solidworks → FEM Modelling of the Blade → Modal Analysis using Ansys → Harmonic Response of the blade using Ansys → Compilation of Analysis for all cases taken

Turbine Blade Dimensions

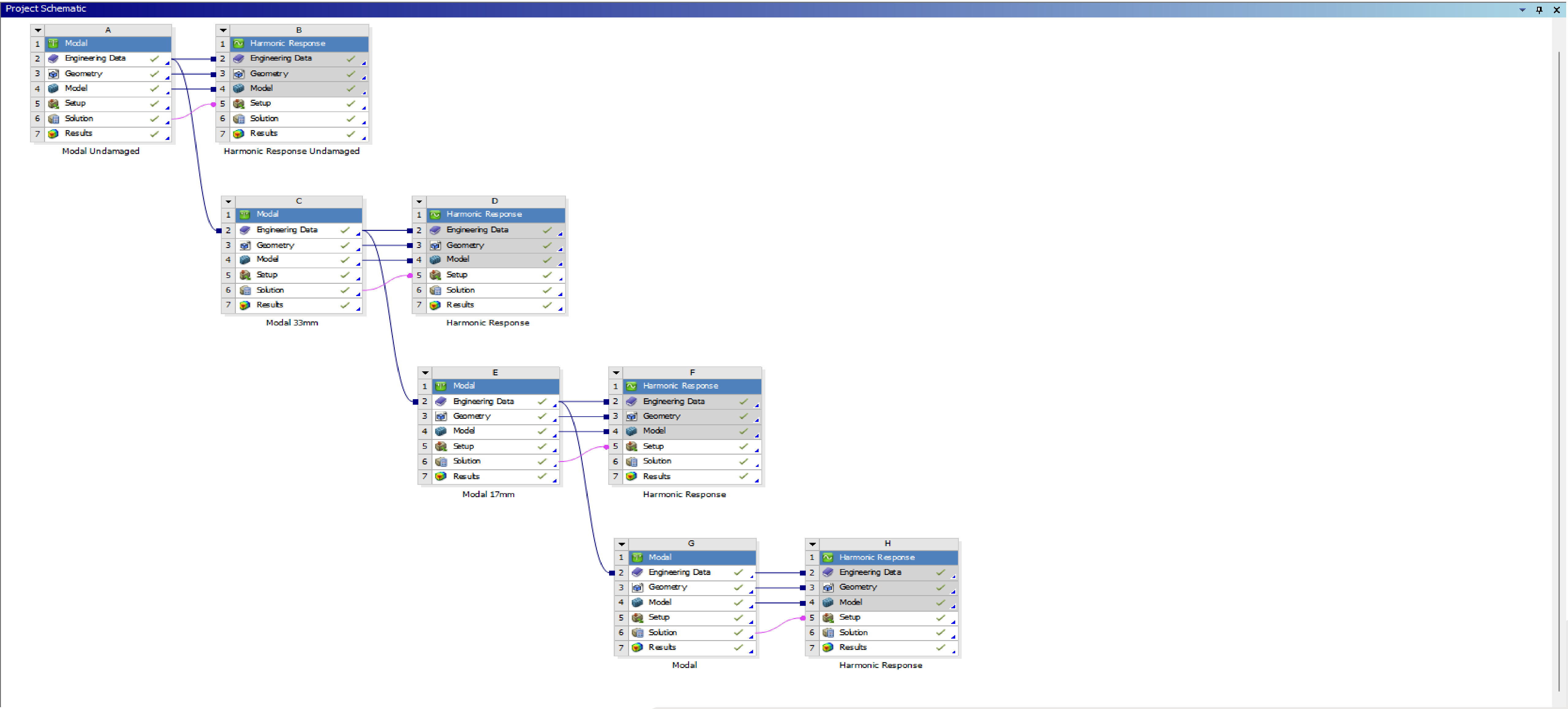


FEM Modelling

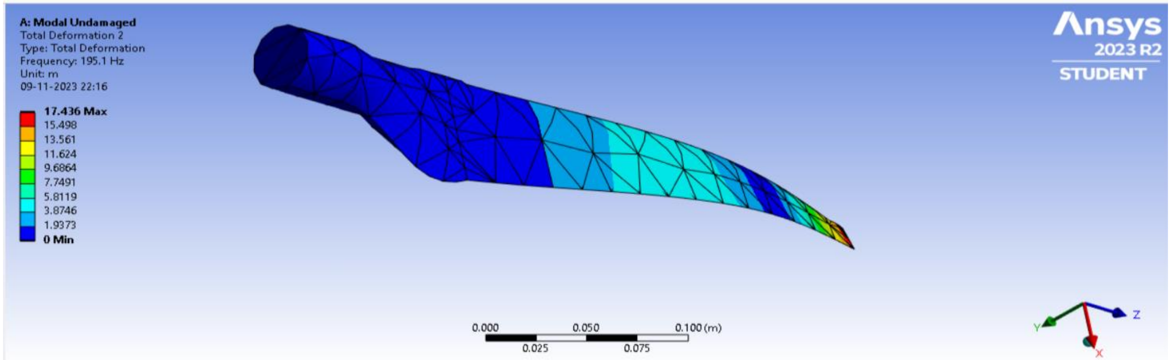
Problem Dimensionality	3D
Number of Total nodes	663
Number of Total Elements	246
Element type	SOLID187(Tetrahedron)
Number of Nodes in the elements	10
Degree of Freedom per node	3
Total Mass	0.30561 Kg
Minimum Edge Length of Element	0.1376 mm
Boundary Conditions	Fixed-Free

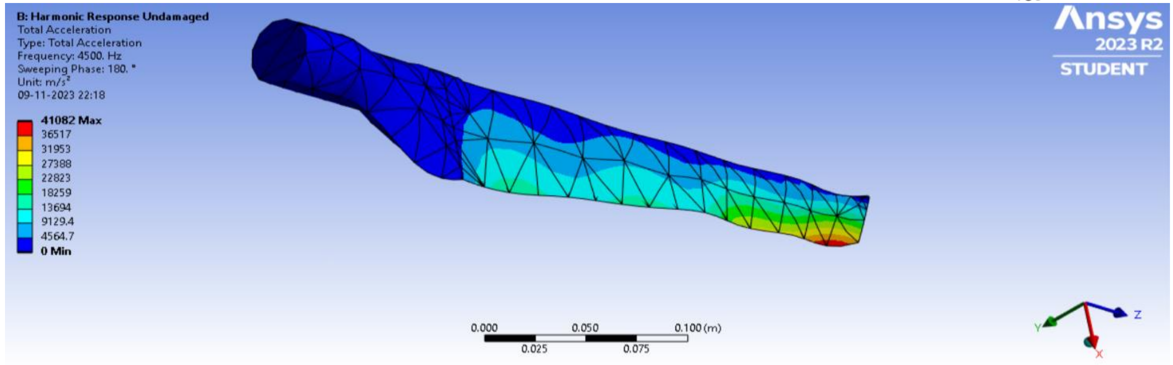


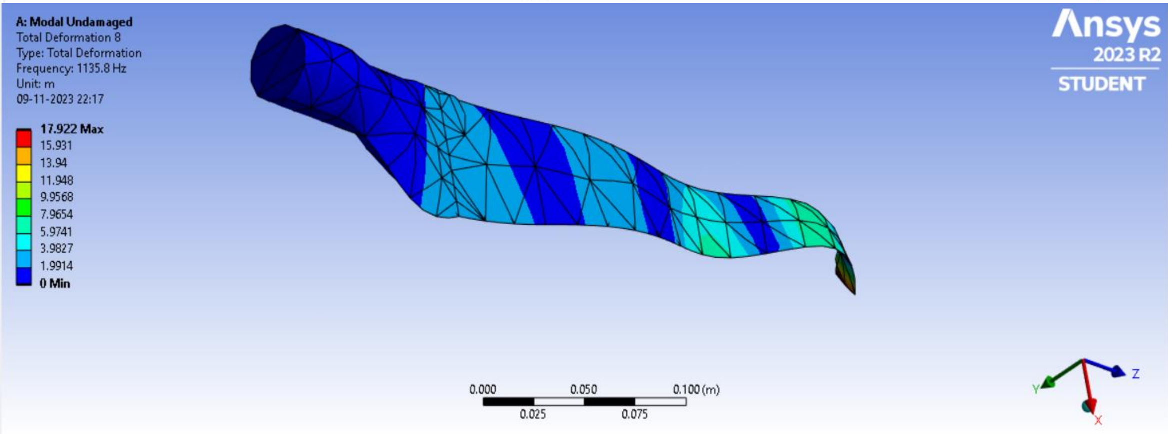
Ansys Workbench Simulation

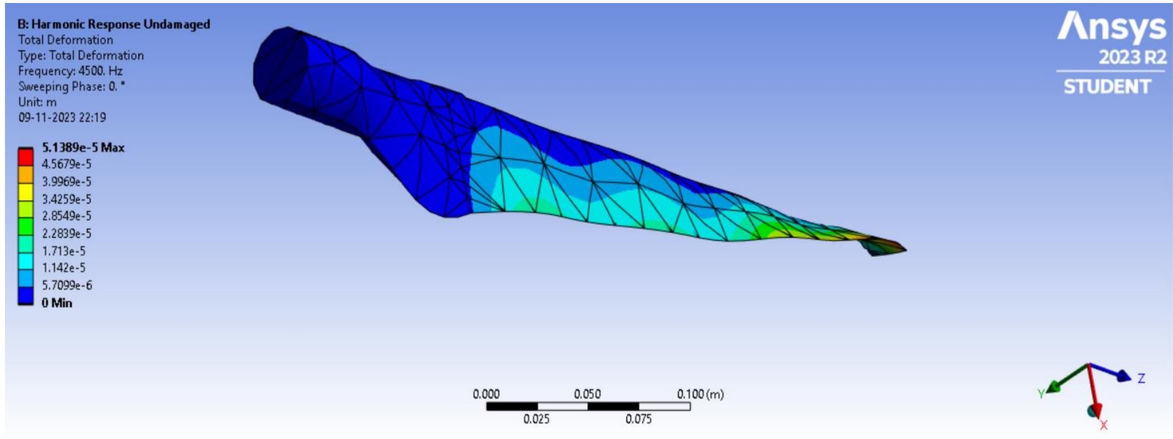


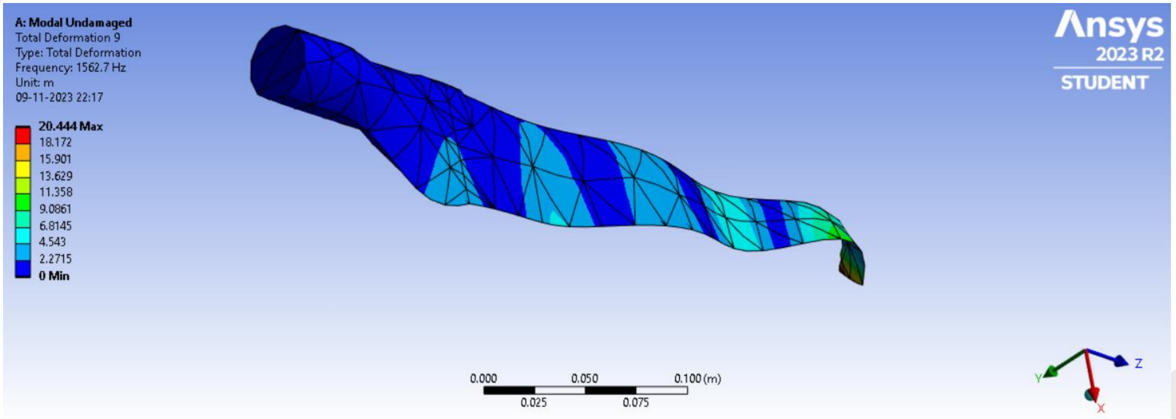
Snips of Analysis Performed in Ansys

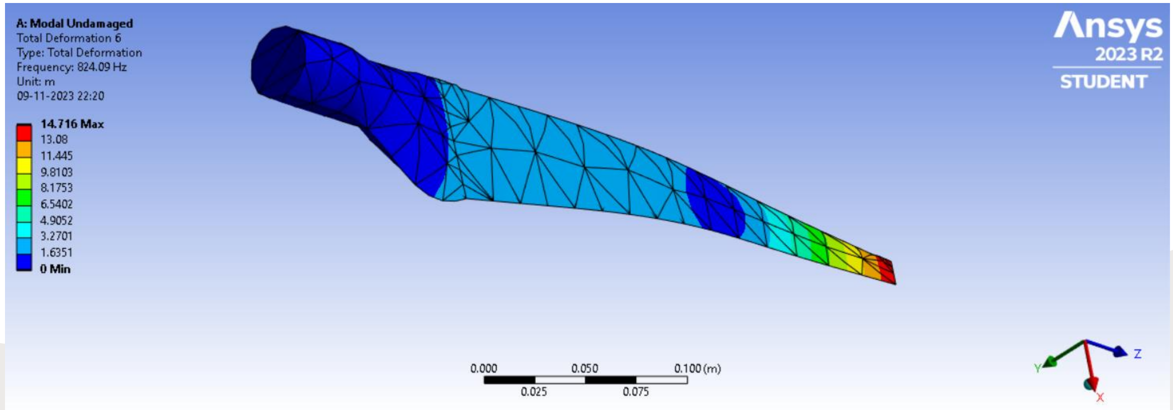












Results & Conclusions

Modal Analysis

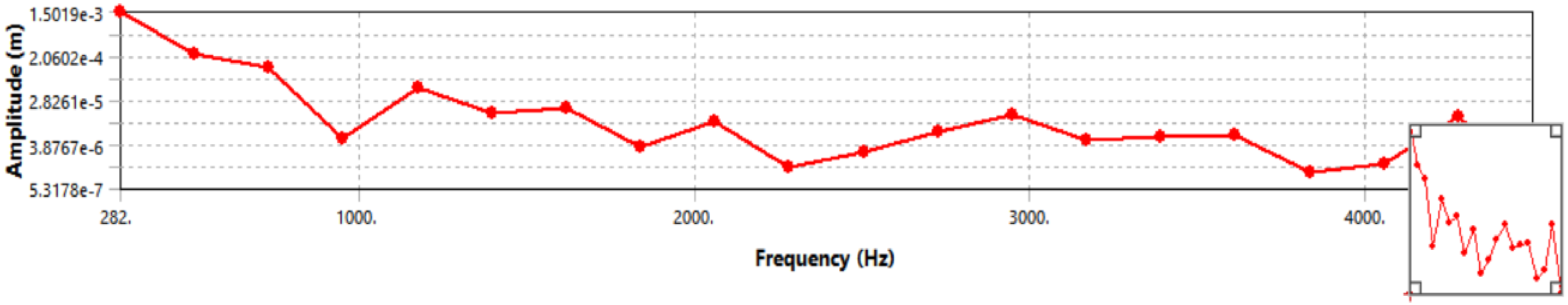
	Natural Frequency (Hz)			
Mode No	Undamaged	Damaged 17.4mm(Crack)	Damaged 22mm(Crack)	Damaged(32.6mm Crack)
1	60.189	0	0	0
2	195.1	0	0	0
3	303.8	3.85E-04	7.80E-04	6.80E-04
4	437.02	1.26E-03	1.28E-03	1.32E-03
5	776.16	1.48E-03	1.96E-03	1.63E-03
6	824.09	2.54E-03	2.55E-03	2.22E-03
7	1028.7	109.94	98.98	112.67
8	1135.8	275.2	244.3	278.39
9	1562.7	539.15	468.8	530.82
10	1699.7	697.1	759.96	715.71
11	1855.5	917.12	777.74	811.52
12	2146.9	1107.7	809.91	912.31
13	2691.5	1252	1198.9	1149.1
14	2882.1	1476.6	1328.5	1387
15	2895.2	1652	1670.2	1680.5
16	3262.6	1987	1760.4	1980
17	3439.1	2145.5	1775.5	2016.9
18	3653	2893.2	2170.9	2639.6
19	4249	2942.3	2331.7	2839.3
20	4286.8	2950.6	2883.9	2915.6

Excitation Response Amplitude

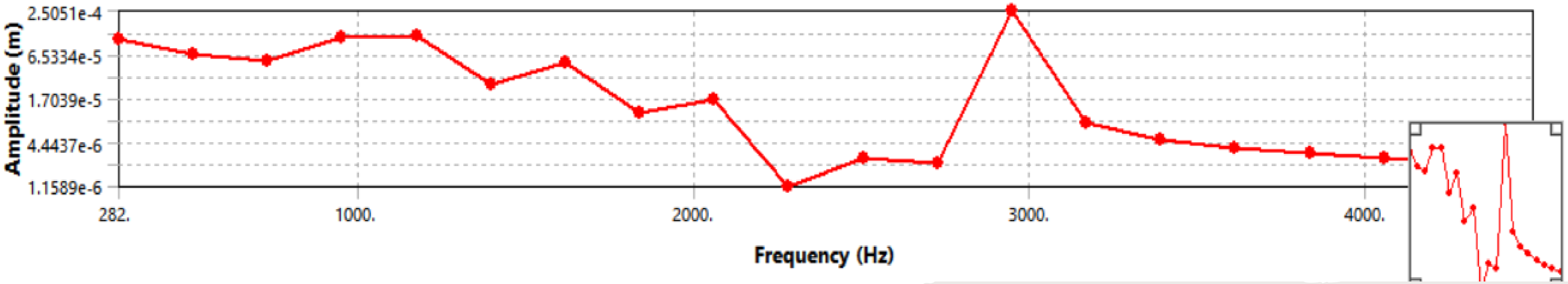
	Amplitude(m)			
Excitation Frequency(Hertz)	Undamaged	Damaged 17.4mm(Crack)	Damaged 22mm(Crack)	Damaged(32.6mm Crack)
282	1.50E-03	1.02E-04	3.00E-04	6.56E-04
504	2.28E-04	6.53E-05	2.38E-04	1.96E-04
726	1.23E-04	5.35E-05	4.67E-04	4.82E-05
948	5.03E-06	1.12E-04	6.43E-06	6.79E-05
1170	4.87E-05	1.15E-04	1.60E-05	4.15E-05
1392	1.61E-05	2.69E-05	1.34E-05	2.83E-04
1614	2.09E-05	5.06E-05	1.67E-05	4.03E-05
1836	3.62E-06	1.10E-05	9.54E-06	1.65E-05
2058	1.11E-05	1.67E-05	1.13E-06	1.15E-05
2280	1.40E-06	1.16E-06	6.09E-06	2.90E-06
2502	2.78E-06	2.84E-06	3.63E-06	1.44E-06
2724	7.24E-06	2.40E-06	2.83E-06	1.23E-05
2946	1.47E-05	2.51E-04	5.05E-07	4.74E-05
3168	4.89E-06	7.97E-06	1.32E-06	6.93E-06
3390	5.67E-06	4.92E-06	1.25E-06	4.81E-06
3612	6.04E-06	3.82E-06	1.13E-06	3.89E-06
3834	1.10E-06	3.18E-06	1.03E-06	3.31E-06
4056	1.72E-06	2.74E-06	9.28E-07	2.88E-06
4278	1.40E-05	2.40E-06	8.42E-07	2.55E-06
4500	5.32E-07	2.13E-06	7.66E-07	2.28E-06

Amplitude V/S Excitation Frequency

Frequency Response of Undamaged Blade

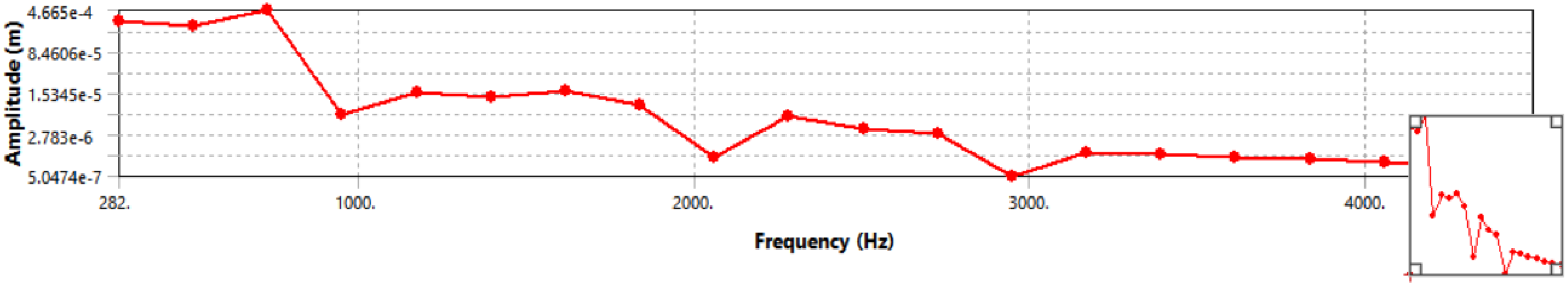


Frequency Response of 17mm Damaged Blade

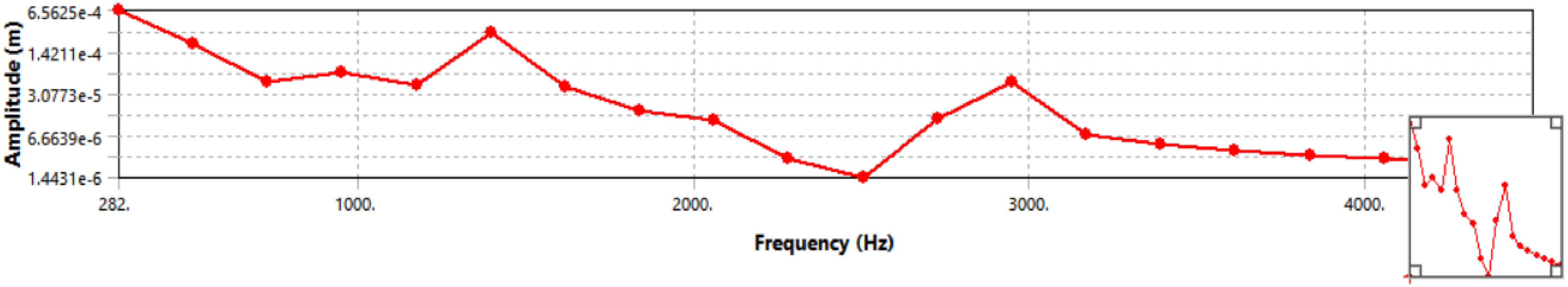


Amplitude V/S Excitation Frequency

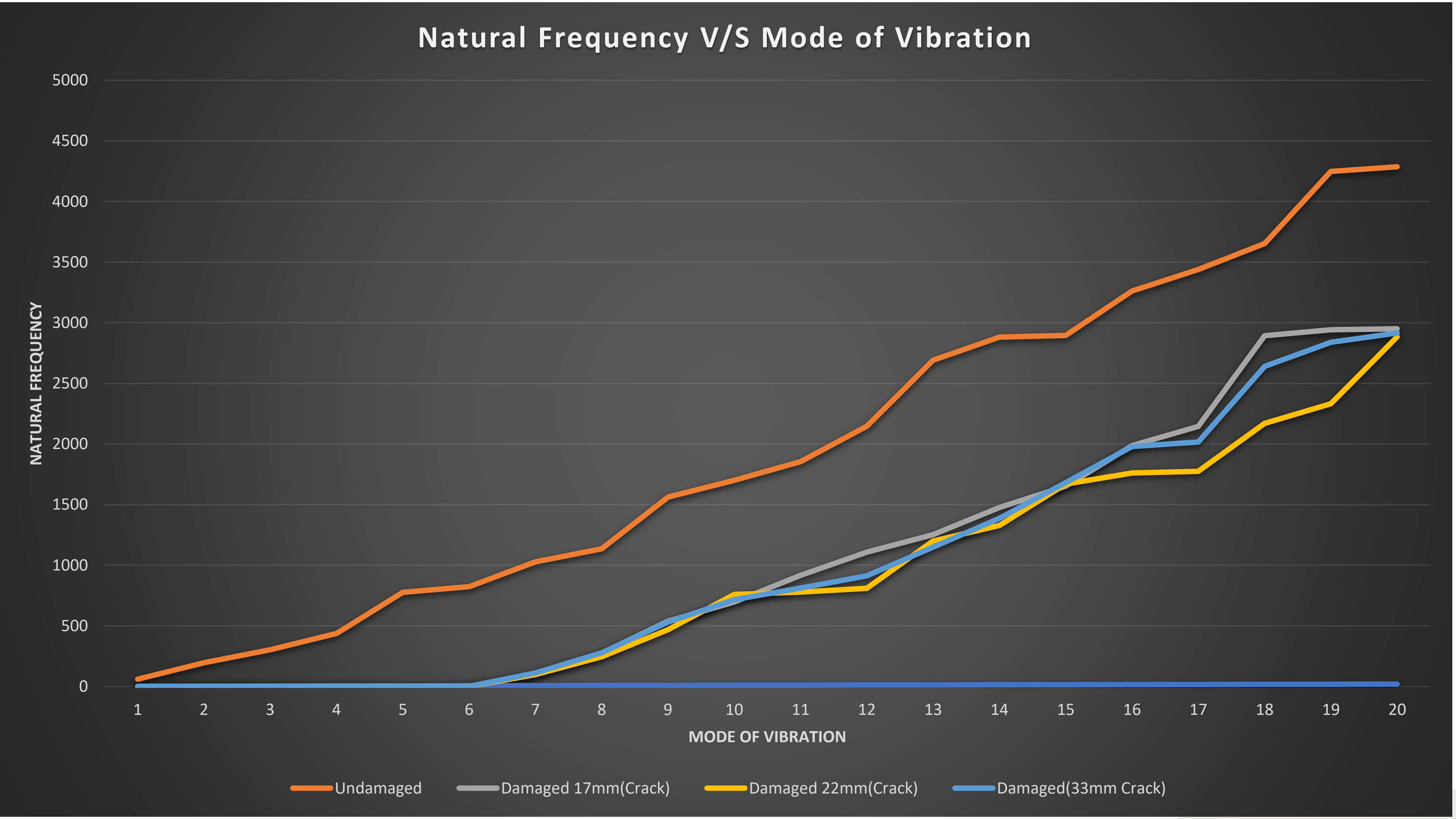
Damaged Blade with 22mm Crack



Damaged Blade with 32mm Crack

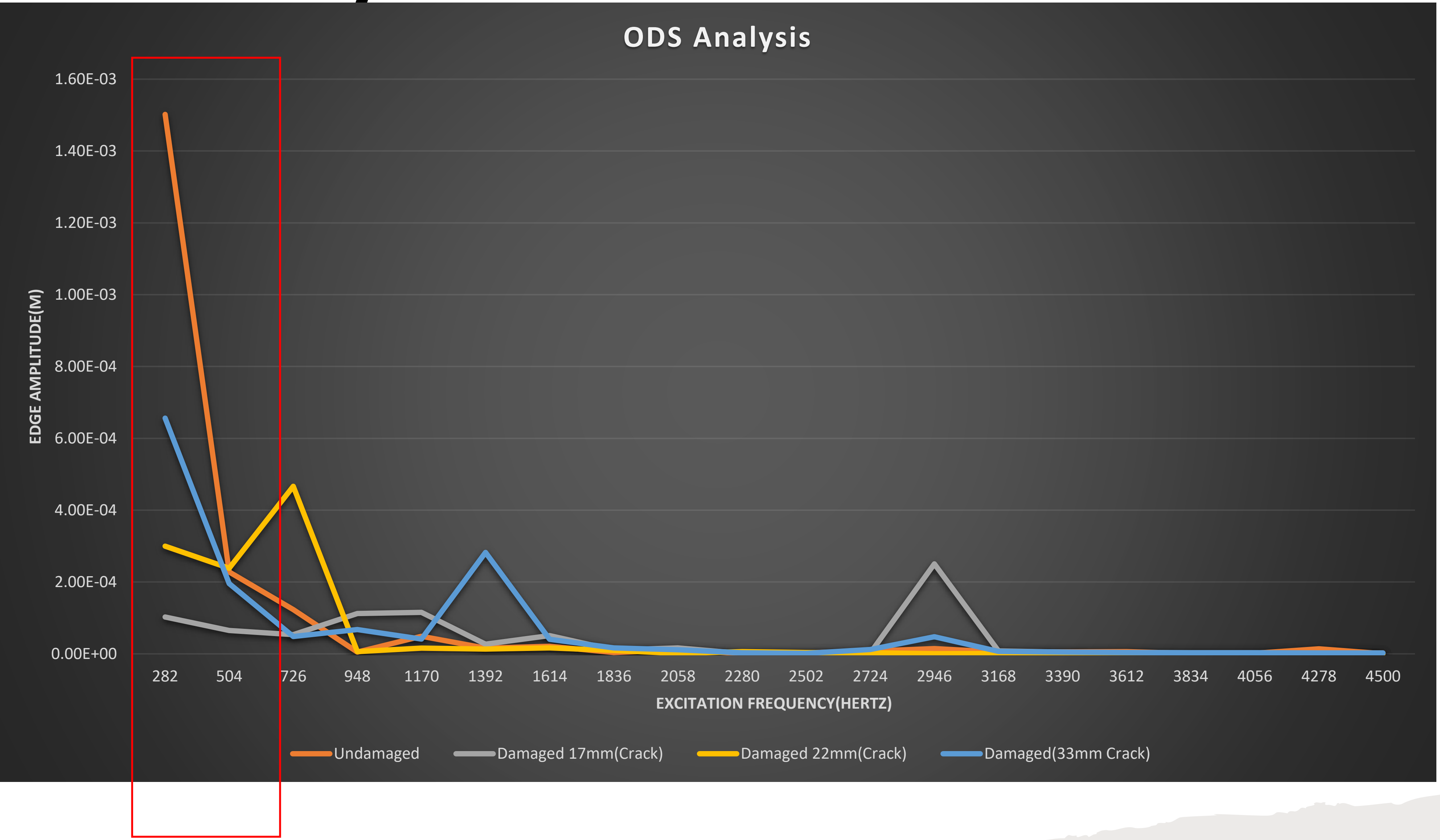


Variation of Natural Frequency With Damage



- A drastic change in natural frequency of the system is observed with the onset of cracks.
- Thus, Modal Analysis helps identify the existence of crack ,if any at the blade edge.

ODS Analysis



- Overall the response amplitude at the edge falls with the onset of the crack.
- The amplitude value is found to decrease with the crack propagation.
- There seems almost no distinction at higher frequencies of excitation.

References

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Thank You!