EFFECT OF THE IMPACT LOCATION ON THE FREQUENCY RESPONSE FUNCTION (FRF) IN FINITE ELEMENT MODAL ANALYSIS.

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Abstract: The most important tool for understanding the vibration characteristics of mechanical structures or component is modal analysis. It converts the vibration signals of excitation and responses measured on a complex structure which are difficult to perceive, into a set of modal parameters. Previously, methods used for studying vibration of plates are essentially based on either theoretical solutions or experimental works. However, due to the inherent difficulties and mathematical complications, to provide approximate solutions, numerical methods along with experimental and analytical methods are widely preferable. The Finite Element Method is a numerical tool to find the field variable in complex situation. Effect of the impact location on the resulting Frequency Response Function (FRF) is discussed in this research work. For this analysis, Aluminum (Al 6061T6) is used as the parent material and Butyl Rubber is used as Viscoelastic Damping Material (VDM) for preparing the composite material specimen. This structure/specimen is with butyl rubber plate which is sandwiched between two aluminum plates. The dimensions of the specimen are with length 350mm (with 50mm constrained at one end) and width 50mm.The thickness of the specimen may be vary and depends upon the thickness of Viscoelastic Damping Material (VDM) i.e. Butyl Rubber. The Main objective of the finite element modal analysis here is to study the effect of impact location on natural frequency and Frequency Response Function (FRF) especially in terms of acceleration magnitude for composite structure/specimen.

Keywords: FRF, Modal analysis, Impact Location, Composite Specimen, Abacus 6.13-1.

I. INTRODUCTION

An FRF is a measure of how much displacement, velocity, or acceleration response a structure/specimen has at an output DOF, per unit of excitation force at an input DOF. The displacement is found by dividing the acceleration signal by a factor proportional to the square of frequency. This is generally calculated by the measuring device. The vibration values are measured using metric with ISO standards. Generally for measuring low frequencies i.e. low RPM, displacement is used while acceleration is used for measuring high frequencies like bearing frequencies. Acceleration is the second derivative of displacement, it is the rate of change of velocity (the change in speed of the vibration). The velocity is best over a wide frequency range and it is the first derivative of displacement as a function of time i.e. it is the rate of change in displacement (the speed of the vibration). Here the effect on the relative magnitude acceleration of the first six frequencies for the different hammer locations are analyzed. **Amplitude vs. Frequency** – The Vibration amplitude indicates the severity of the problem while Vibration frequency indicates the source of the problem.

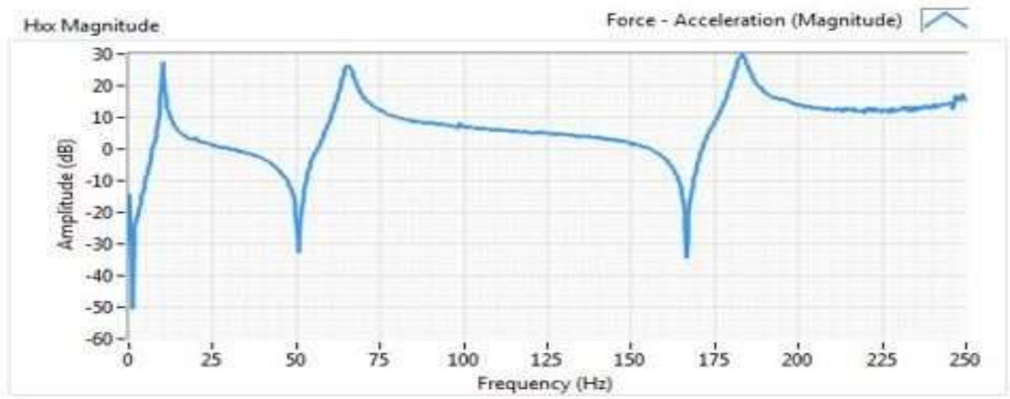


Figure 1. Amplitude vs. Frequency

Modal analysis is defined as the study of the dynamic characteristics of a mechanical structure. This application note emphasizes numerical modal techniques, specifically the method known as Frequency Response Function (FRF) technique. Other areas are treated in a general sense to introduce their elementary concepts and relationships to one another. Although modal techniques are mathematical in nature, the discussion is inclined toward practical application.

Abaqus CAE:-Abaqus/CAE is a complete Abaqus environment that provides a simple, consistent interface for creating, submitting, monitoring, and evaluating results from Abaqus/Standard and Abaqus/Explicit simulations. Abaqus/CAE is divided into modules, where each module defines a logical aspect of the modeling process; for example, defining the geometry, defining material properties, generating a mesh, submitting analysis jobs, and interpreting results. As we move from module to module, we build the model from which Abaqus/CAE generates an input file that we submit to the Abaqus/Standard or Abaqus/Explicit analysis product. The analysis product performs the analysis, sends information to Abaqus/CAE to allow us to monitor the progress of the job, and generates an output database. Finally, we use the Visualization module of Abaqus/CAE (also licensed separately as Abaqus/Viewer) to read the output database and view the results of our analysis. [13]

II. FREQUENCY RESPONSE FUNCTION (FRF)

2.1 Frequency Response Measurement:-

The basic test setup required for making frequency response measurements depends on a few major factors. These include the type of structure/specimen to be tested and the level of results desired. Other factors, including the support fixture and the excitation mechanism, also affect the amount of hardware needed to perform the test. The controller, or computer is the heart of the test system, which is the operator's communication link to the analyzer. It can be configured with various levels of memory, displays and data storage. The first step in setting up a structure/specimen for frequency response measurements is to consider the fixturing mechanism necessary to obtain the desired constraints i.e. boundary conditions. This is a key step in the process as it affects the overall structural characteristics, particularly for subsequent analyses such as structural modification, finite element correlation and substructure coupling. Analytically, boundary conditions can be specified in a completely free or completely constrained sense. The free condition means that the structure is floating in space with no attachments to ground and exhibits rigid body behavior at zero frequency. The constrained condition implies that the motion, (displacements/rotations) is set to zero. However, in reality most structures exhibit some degree of flexibility at the grounded connections. Another reason for choosing the appropriate boundary conditions is for finite element model correlation or substructure coupling analyses. [12]

2.2 Exciting the Structure

The next step in the measurement process involves selecting an excitation function along with an excitation system (e.g., a shaker, impact hammer etc.) that best suits the application. The choice of excitation can make the difference between a good measurement and a poor one. Excitation selection should be approached from both the type of function desired and the type of excitation system available because they are interrelated. The excitation function is the mathematical signal used for the input. Choosing a hammer for the excitation system dictates an impulsive type excitation function. Excitation functions fall into four general categories: steady-state, random, periodic and transient. When the output is fixed and FRFs are measured for multiple inputs, this corresponds to measuring elements from a single row of the FRF matrix. This is typical of a roving hammer impact test. Another common excitation mechanism in modal testing is an impact device. Although it is a relatively simple technique to implement, it's difficult to obtain consistent results. The convenience of this technique is attractive because it requires very little hardware and provides shorter measurement times. When the input is fixed and FRFs are measured for multiple outputs, this corresponds to measuring elements from a single column of the FRF matrix. [12]

III. FINITE ELEMENT MODAL ANALYSIS

In FEA, modal analysis is carried out by using the actual boundary conditions to find out the Natural frequency, Mode shapes and Frequency Response Functions (FRFs).The size of test specimen is initially considered as the free length (L) as 350 mm and width as 50 mm. The thicknesses of Viscoelastic Damping Material (VDM) varies from 0.8mm to 1.5 mm i.e.0.8mm, 1mm and 1.5mm. Accordingly, three specimens of composite plate are prepared which are shown in following table.

Table-1:Description of Specimen

Specimen Type	Composed Materials	Thickness (mm)		
		AL	VDM	AL
1	AL –VDM- AL	2	0.8	2
2	AL –VDM- AL	2	1	2
3	AL –VDM- AL	2	1.5	2

Table-2 :-Properties of Materials:-

Properties	Materials	
	Al 6061 T6	Butyl Rubber
Young's Modulus	68.9 GPa	0.0015GPa (0.001 -0.002GPa)
Poission's Ratio	0.33	0.4
Density	2.7 g/cm^3	1.35 g/cm^3(1.15-1.35 g/cm^3)

3.1 Steps in Modal Analysis:

1) **CAD Modeling:-** Prepare the CAD model of test specimen using the CAD software/tool such as CATIA V5-6R (2016). It is used for creating geometry and assemblies

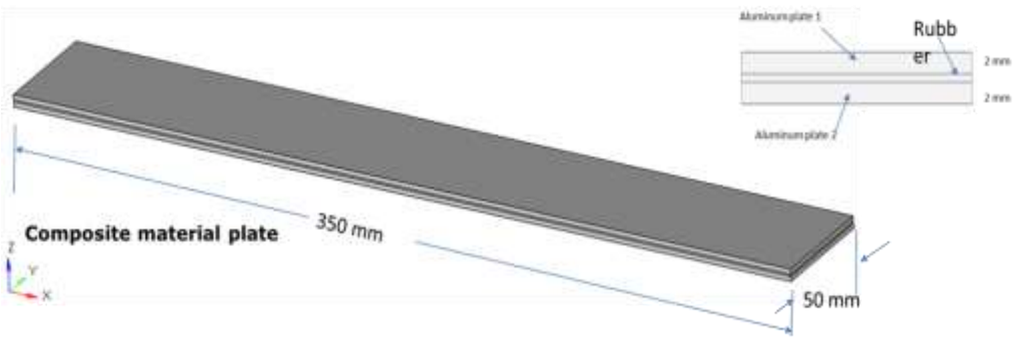


Figure 2: Composite Material Plate

2) Pre-processing- Meshing:-

In meshing, import the neutral format of CAD geometry in Pre-processor such as Hypermesh. The input data to be specified using the preprocessor. Three layers are created using 3D mesh having thickness 2mm-1mm-2mm. Modelling includes the features related to creating the model, such as node and element definition in Abaqus/Standard, Abaqus/Explicit, and Abaqus/CFD. It also includes part and assembly definition in Abaqus/CAE; and importing models to Abaqus/CAE. Here the element used for finite element modelling is C3D8 (8 Noded brick element). The preprocessor Hypermesh -v12 is used to discretize or mesh the geometries.

3) Preprocessor -Hypermesh:-

The **Hypermesh -v12** is used to discretize or mesh the geometries and apply material properties and boundary conditions. The material properties to be assigned for the respective layers and boundary conditions are applied as per the test standard (Cantilever type). Then the Respective cards to be assigned considering the type of analysis and specify the `type of analysis while creating the load step. Finally, select the desired output using the dialogue box and submit the output file to the solver.

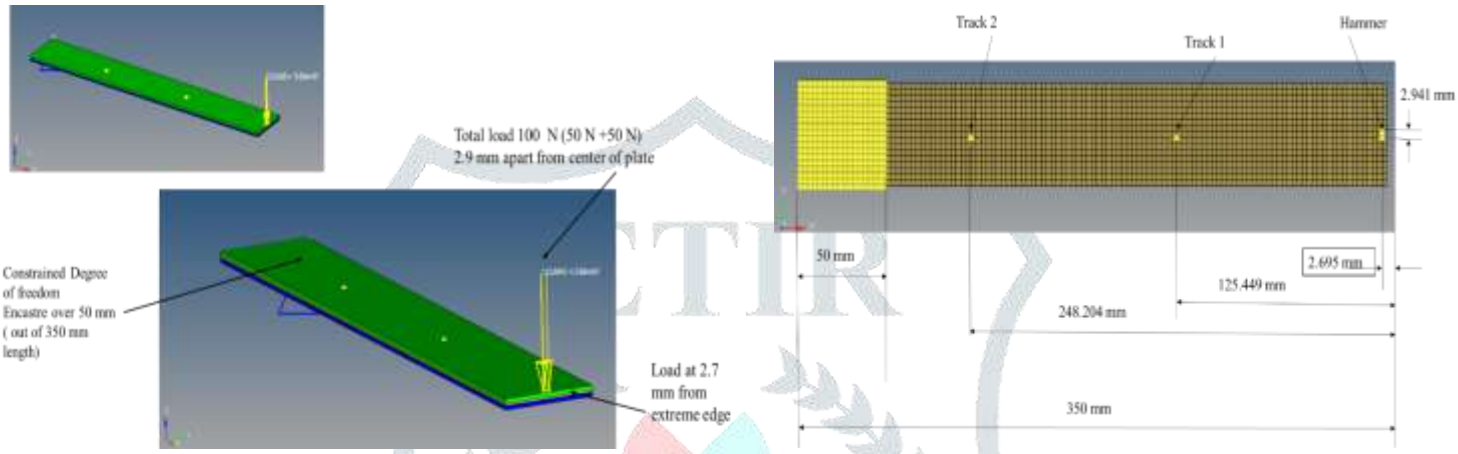


Figure 3. Boundary Conditions - Position of Hammer Location and Load Applied

Hammer point is 2.695 mm apart from extreme edge of specimen from R.H.S.Track point 1 is 125.449mm from extreme edge of specimen from R.H.S. i.e.125.449-2.695=122.754mm from hammer point.Track point 2 is 248.204 mm from extreme edge of specimen from R.H.S. i.e.248.204 -2.695 = 245.509mm from hammer point and 245.509 -122.754 =122.755mm(or 248.204-125.449=122.755mm) from track 1.Out of 350mm length of the specimen 50mm length from L.H.S. encastre i.e.constrained degree of freedom encastre over 50 mm length, hence free length of the specimen is 300mm.Total load of 100N (50N+50N) which is 2.941 mm apart from centre of specimen is applied by hammer.This load is applied at 2.695mm apart from extreme edge of the specimen as shown in fig.

4) Processing (Solver):-

Meshed model submitted to solver using Abaqus. Here Abaqus 6.13-1 version is used to set up the deck and run the analysis to obtain frequency response function(FRF) in constrained condition**.** Also the Frequency and Eigen Solver used is **Lanczos** .

5) Postprocessor-Abaqus Viewer:-

Abaqus/Viewer provides graphical display of Abaqus finite element models and results. Abaqus/Viewer is incorporated into Abaqus/CAE as the Visualization module. This subset of Abaqus/CAE contains only the postprocessing capabilities of the Visualization module. It is used for visualizing the results typically using HyperView as post processor. It uses the output database (.odb) to obtain results from the analysis products.

6) Comparison: - Comparing the results with alternate method used for the same test sample/specimen.

IV. RESULTS AND DISCUSSION

4.1 Result Table: -

Table 3. Acceleration Magnitude

Acceleration Magnitude											
Specimen 1				Specimen 2				Specimen 3			
Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2
0	0	0	0	0	0	0	0	0	0	0	0
1	2266.43	969.034	103.781	1	2305.49	987.57	107.209	1	2328.42	997.766	108.305
1.06441	2568.15	1098.06	117.6	1.06402	2610.48	1118.23	121.395	1.0634	2633.4	1128.47	122.494
1.13878	2940.03	1257.08	134.634	1.1379	2986.09	1279.15	138.867	1.13652	3008.55	1289.25	139.95
1.22605	3408.61	1457.46	156.098	1.22456	3458.98	1481.76	160.866	1.22223	3480.23	1491.42	161.899
1.33064	4016.01	1717.22	183.924	1.32837	4071.41	1744.16	189.359	1.32483	4090.23	1752.88	190.287
1.45958	4833.79	2066.98	221.392	1.45629	4895.12	2097.11	227.686	1.45116	4909.35	2104	228.413
1.62513	5995.57	2563.9	274.632	1.62042	6063.95	2597.99	282.082	1.6131	6069.55	2601.37	282.424

1.85158	7789.01	3331.11	356.838	1.84478	7865.75	3370.22	365.958	1.83421	7854.16	3366.54	365.527
2.19927	11004.4	4706.91	504.289	2.18894	11090.4	4752.59	516.14	2.1729	11039.3	4732.5	513.917
2.92234	19502.5	8344.97	894.394	2.90368	19590.1	8398.23	912.414	2.87477	19399.4	8319.8	903.836
10.5688	284814	123176	13337.3	10.421	282127	122256	13422.7	10.1942	273364	118524	13015.3
14.0437	557124	243096	26543.6	13.8238	550403	240642	26648	13.4871	531100	232340	25735.9
16.6807	876107	385527	42428.1	16.4027	864248	381065	42537.8	15.9776	832003	367064	40989
19.0051	1.29E+06	572413	63499.9	18.6738	1.27E+06	565175	63603.8	18.1676	1.22E+06	543492	61187.5
21.1607	1.86E+06	833245	93200	20.7785	1.83E+06	821994	93283.4	20.195	1.76E+06	789392	89620.5
23.2113	2.71E+06	1.22E+06	138033	22.7794	2.66E+06	1.21E+06	138070	22.1206	2.55E+06	1.16E+06	132495
25.1912	4.09E+06	1.87E+06	212546	24.7104	4.02E+06	1.84E+06	212478	23.9775	3.85E+06	1.76E+06	203675
27.1217	6.73E+06	3.11E+06	356867	26.5923	6.61E+06	3.06E+06	356506	25.7859	6.33E+06	2.93E+06	341297
29.0166	1.33E+07	6.19E+06	716817	28.4388	1.30E+07	6.08E+06	714912	27.5589	1.24E+07	5.80E+06	682501
30.8857	**99001.6**	**55719.6**	**16499.5**	**30.2594**	**96519.5**	**54296.9**	**16516**	**29.3061**	**91132.3**	**51226.9**	**15663.4**
31.814	2.14E+07	1.02E+07	1.21E+06	31.1684	2.09E+07	1.00E+07	1.20E+06	30.1871	1.98E+07	9.49E+06	1.14E+06
32.8497	1.55E+07	7.44E+06	883701	32.1826	1.51E+07	7.27E+06	877773	31.1701	1.43E+07	6.89E+06	831462
34.0206	1.10E+07	5.35E+06	639728	33.3292	1.08E+07	5.23E+06	635523	32.2815	1.02E+07	4.95E+06	601951
35.3676	8.37E+06	4.10E+06	493787	34.6482	8.17E+06	4.01E+06	490594	33.5599	7.74E+06	3.79E+06	464680
36.9539	6.63E+06	3.29E+06	400209	36.2015	6.48E+06	3.22E+06	397666	35.0655	6.13E+06	3.04E+06	376674
38.886	5.40E+06	2.72E+06	335901	38.0934	5.28E+06	2.66E+06	333812	36.8993	5.00E+06	2.52E+06	316207
41.3683	4.47E+06	2.31E+06	289351	40.5239	4.37E+06	2.26E+06	287601	39.2554	4.14E+06	2.14E+06	272452
44.8868	3.70E+06	1.98E+06	254581	43.969	3.62E+06	1.94E+06	253106	42.595	3.43E+06	1.83E+06	239797
51.3664	2.95E+06	1.70E+06	229662	50.3129	2.88E+06	1.66E+06	228440	48.7454	2.73E+06	1.57E+06	216463
94.5169	991147	1.87E+06	378190	92.5522	970450	1.82E+06	377116	89.7072	920512	1.73E+06	357441
108.161	194162	2.28E+06	530711	105.906	193185	2.22E+06	529400	102.66	184099	2.11E+06	501660
117.36	615014	2.74E+06	700816	114.909	595808	2.67E+06	699176	111.394	563419	2.53E+06	662380
124.852	1.58E+06	3.31E+06	915221	122.241	1.53E+06	3.23E+06	913114	118.507	1.45E+06	3.06E+06	864856
131.38	2.83E+06	4.07E+06	1.20E+06	128.629	2.76E+06	3.97E+06	1.20E+06	124.704	2.61E+06	3.76E+06	1.14E+06
137.272	4.59E+06	5.16E+06	1.62E+06	134.396	4.47E+06	5.02E+06	1.62E+06	130.299	4.24E+06	4.76E+06	1.53E+06
142.707	7.27E+06	6.82E+06	2.27E+06	139.714	7.09E+06	6.64E+06	2.26E+06	135.459	6.72E+06	6.29E+06	2.14E+06
147.794	1.17E+07	9.58E+06	3.34E+06	144.692	1.14E+07	9.33E+06	3.33E+06	140.289	1.08E+07	8.84E+06	3.15E+06
152.606	1.78E+07	1.34E+07	4.84E+06	149.4	1.74E+07	1.31E+07	4.82E+06	144.857	1.65E+07	1.24E+07	4.57E+06
157.192	**1.72E+06**	**1.11E+06**	**12987.9**	**153.888**	**1.68E+06**	**1.09E+06**	**12026.8**	**149.212**	**1.60E+06**	**1.03E+06**	**9265.13**
158.104	1.11E+07	4.78E+06	2.33E+06	154.798	1.10E+07	4.74E+06	2.36E+06	150.118	1.06E+07	4.64E+06	2.29E+06
159.096	1.86E+07	9.53E+06	4.20E+06	155.789	1.84E+07	9.39E+06	4.24E+06	151.104	1.77E+07	9.08E+06	4.08E+06
160.187	2.27E+07	1.21E+07	5.23E+06	156.879	2.23E+07	1.19E+07	5.24E+06	152.19	2.13E+07	1.13E+07	4.99E+06
161.407	2.37E+07	1.27E+07	5.47E+06	158.096	2.31E+07	1.24E+07	5.45E+06	153.403	2.19E+07	1.17E+07	5.15E+06
162.795	2.27E+07	1.21E+07	5.22E+06	159.483	2.20E+07	1.17E+07	5.18E+06	154.786	2.07E+07	1.10E+07	4.85E+06
164.423	2.07E+07	1.08E+07	4.73E+06	161.11	2.00E+07	1.04E+07	4.67E+06	156.407	1.87E+07	9.75E+06	4.36E+06
166.422	1.82E+07	9.33E+06	4.14E+06	163.107	1.76E+07	8.94E+06	4.08E+06	158.399	1.64E+07	8.32E+06	3.79E+06
169.096	1.56E+07	7.70E+06	3.51E+06	165.779	1.51E+07	7.36E+06	3.45E+06	161.065	1.41E+07	6.83E+06	3.20E+06
173.607	1.26E+07	5.83E+06	2.79E+06	170.29	1.22E+07	5.56E+06	2.74E+06	165.567	1.13E+07	5.15E+06	2.53E+06
195.559	7.27E+06	2.53E+06	1.57E+06	192.271	7.01E+06	2.40E+06	1.54E+06	187.553	6.54E+06	2.21E+06	1.43E+06
200.776	6.73E+06	2.21E+06	1.46E+06	197.503	6.48E+06	2.09E+06	1.44E+06	192.796	6.05E+06	1.93E+06	1.34E+06
204.001	6.44E+06	2.05E+06	1.41E+06	200.739	6.21E+06	1.93E+06	1.39E+06	196.041	5.80E+06	1.78E+06	1.29E+06

Acceleration Magnitude											
Specimen 1				Specimen 2				Specimen 3			
Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2
206.481	6.25E+06	1.93E+06	1.38E+06	203.227	6.02E+06	1.83E+06	1.36E+06	198.537	5.62E+06	1.68E+06	1.26E+06
208.546	6.10E+06	1.85E+06	1.35E+06	205.3	5.88E+06	1.74E+06	1.33E+06	200.617	5.49E+06	1.61E+06	1.24E+06
210.34	5.97E+06	1.78E+06	1.33E+06	207.101	5.76E+06	1.68E+06	1.31E+06	202.425	5.38E+06	1.55E+06	1.22E+06
211.941	5.87E+06	1.72E+06	1.32E+06	208.708	5.66E+06	1.62E+06	1.30E+06	204.038	5.28E+06	1.49E+06	1.21E+06
213.396	5.78E+06	1.67E+06	1.30E+06	210.168	5.57E+06	1.57E+06	1.29E+06	205.505	5.20E+06	1.45E+06	1.20E+06
214.735	5.70E+06	1.62E+06	1.29E+06	211.513	5.49E+06	1.53E+06	1.28E+06	206.856	5.13E+06	1.41E+06	1.19E+06
215.98	**5.62E+06**	**1.58E+06**	**1.28E+06**	**212.764**	**5.42E+06**	**1.49E+06**	**1.27E+06**	**208.112**	**5.06E+06**	**1.37E+06**	**1.18E+06**
218.601	5.48E+06	1.50E+06	1.27E+06	215.332	5.29E+06	1.42E+06	1.25E+06	210.597	4.94E+06	1.31E+06	1.17E+06
221.473	5.33E+06	1.42E+06	1.25E+06	218.145	5.15E+06	1.34E+06	1.24E+06	213.318	4.81E+06	1.24E+06	1.16E+06
224.657	5.17E+06	1.34E+06	1.23E+06	221.262	5.00E+06	1.26E+06	1.22E+06	216.334	4.68E+06	1.17E+06	1.15E+06
228.239	5.01E+06	1.25E+06	1.22E+06	224.771	4.84E+06	1.18E+06	1.21E+06	219.727	4.54E+06	1.10E+06	1.14E+06
232.356	4.83E+06	1.16E+06	1.21E+06	228.802	4.68E+06	1.10E+06	1.20E+06	223.626	4.38E+06	1.02E+06	1.13E+06
237.231	4.64E+06	1.07E+06	1.20E+06	233.575	4.49E+06	1.00E+06	1.20E+06	228.241	4.21E+06	933635	1.13E+06
243.289	4.41E+06	955596	1.20E+06	239.505	4.27E+06	898999	1.20E+06	233.973	4.01E+06	837864	1.13E+06
251.516	4.13E+06	820697	1.21E+06	247.558	4.00E+06	769941	1.21E+06	241.755	3.76E+06	719481	1.14E+06
265.721	3.66E+06	612967	1.26E+06	261.459	3.55E+06	569934	1.26E+06	255.18	3.34E+06	534783	1.19E+06

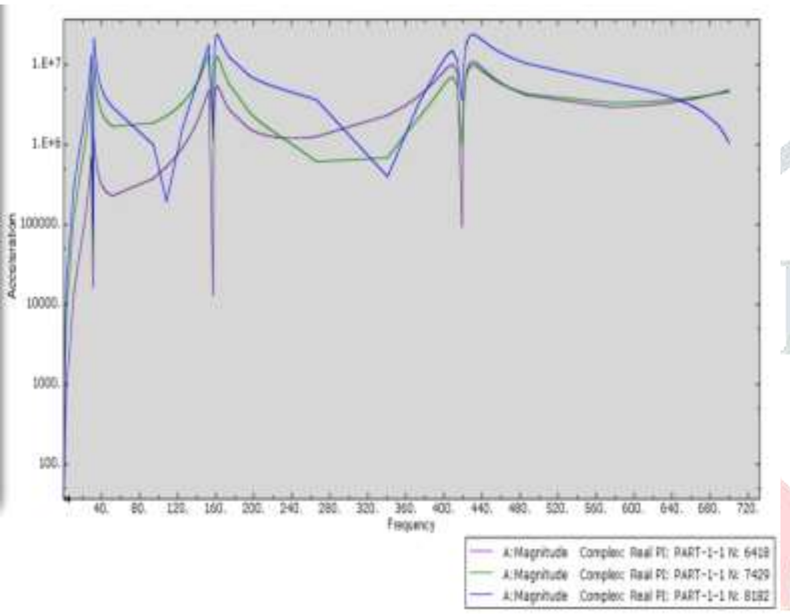
340.667	397395	685905	2.33E+06	334.733	370797	705383	2.32E+06	325.834	328874	666398	2.22E+06
359.907	1.36E+06	1.38E+06	3.13E+06	353.529	1.35E+06	1.39E+06	3.12E+06	343.929	1.31E+06	1.32E+06	2.98E+06
372.079	3.06E+06	2.07E+06	3.95E+06	365.416	3.01E+06	2.07E+06	3.94E+06	355.368	2.89E+06	1.97E+06	3.76E+06
381.579	4.98E+06	2.86E+06	4.92E+06	374.693	4.89E+06	2.86E+06	4.91E+06	364.293	4.69E+06	2.71E+06	4.68E+06
389.586	7.28E+06	3.82E+06	6.09E+06	382.51	7.14E+06	3.81E+06	6.07E+06	371.811	6.82E+06	3.61E+06	5.79E+06
396.613	1.00E+07	4.98E+06	7.52E+06	389.37	9.84E+06	4.95E+06	7.49E+06	378.407	9.38E+06	4.69E+06	7.14E+06
402.937	1.31E+07	6.27E+06	9.12E+06	395.544	1.28E+07	6.22E+06	9.07E+06	384.343	1.22E+07	5.88E+06	8.62E+06
408.729	1.51E+07	7.12E+06	1.02E+07	401.197	1.48E+07	7.04E+06	1.01E+07	389.777	1.39E+07	6.63E+06	9.54E+06
414.099	1.14E+07	5.48E+06	8.12E+06	406.438	1.10E+07	5.40E+06	8.03E+06	394.814	1.03E+07	5.04E+06	7.54E+06
419.125	**3.52E+06**	**968646**	**93513.8**	**411.344**	**3.46E+06**	**938218**	**95916.9**	**399.528**	**3.31E+06**	**916820**	**79830.8**
419.221	3.88E+06	1.12E+06	99237.6	411.441	3.82E+06	1.10E+06	102076	399.636	3.71E+06	1.09E+06	135945
419.324	4.27E+06	1.29E+06	307594	411.545	4.21E+06	1.27E+06	316250	399.753	4.13E+06	1.27E+06	369115
419.437	4.69E+06	1.47E+06	535554	411.66	4.64E+06	1.45E+06	550538	399.881	4.60E+06	1.48E+06	624164
419.562	5.16E+06	1.68E+06	788198	411.787	5.11E+06	1.66E+06	810166	400.023	5.12E+06	1.70E+06	906679
419.703	5.69E+06	1.90E+06	1.07E+06	411.931	5.65E+06	1.89E+06	1.10E+06	400.184	5.70E+06	1.96E+06	1.23E+06
419.867	6.30E+06	2.17E+06	1.40E+06	412.098	6.27E+06	2.17E+06	1.44E+06	400.37	6.37E+06	2.25E+06	1.59E+06
420.067	7.05E+06	2.49E+06	1.80E+06	412.301	7.02E+06	2.49E+06	1.85E+06	400.597	7.19E+06	2.60E+06	2.04E+06
420.33	8.02E+06	2.91E+06	2.32E+06	412.569	8.00E+06	2.92E+06	2.39E+06	400.896	8.24E+06	3.06E+06	2.62E+06
420.766	9.59E+06	3.59E+06	3.17E+06	413.012	9.58E+06	3.61E+06	3.25E+06	401.391	9.94E+06	3.80E+06	3.54E+06
422.74	1.59E+07	6.32E+06	6.56E+06	415.02	1.59E+07	6.36E+06	6.70E+06	403.636	1.64E+07	6.63E+06	7.08E+06
423.178	1.71E+07	6.82E+06	7.19E+06	415.465	1.70E+07	6.86E+06	7.32E+06	404.134	1.75E+07	7.11E+06	7.68E+06
423.444	1.77E+07	7.10E+06	7.54E+06	415.735	1.77E+07	7.14E+06	7.68E+06	404.436	1.81E+07	7.37E+06	8.01E+06
423.645	1.82E+07	7.31E+06	7.80E+06	415.94	1.81E+07	7.35E+06	7.93E+06	404.664	1.85E+07	7.55E+06	8.25E+06
423.811	1.86E+07	7.47E+06	8.00E+06	416.108	1.85E+07	7.50E+06	8.13E+06	404.853	1.89E+07	7.70E+06	8.43E+06
423.954	1.89E+07	7.60E+06	8.17E+06	416.254	1.88E+07	7.64E+06	8.29E+06	405.016	1.91E+07	7.82E+06	8.57E+06
424.08	1.91E+07	7.72E+06	8.31E+06	416.382	1.90E+07	7.75E+06	8.43E+06	405.159	1.94E+07	7.91E+06	8.70E+06
424.194	1.94E+07	7.82E+06	8.44E+06	416.498	1.93E+07	7.85E+06	8.56E+06	405.289	1.96E+07	8.00E+06	8.81E+06
424.298	1.96E+07	7.91E+06	8.55E+06	416.604	1.95E+07	7.93E+06	8.67E+06	405.408	1.97E+07	8.08E+06	8.90E+06
424.395	**1.98E+07**	**7.99E+06**	**8.65E+06**	**416.703**	**1.97E+07**	**8.01E+06**	**8.77E+06**	**405.518**	**1.99E+07**	**8.14E+06**	**8.99E+06**
427.815	2.37E+07	9.69E+06	1.08E+07	420.082	2.32E+07	9.58E+06	1.07E+07	408.813	2.23E+07	9.20E+06	1.03E+07
431.547	2.40E+07	9.84E+06	1.10E+07	423.77	2.33E+07	9.66E+06	1.08E+07	412.407	2.19E+07	9.07E+06	1.02E+07
435.664	2.25E+07	9.22E+06	1.02E+07	427.838	2.18E+07	9.02E+06	1.00E+07	416.374	2.04E+07	8.41E+06	9.33E+06
440.274	2.04E+07	8.34E+06	9.11E+06	432.395	1.98E+07	8.16E+06	8.96E+06	420.815	1.84E+07	7.59E+06	8.31E+06
445.541	1.82E+07	7.44E+06	7.99E+06	437.601	1.77E+07	7.27E+06	7.86E+06	425.891	1.65E+07	6.78E+06	7.30E+06
451.739	1.62E+07	6.59E+06	6.94E+06	443.727	1.57E+07	6.44E+06	6.83E+06	431.864	1.47E+07	6.02E+06	6.36E+06
459.381	1.43E+07	5.82E+06	5.98E+06	451.282	1.38E+07	5.68E+06	5.88E+06	439.229	1.30E+07	5.33E+06	5.49E+06
469.659	1.24E+07	5.09E+06	5.08E+06	461.444	1.21E+07	4.97E+06	5.00E+06	449.137	1.13E+07	4.68E+06	4.69E+06
487.144	1.04E+07	4.33E+06	4.15E+06	478.734	1.01E+07	4.23E+06	4.09E+06	465.996	9.51E+06	4.01E+06	3.84E+06

Acceleration Magnitude											
Specimen 1				Specimen 2				Specimen 3			
Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2	Frequency	Hammer	Track 1	Track 2
574.708	6.02E+06	3.35E+06	2.97E+06	565.38	5.88E+06	3.28E+06	2.94E+06	550.495	5.60E+06	3.15E+06	2.80E+06
596.104	5.34E+06	3.37E+06	3.02E+06	586.565	5.21E+06	3.30E+06	2.99E+06	571.158	4.98E+06	3.19E+06	2.85E+06
609.442	4.91E+06	3.42E+06	3.09E+06	599.774	4.79E+06	3.35E+06	3.06E+06	584.042	4.59E+06	3.24E+06	2.93E+06
619.751	4.58E+06	3.48E+06	3.17E+06	609.984	4.46E+06	3.41E+06	3.14E+06	594.003	4.27E+06	3.29E+06	3.01E+06
628.372	4.29E+06	3.54E+06	3.25E+06	618.524	4.18E+06	3.47E+06	3.23E+06	602.333	4.01E+06	3.35E+06	3.09E+06
635.89	4.02E+06	3.60E+06	3.34E+06	625.972	3.92E+06	3.53E+06	3.32E+06	609.599	3.76E+06	3.41E+06	3.18E+06
642.619	3.78E+06	3.66E+06	3.42E+06	632.638	3.68E+06	3.59E+06	3.41E+06	616.102	3.53E+06	3.47E+06	3.27E+06
648.75	3.55E+06	3.72E+06	3.51E+06	638.712	3.45E+06	3.65E+06	3.50E+06	622.027	3.32E+06	3.54E+06	3.36E+06
654.408	3.33E+06	3.79E+06	3.61E+06	644.318	3.23E+06	3.72E+06	3.59E+06	627.496	3.11E+06	3.60E+06	3.45E+06
659.682	**3.11E+06**	**3.86E+06**	**3.70E+06**	**649.544**	**3.02E+06**	**3.78E+06**	**3.69E+06**	**632.595**	**2.90E+06**	**3.67E+06**	**3.55E+06**
660.395	3.08E+06	3.87E+06	3.72E+06	650.429	2.98E+06	3.80E+06	3.71E+06	633.761	2.86E+06	3.68E+06	3.57E+06
661.167	3.05E+06	3.88E+06	3.73E+06	651.388	2.94E+06	3.81E+06	3.73E+06	635.026	2.80E+06	3.70E+06	3.59E+06
662.011	3.01E+06	3.89E+06	3.75E+06	652.438	2.89E+06	3.82E+06	3.75E+06	636.412	2.74E+06	3.72E+06	3.62E+06
662.949	2.97E+06	3.90E+06	3.77E+06	653.603	2.84E+06	3.84E+06	3.77E+06	637.951	2.68E+06	3.74E+06	3.66E+06
664.01	2.93E+06	3.92E+06	3.79E+06	654.923	2.79E+06	3.86E+06	3.80E+06	639.695	2.60E+06	3.77E+06	3.69E+06
665.245	2.87E+06	3.93E+06	3.81E+06	656.459	2.72E+06	3.88E+06	3.84E+06	641.727	2.51E+06	3.80E+06	3.74E+06
666.748	2.81E+06	3.96E+06	3.84E+06	658.33	2.63E+06	3.91E+06	3.88E+06	644.203	2.40E+06	3.84E+06	3.80E+06
668.735	2.72E+06	3.99E+06	3.89E+06	660.805	2.52E+06	3.95E+06	3.94E+06	647.483	2.25E+06	3.90E+06	3.88E+06
672.03	2.57E+06	4.04E+06	3.96E+06	664.914	2.32E+06	4.02E+06	4.04E+06	652.939	1.98E+06	4.00E+06	4.03E+06
687.138	1.80E+06	4.32E+06	4.37E+06	683.819	1.29E+06	4.41E+06	4.62E+06	678.19	470862	4.62E+06	4.95E+06

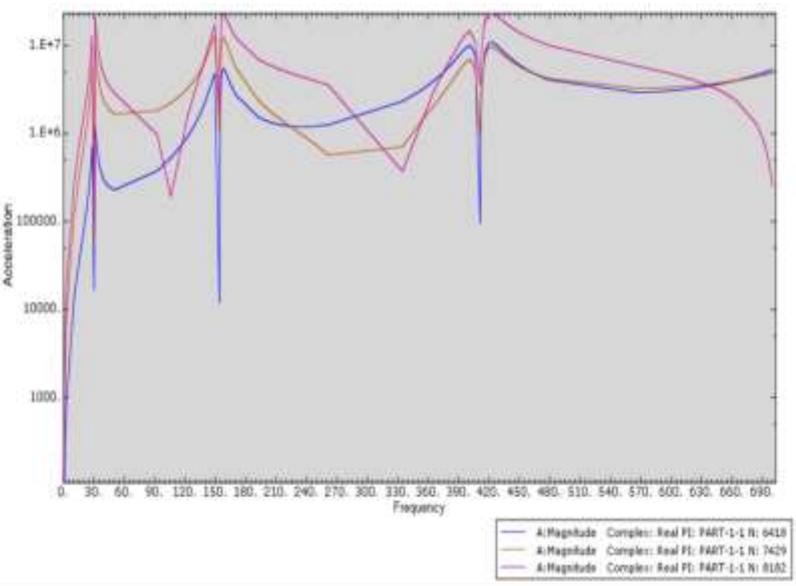
690.524	1.61E+06	4.39E+06	4.48E+06	688.071	1.03E+06	4.52E+06	4.78E+06	683.904	178059	4.80E+06	5.23E+06
692.582	1.49E+06	4.44E+06	4.54E+06	690.659	860605	4.59E+06	4.88E+06	687.387	340098	4.93E+06	5.42E+06
694.146	1.40E+06	4.48E+06	4.60E+06	692.626	729351	4.64E+06	4.97E+06	690.039	551295	5.03E+06	5.57E+06
695.437	1.32E+06	4.51E+06	4.64E+06	694.251	619386	4.69E+06	5.04E+06	692.23	743858	5.12E+06	5.70E+06
696.55	1.25E+06	4.54E+06	4.68E+06	695.653	524017	4.73E+06	5.10E+06	694.123	919531	5.20E+06	5.82E+06
697.537	1.19E+06	4.56E+06	4.72E+06	696.896	440003	4.77E+06	5.16E+06	695.802	1.08E+06	5.27E+06	5.93E+06
698.429	1.14E+06	4.58E+06	4.75E+06	698.019	365947	4.80E+06	5.21E+06	697.32	1.23E+06	5.34E+06	6.04E+06
699.245	1.09E+06	4.60E+06	4.78E+06	699.048	301872	4.84E+06	5.26E+06	698.711	1.38E+06	5.40E+06	6.14E+06
700	1.04E+06	4.62E+06	4.81E+06	700	249343	4.87E+06	5.31E+06	700	1.52E+06	5.46E+06	6.23E+06

4.2 Graphs:-FRFs (Frequency vs Acceleration) at Point Hammer, Track 1 and Track 2:-

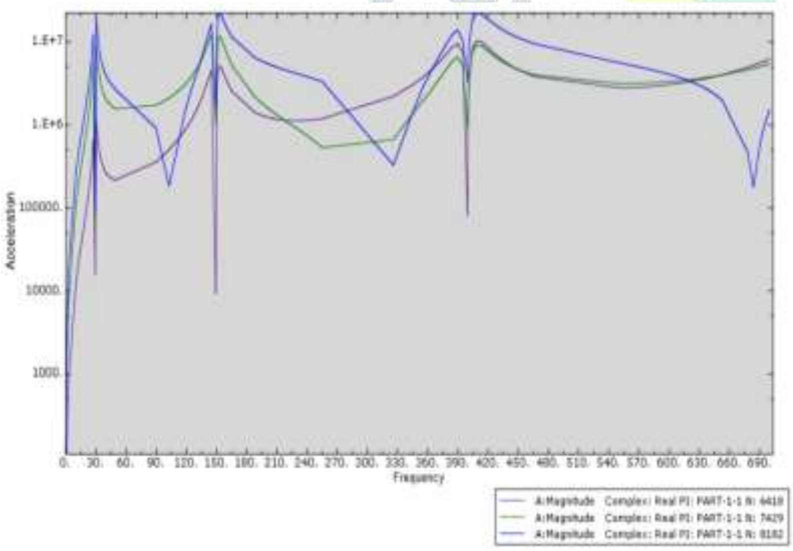
Linear scale on X axis and Y axis is displayed in a base 10 logarithmic progression. (Nset means Node Set)



Graph 1. FRF for Specimen 1



Graph 2. FRF for Specimen 2

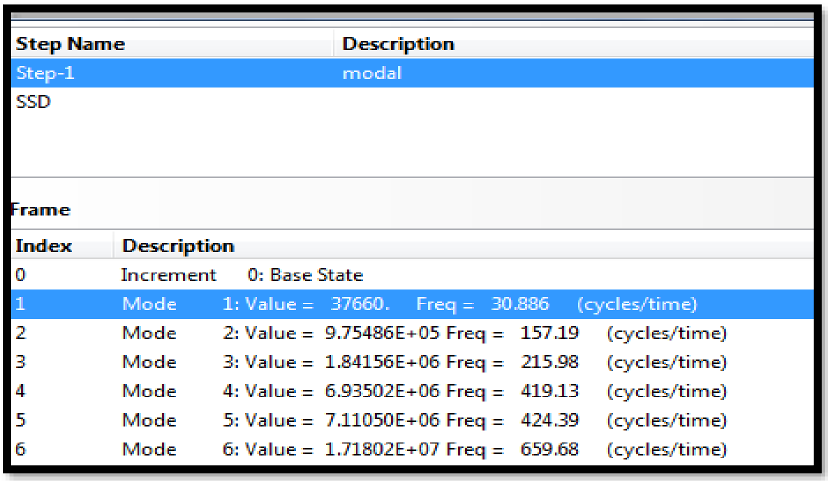



```
*Nset, nset=HAMMER
 8182, 8298
*Nset, nset=TRACK1
 7429,
*Nset, nset=TRACK2
 6418,
```

Graph 3. FRF for Specimen 3

4.3 Comparison of Acceleration at Hammer ,Track 1 and Track 2 Point for Specimen 1,2 and 3:-

From the above FRF analysis (table 3.),the acceleration magnitude at Hammer point,Track 1 point and track 2 point are compared for the frequency of interest for each specimen in following tables. These frequencies are extracted from constrained modal analysis of composite structure/specimen in FEA by using Abaqus 6.13-1 software for first six modes (as given in Fig.4 & 5) which are highlighted as bold in above table 3.This analysis is then represented by plotting the graphs i.e.graphical representation.

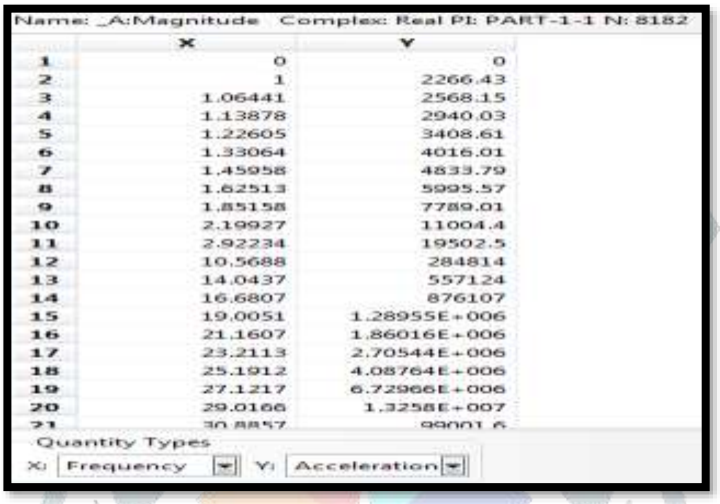


Step Name	Description
Step-1	modal
SSD	

Frame

Index	Description
0	Increment 0: Base State
1	Mode 1: Value = 37660. Freq = 30.886 (cycles/time)
2	Mode 2: Value = 9.75486E+05 Freq = 157.19 (cycles/time)
3	Mode 3: Value = 1.84156E+06 Freq = 215.98 (cycles/time)
4	Mode 4: Value = 6.93502E+06 Freq = 419.13 (cycles/time)
5	Mode 5: Value = 7.11050E+06 Freq = 424.39 (cycles/time)
6	Mode 6: Value = 1.71802E+07 Freq = 659.68 (cycles/time)

Figure 4.Frequency For Specimen 1 for First Six Modes



Name: _A:Magnitude Complex: Real PI: PART-1-1 N: 8182

	X	Y
1	0	0
2	1	2266.43
3	1.06441	2568.15
4	1.13878	2940.03
5	1.22605	3408.61
6	1.33064	4016.01
7	1.45958	4833.79
8	1.62513	5995.57
9	1.85158	7789.01
10	2.19927	11004.4
11	2.92234	19502.5
12	10.5688	284814
13	14.0437	557124
14	16.6807	876107
15	19.0051	1.28955E+006
16	21.1607	1.86016E+006
17	23.2113	2.70544E+006
18	25.1912	4.08764E+006
19	27.1217	6.72966E+006
20	29.0166	1.3258E+007
21	30.8857	99001.6

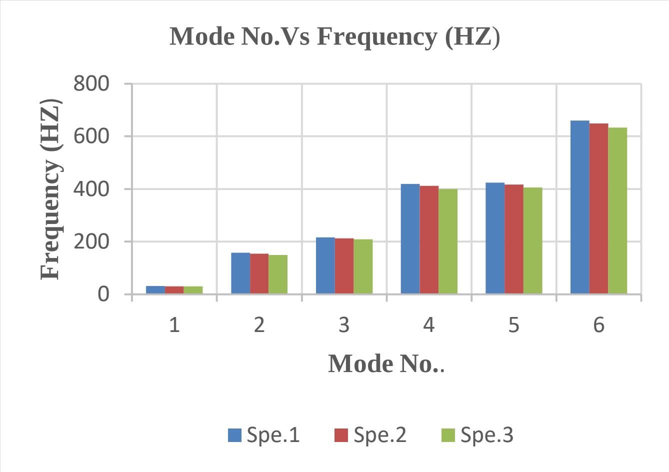
Quantity Types
X: Frequency Y: Acceleration

Figure 5.Frequency and Acceleration For Specimen 1

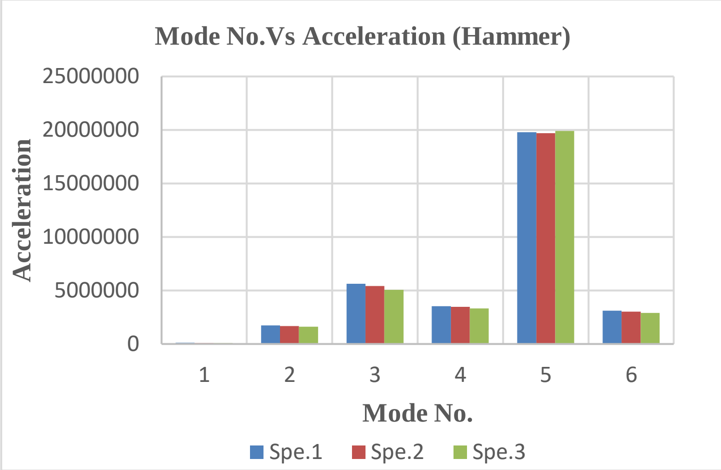
Table 4. Comparative Acceleration Magnitude of Specimen 1,2 and 3:-

Mode No.	Frequency(HZ)			Acceleration Magnitude								
				Hammer Point			Track 1 Point			Track 2 Point		
	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3	Spe.1	Spe.2	Spe.3
1	30.8857	30.2594	29.3061	99001.6	96519.5	91132.3	55719.6	54296.9	51226.9	16499.5	16516	15663.4
2	157.192	153.888	149.212	1.72E+06	1.68E+06	1.60E+06	1.11E+06	1.09E+06	1.03E+06	12987.9	12026.8	9265.13
3	215.98	212.764	208.112	5.62E+06	5.42E+06	5.06E+06	1.58E+06	1.49E+06	1.37E+06	1.28E+06	1.27E+06	1.18E+06
4	419.125	411.344	399.528	3.52E+06	3.46E+06	3.31E+06	968646	938218	916820	93513.8	95916.9	79830.8
5	424.395	416.703	405.518	**1.98E+07**	**1.97E+07**	**1.99E+07**	**7.99E+06**	**8.01E+06**	**8.14E+06**	**8.65E+06**	**8.77E+06**	**8.99E+06**
6	659.682	649.544	632.595	3.11E+06	3.02E+06	2.90E+06	3.86E+06	3.78E+06	3.67E+06	3.70E+06	3.69E+06	3.55E+06

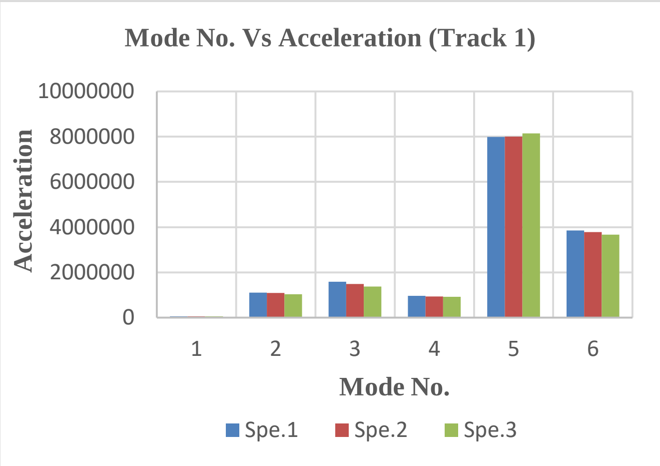
4.4 Graphical Representation:-



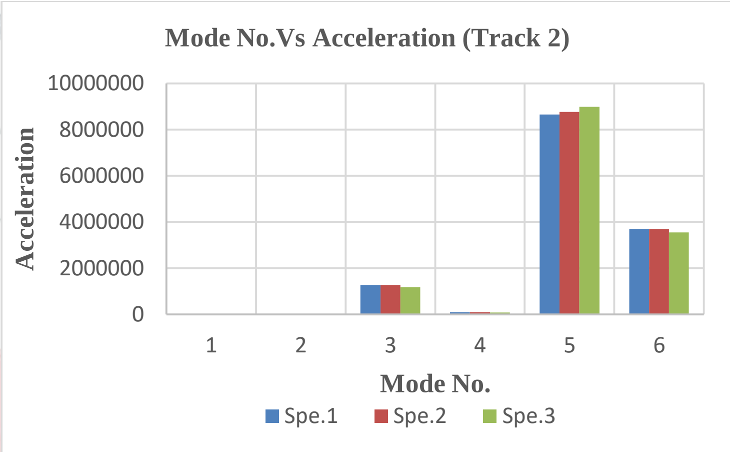
Graph 4:-Mode No. VsFrequency (HZ)



Graph 5:-Mode No. Vs Acceleration (Hammer)



Graph 6:-Mode No. Vs Acceleration (Track 1)



Graph 7:-Mode No. Vs Acceleration (Track 2)

V. CONCLUSION

After the finite element modal analysis for Frequency Response Function (FRF), we have the comparative table for the values of acceleration magnitude for each specimen 1, 2 and 3 at the location of impact hammer. Here three locations of hammering are considered i.e. at hammer point, track 1point and track 2 point and the acceleration magnitude is extracted at each point which is summarized in table 3.From this data it is analyzed that the acceleration magnitude which is actually relative acceleration magnitude is maximum at first point i.e. Hammer point which is very near to extreme edge of the specimen from its R.H.S. For the second hammering point i.e. Track 1 point the acceleration magnitude goes on decreasing as compared to first hammering point i.e. Hammer point. Also for the third hammering point i.e. Track 2 point, the acceleration magnitude is lower than other two points. From this it is conclude that,
Acceleration Magnitude (Track 2 Point) < Acceleration Magnitude (Track 1 Point) < Acceleration Magnitude (Hammer Point)

In table 4, the acceleration magnitude at Hammer point, Track 1 point and Track 2 point is compared for each type of specimen 1, 2 and 3 at first six modes. This is the analysis of Frequency Response Function (FRF) in terms of acceleration magnitude for each type of specimen. Here also the modal frequency at first six modes are compared for the specimen type 1,2 and 3. From this analysis it conclude that the modal frequency of specimen 1 is higher than other two specimens i.e. specimen 2 and 3 and for specimen 3 has lowest frequency at each mode than specimen 1 and 2. It means that , frequency for specimen 3< frequency for specimen 2< frequency for specimen 1.Also acceleration magnitude at Hammer, Track 1and Track 2 point goes on decreasing from specimen 1 to specimen 3 except at mode 5 at which it is slightly increasing. The FRF is almost the same irrespective of the hammer location. More modes were excited when the impact was given at the corner positions compared to when it was given at the center position. All this analysis is also represented graphically by plotting the graphs as shown above. In next part of this analysis, the other two parameters i.e. velocity and displacement will be studied and Frequency Response Function (FRF) curves are identified and analyzed for the all specimens under study. Also by comparing the speciemen 1,2 and specimen 3, it may be suggested that the composite specimen 2 (with 1mm thickness of VDM) have better Frequency Response Function (FRF) in respect of acceleration magnitude as compared to other composite specimens and may be the best suitable alternative composite specimen.

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