

Experimental Study of the Effect of Rivets on Damping in Jointed Structures

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Abstract : Riveted joints are often used to fabricate assembled structures in machine tools, automotive, trusses and many such industries requiring high damping. The present work aims to study the mechanism of damping and its FEA evaluation for jointed cantilever beam with number of equispaced connecting rivets resulting in uniform pressure distribution at interfaces. Vibration attenuation in these structures can enhance the dynamic stability significantly. A little amount of work has been reported till date on the damping capacity of riveted structures. Using OROS Series (OR34 - 4 Channel) FFT analyzer experiments are performed on various specimens. The damping ratio is calculated from FFT spectrum obtained from FFT Analyzer. It is established that the damping capacity of structures jointed with connecting rivets can be improved substantially with an increase in number of rivets maintaining uniform intensity of pressure distribution at the interfaces.

Keywords - Ansys 11.0, Built-up Structure, Damping Mechanism, Damping ratio (ξ), Riveted joints.

I. INTRODUCTION

The study of damping and its importance in structures has become increasingly significant for controlling the undesirable effects of vibration. Following are the requirements of modern technology, there has been significant increase in demand to design, develop and fabricate machine tools, space structures, high speed automobiles, etc. to meet the global demand. The manufacturer of such structures also requires high damping capacity and stiffness with light weight for its effective use. Such requirements demanded and popularized the use of welded, bolted and riveted layered beams as structural members with high damping capacity. In the alternative, cast structures can be used, but unfortunately, these are more expensive to manufacture and as a result, the development of welded, bolted and riveted multi-layered beam structures is becoming increasingly common in such industries. Joints have a great potential for reducing the vibration levels of a structure and have attracted the interest of many researchers. Many comprehensive review papers on joints and fasteners have appeared in recent years. Although a lot of work has been carried out on the damping capacity of bolted structures, but a little amount of work has been reported till date on the mechanism of damping in layered and jointed riveted structures. Furthermore, the effect of the influencing parameters on the damping rate of such structures is investigated and discussed in this study. Damping ratio, a measure of damping capacity of jointed structures is determined by energy principle considering interface pressure at the interfaces of contacting layers. Huge amount of work has been reported by Masuko et al. [2], Nishiwaki et al. [3], on damping capacity of such structures assuming uniform pressure distribution at interfaces of jointed structures. B.K Nanda and Behera [8] have established that energy dissipation in jointed structure take place due to micro-slip at the interfaces of contacting layers. B.K Nanda [1] found that the damping increases with an increase in number of layers in jointed structure due to an increase in interface friction layers which causes an increase in energy loss.

1.1 Riveted Joints

A rivet is a short cylindrical bar with a head at one end. This head is formed on the shank by upsetting process in a machine called Riveting machine. The rivet is inserted in the holes of the parts being assembled as shown in Fig.1.

There two methods of riveting:- hand riveting, machine riveting. In hand riveting a die is placed on the protruding end of the shank. In machine riveting, the die is a part of hammer, which is operated by pneumatic, hydraulic pressure.

1.1.1 Advantages of Riveted joints

1) Riveted joint are more reliable than welded joint in applications which are subjected to vibrations and impact forces.

- 2) Welded joints are restricted to steel parts. Riveted joints can be used for non-ferrous metals like aluminium alloy, copper, brass or non-metals like asbestos or plastics
- 3) The heat required for welding causes warping and affects the structure of heat treated components. The parts assembled by riveted joint are free from such thermal effects.
- 4) When the riveted joint is dismantled, the connected components are less damaged compared with those welded joint.

1.1.2 Drawbacks of Riveted joints

- 1) The overall cost of riveted joint is more than that of welded joint due to increased metal consumption and higher labour cost.
- 2) Riveted assemblies have more weight than welded assemblies due to strap plates and rivets.

1.1.3 Applications of Riveted joints

- 1) Riveted joints are used where it is necessary to avoid the thermal effects of welding.
- 2) Riveted joints are used where thin plates are to be assembled. They are popular especially for aircraft structures where light structures made of aluminium alloys are to be fastened.

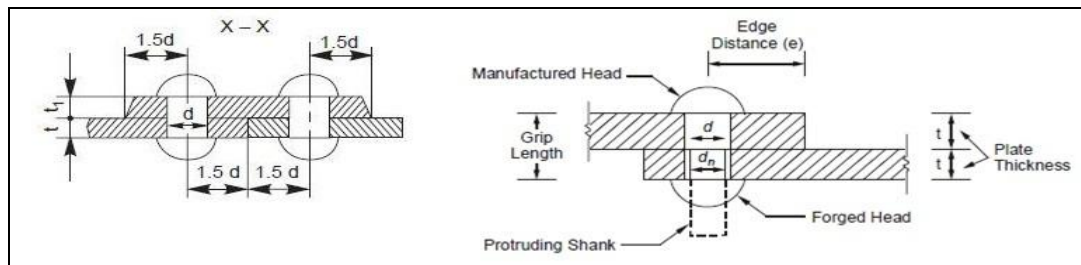


Fig.1: Ordinary forms of rivets after riveting

II. THEORETICAL ANALYSIS

Most structural problems are studied based on the assumption that the structure to be analyzed is either linear or nonlinear. In linear systems, the excitation and response are linearly related and their relationship is given by a linear plot as shown in Fig.2. For many cases, this assumption is more often valid over certain operating ranges. Working with linear models is easier from both an analytical and experimental point of view. For a linear system, the principle of superposition holds which means that doubling the excitation will double the levels of the response. For beams undergoing small displacements, linear beam theory is used to calculate the natural frequencies, mode shapes and the response for a given excitation. It is very clear from Fig. that the linear and nonlinear systems agree well at small values of excitation, while they deviate at higher levels. The nonlinear beam theory is used for larger displacements where the superposition principle is not valid. The linear vibration theory is used when the beam is vibrated at small amplitudes and lower modes of vibration. The present investigation mainly focuses on the study of damping of jointed fixed beams at lower excitation levels which can be considered as linear.

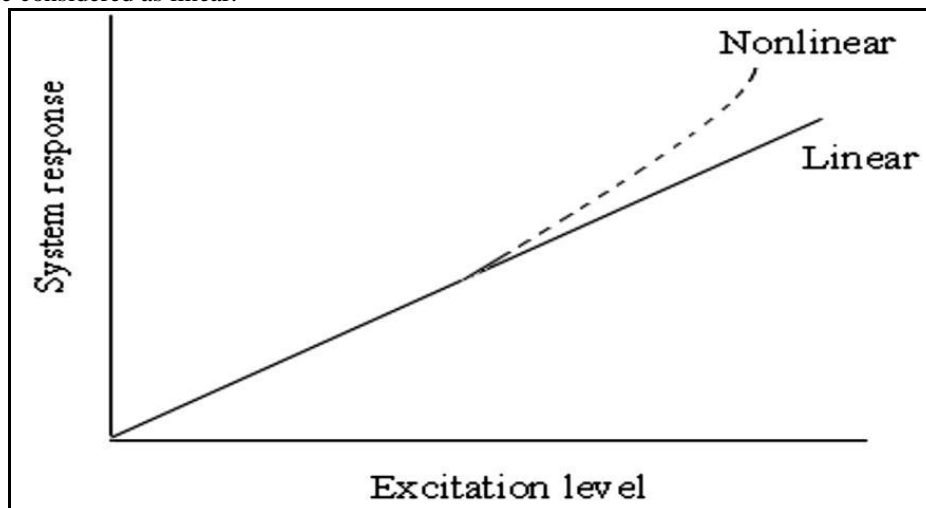


Fig.2: Comparison of Linear and nonlinear systems

III. PROBLEM STATEMENT

Various structures have been tested and the great potential for a friction joint to reduce vibration level has been observed. The problems in utilizing a friction joint as a tool to control the vibration of a fabricated structure have been as:

- 1) Fretting corrosion at joint interface
- 2) Loss of static stiffness of the structure
- 3) Difficulty in design and analysis due to problems of nonlinearity
- 4) The structures are highly subjected to vibration which leads to failure. Due to continuous vibration life of the structure decreases. In order to avoid this type of failure a structure should be damped.
- 5) Damping capacity is higher in bolted joints and least in welded joints. Hence in order to overcome these drawbacks a beam with riveted joints are used.

IV. OBJECTIVES OF THE WORK

Many researchers have emphasized their studies on techniques to improve the damping capacity of laminated structures to control the adverse effects of vibrations. Although the knowledge on the friction joint is limited, efforts have been put in the present investigation to study the damping aspect of the friction joints in built-up structures.

- 1) Experimental analysis of jointed structures is carried out to find damping ratio of jointed structures with increasing number of rivets under different conditions of excitation.
- 2) FEA analysis of jointed structures is developed to calculate damping ratio in ANSYS 11.0 software for mild steel cantilever beams.
- 3) Both the FEA and experimental results are compared for authentication.

V. EXPERIMENTAL TECHNIQUES

In order to find experimentally the damping ratio of jointed beams and to compare it with the simulation ones, an experimental set-up with a number of specimens has been fabricated. The experimental set-up with detailed instrumentation is shown in Fig.4

5.1 Preparation of Specimens

The test specimen of mild steel material is prepared from different sizes of rivets. Rivet 10mm diameter is used to fabricate layered specimens with constant clamping force. Different riveted beam specimen are prepared for increasing number of rivets from 8 to 11. The test specimen are prepared on Orbital riveting machine with pressure 6kg/cm^2 . The distance between the consecutive rivets have been kept constant in order to ensure uniform intensity of pressure distribution at the interfaces of jointed cantilever beams. The centre distance between two consecutive rivets and width of specimen are kept 3.0, 4.0, 4.5 times diameter of rivet for thickness ratios of 1.0, 1.5, 2.0 respectively.

TABLE 1: Details of mild steel specimens with increasing number of Rivets

Sr. No	Width × Thickness (mm×mm)	Type of Specimen	Diameter of Rivet (mm)	Number of Rivets	Fixed beam span(mm)
Thickness Ratio= 1.0					
1.	40× (3+3)	Jointed	10	8	320
				9	360
				10	400
				11	440
Thickness Ratio= 1.5					
2.	40× (3.6+2.4)	Jointed	10	8	320
				9	360
				10	400
				11	440
Thickness Ratio= 2.0					
3.	40× (4+2)	Jointed	10	8	320
				9	360
				10	400
				11	440

From above mentioned tables different test specimens are prepared. While preparation of specimen button type rivets are used of different diameter. The specimen are shown in Fig. 3



Fig.3: Photographs of specimens used for experimentation

5.2 Experimental Setup

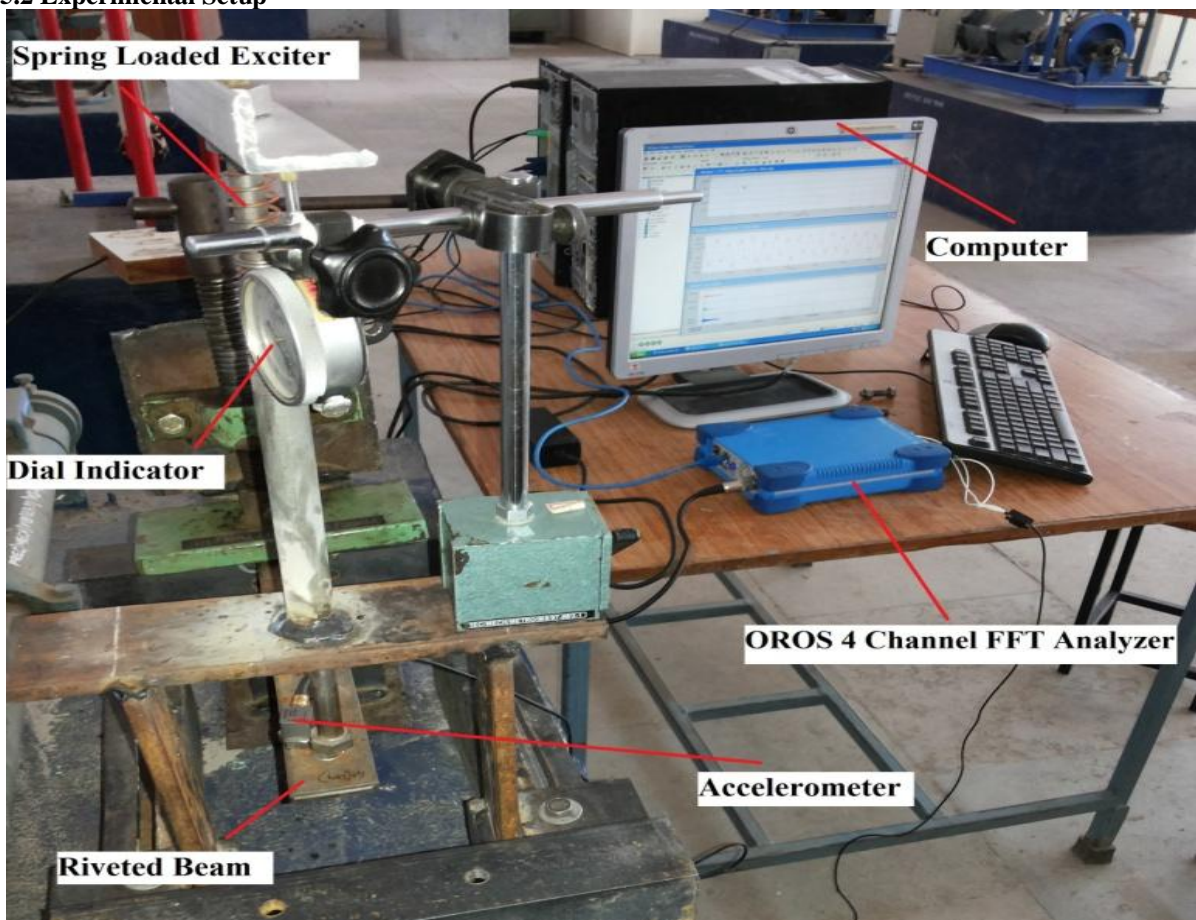


Fig.4: Experimental-Setup for riveted Cantilever beam



Fig.5: Side view of experimental set-up for cantilever beam

Experimental-Setup consists of following parts:-

1. OROS 4 Channel FFT Analyzer
2. Accelerometer
3. Spring Loaded Exciter
4. Riveted beam
5. Dial Indicator

The Experimental Set-up consists of frame work fabricated from steel C, I section by welding. The frame is grounded to concrete base with foundation bolts. The one end of riveted beam is fixed using mechanical vice. The spring loaded exciter is provided for giving excitation at the free end of riveted beam, this excitation is noted on dial gauge.

5.3 Half Power Bandwidth Method

A spring loaded exciter is used to excite the specimens at the free ends. The excitation is imparted for a range of beam-tip amplitudes varying from 1mm to 3mm. For a particular test specimen, the beam is deflected and released to oscillate at its first mode of free vibration. The beam response is sensed by a contacting-type accelerometer attached to the tip of the beam. One end of the accelerometer is held magnetically to the vibrating surface of the specimen and the other is connected output of OROS 4 Channel FFT Analyzer. The output from the accelerometer is proportional to the frequency and amplitude of vibration. These output signals are fed from FFT Analyzer to digital computer using NVGate version 5.0 software for processing and display. The data is then analysed to determine the natural frequency and damping characteristics of the beam structure. To estimate damping ratio from frequency domain, half-power bandwidth method has been used.

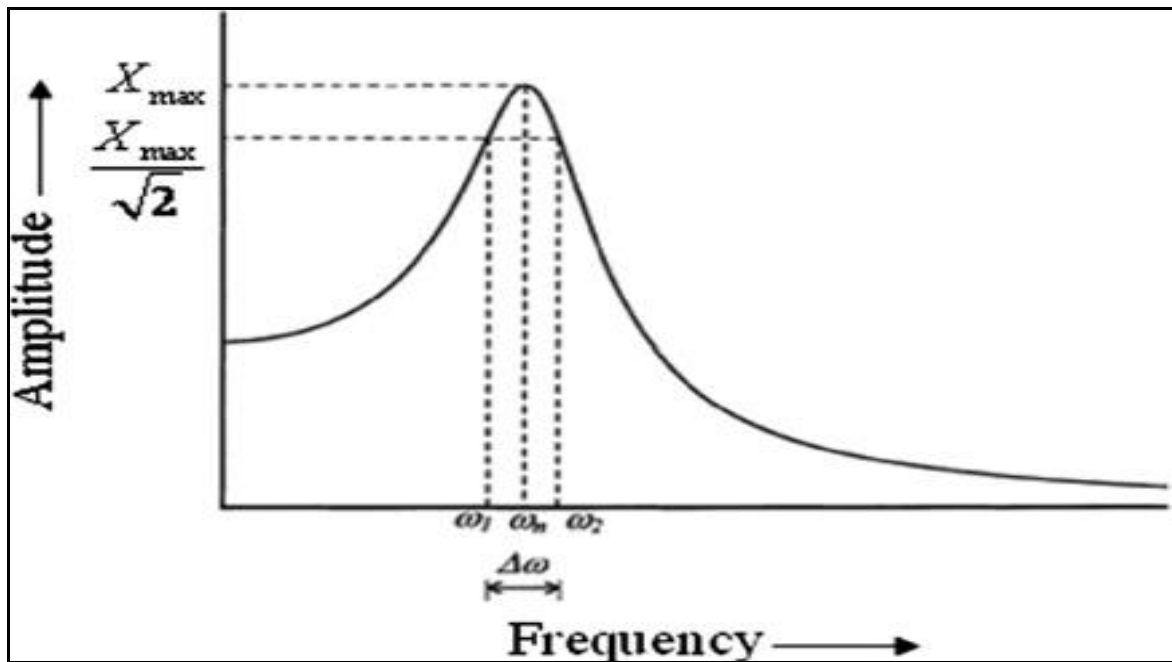


Fig.6: Half Power Bandwidth method of damping measurement

$$\text{Damping Ratio}(\xi) = \frac{F_2 - F_1}{2F_{\max}}$$

VI. FINITE ELEMENT ANALYSIS

FEA model of riveted beam is prepared using Ansys 11.0 software. The element type SHELL63 is used for constructing the riveted beam. By applying the boundary condition to riveted cantilever beam, the problem is solved using Harmonic analysis. The graph is plotted using Time History Post Processing tool.

TABLE 2: Steps of FEA model construction

Preferences	Structural
Element Type	SHELL63 (for Plate)
Material Properties	EX= 1.96e5 N/mm2 PRXY= 0.3
Dimensions	Width= 40mm Thickness= 2mm,2.4mm,3mm,3.6mm,4mm Length= 320mm,360mm,400mm,440mm
Number of Plates	2
Element Type	BEAM188 (for Rivet)
Dimension of Rivets	Diameter=10mm Number of Rivets= 8,9,10,11

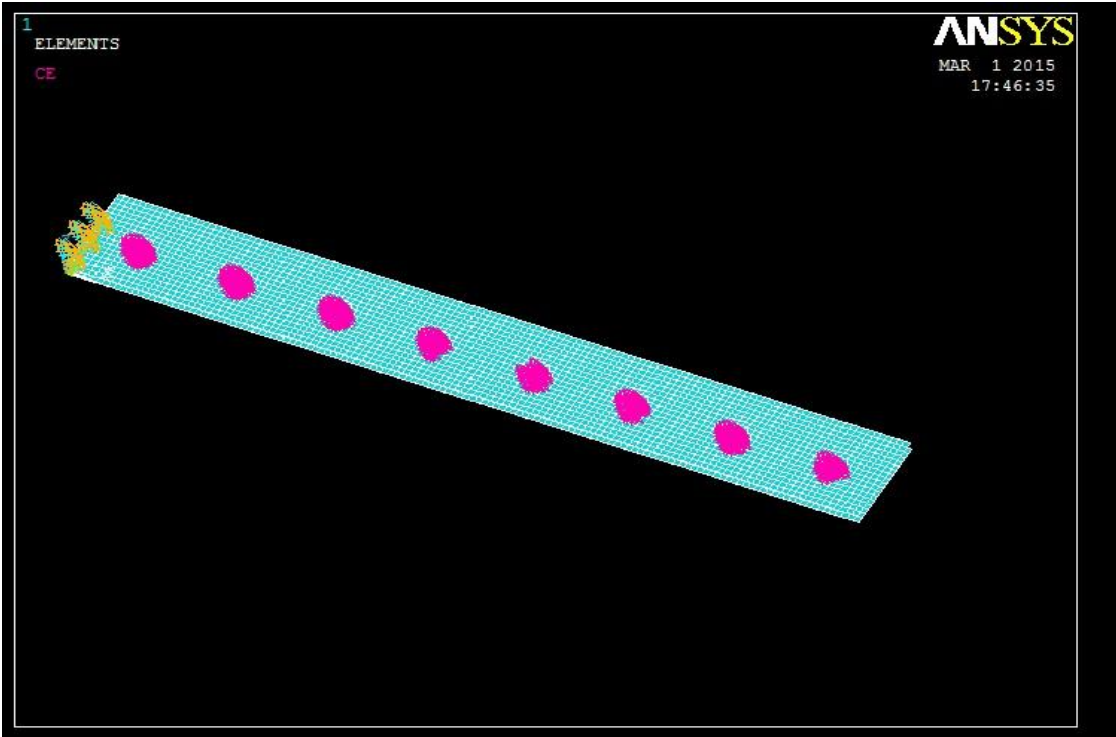


Fig.7: FEA Model of Riveted beam with 8 number of rivets

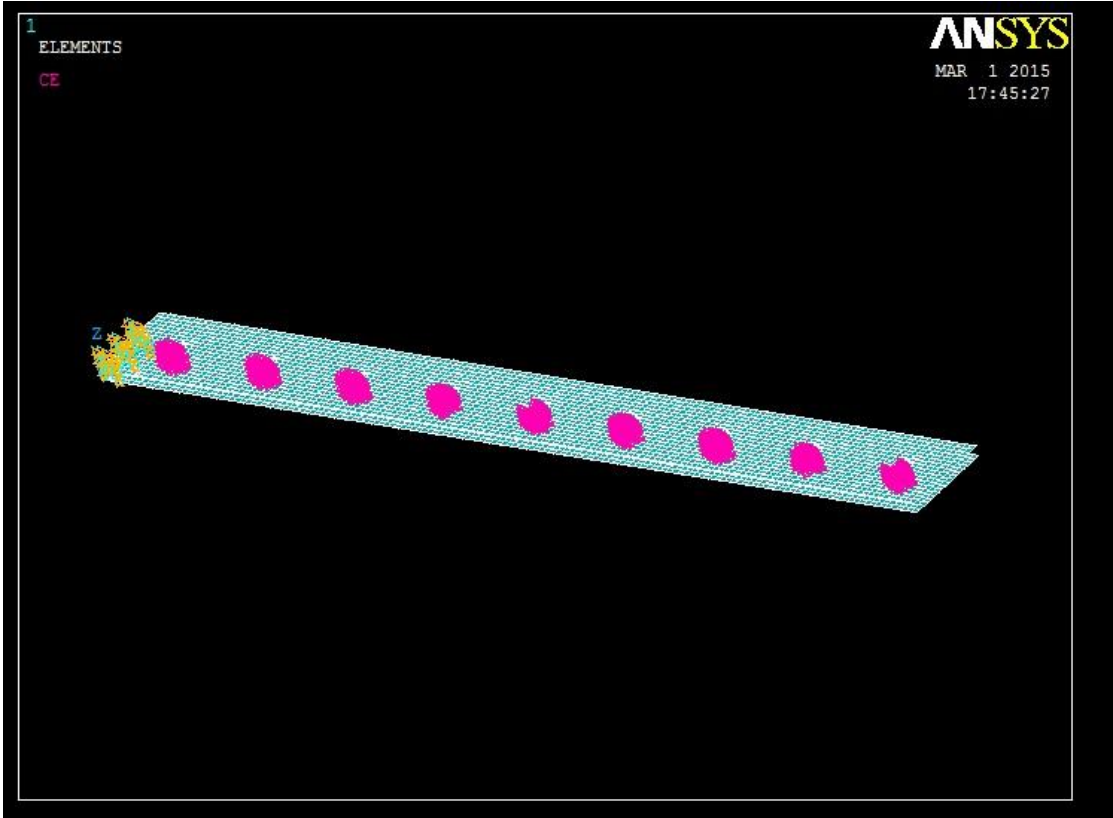


Fig.8: FEA Model of Riveted beam with 9 number of rivets

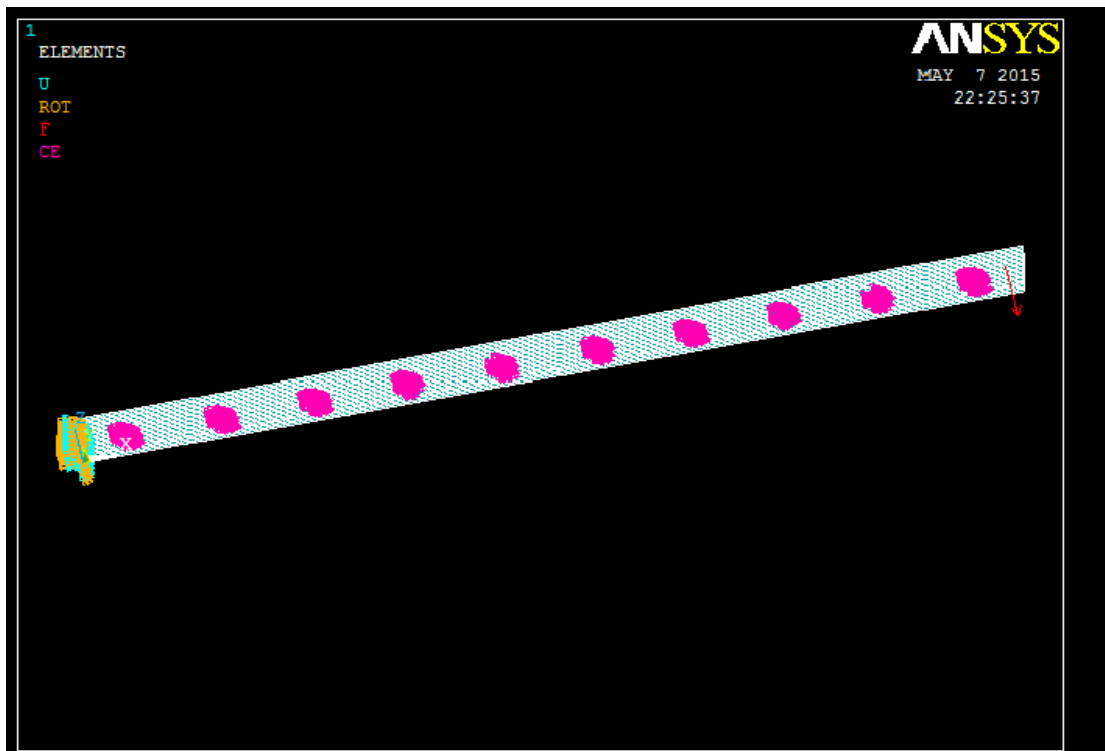


Fig.9: FEA Model of Riveted beam with 10 number of rivets

VII. RESULTS & DISCUSSION

7.1 Experimental Results

The following graph is obtained by performing experiments on various specimens of mild steel as discussed in table 1. Time Domain graph, frequency domain graph are plotted for various specimen. Comparison is made with the solid beam and jointed beam of different thickness ratio. By using half power bandwidth method the damping ratio (ξ) of specimen are evaluated. In present results, the variation of damping ratio with respect to different influencing parameters such as beam thickness ratio, number of rivets is shown.

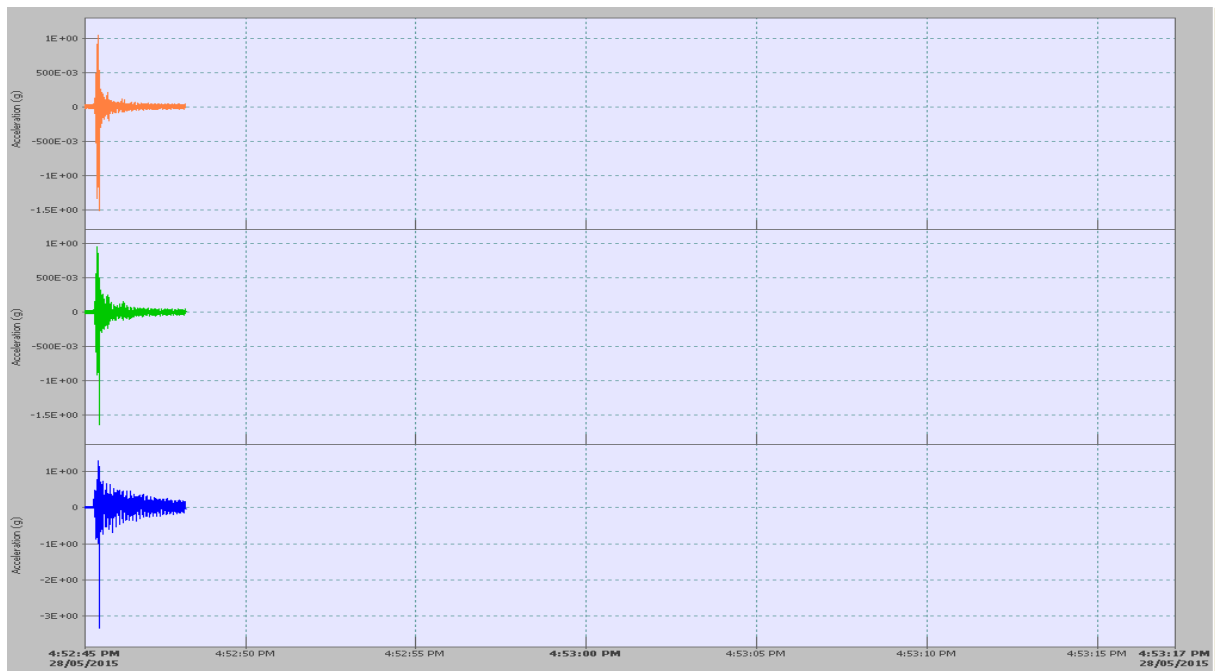


Fig.10: 3 axis (X, Y and Z) & vibration graph

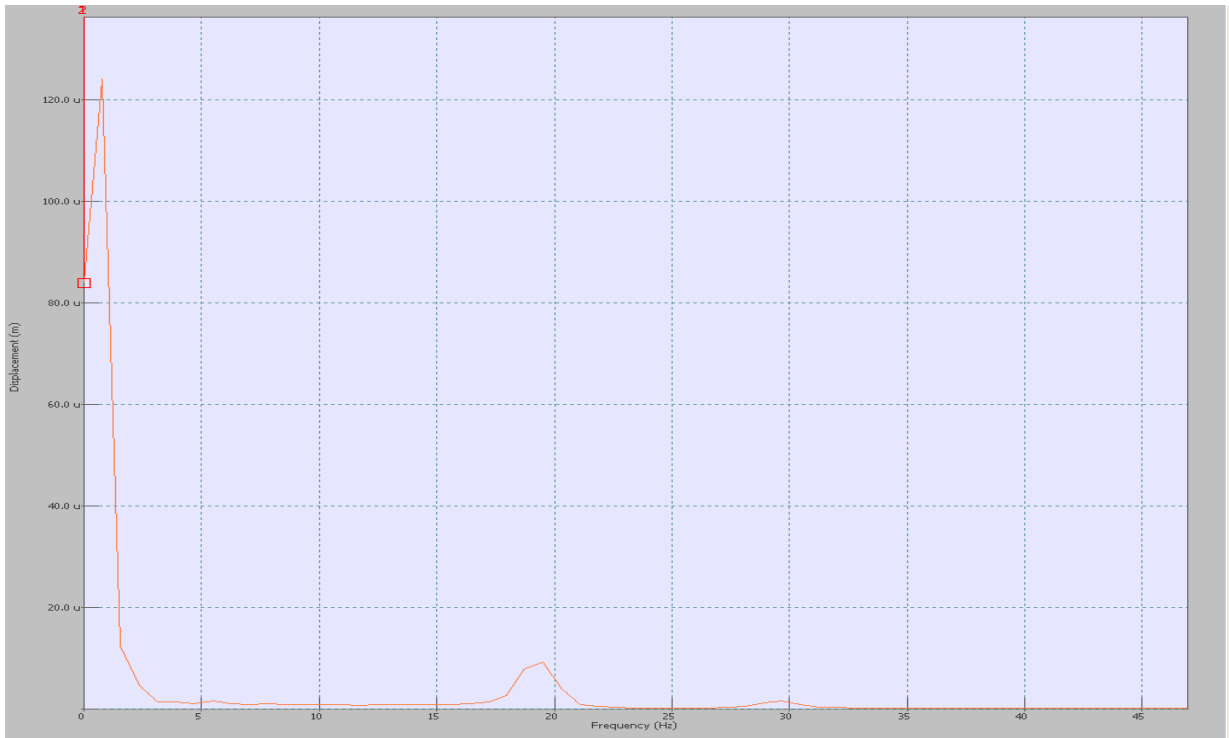


Fig.11: Frequency response graph of 40(3.6+2.4) mm riveted beam

By using data obtained from NVGate software graph is plotted using MATLAB software.

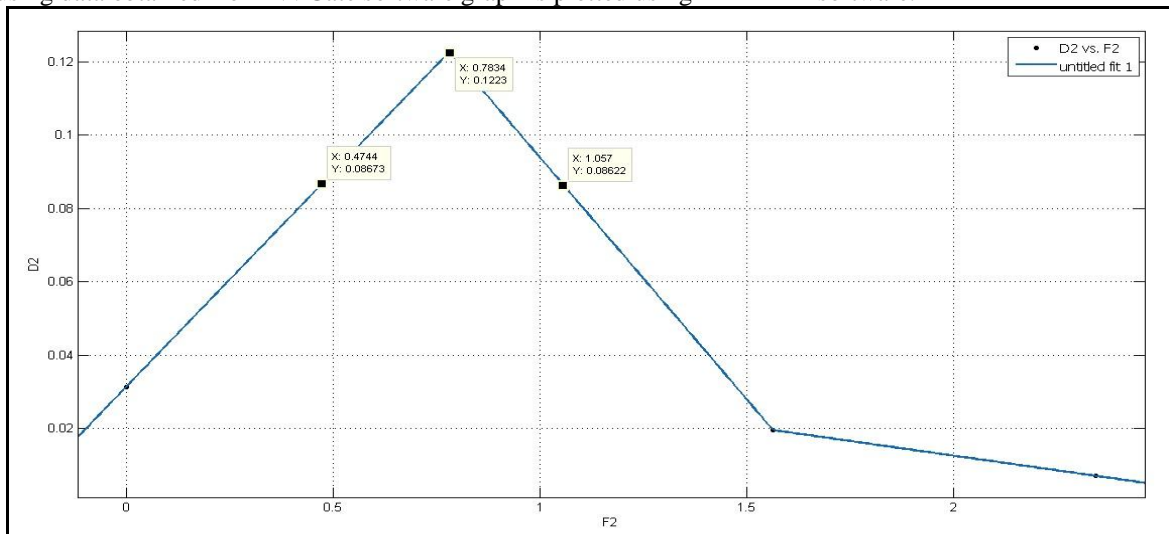


Fig.12: Frequency response graph of 40(3.6+2.4) mm riveted beam with 8 number of rivets

From the Displacement Vs Frequency graph the frequency are obtained are $F_1 = 0.5009\text{Hz}$, $F_2 = 1.168\text{Hz}$, $F_{\max} = 0.7834\text{Hz}$

$$\xi = \frac{F_2 - F_1}{2F_{\max}}$$

$$= \frac{1.1057 - 0.4744}{2 \times 0.7834}$$

$$\xi = 0.374$$

7.2 FEA Results

The FEA models of the entire riveted beam specimen are prepared in ANSYS 11.0. By Harmonic analysis following graph are plotted of riveted beam of increasing number of rivets. The result summary obtained from the graph is used for calculating the damping ratio (ξ).

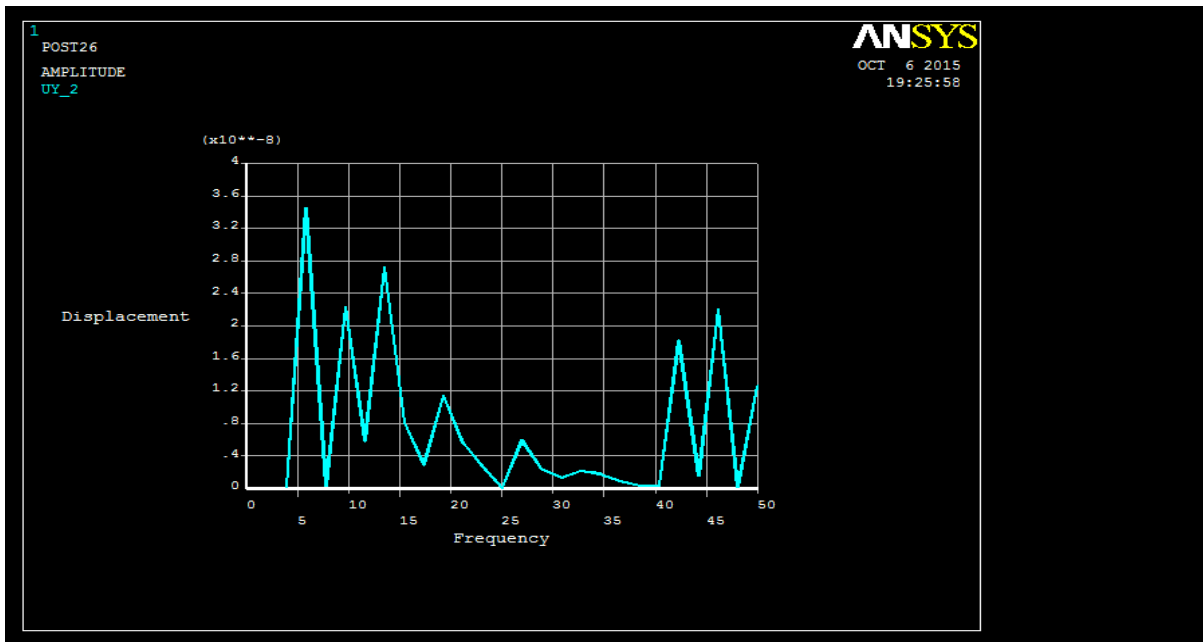


Fig.13: FEA Results of riveted cantilever beam

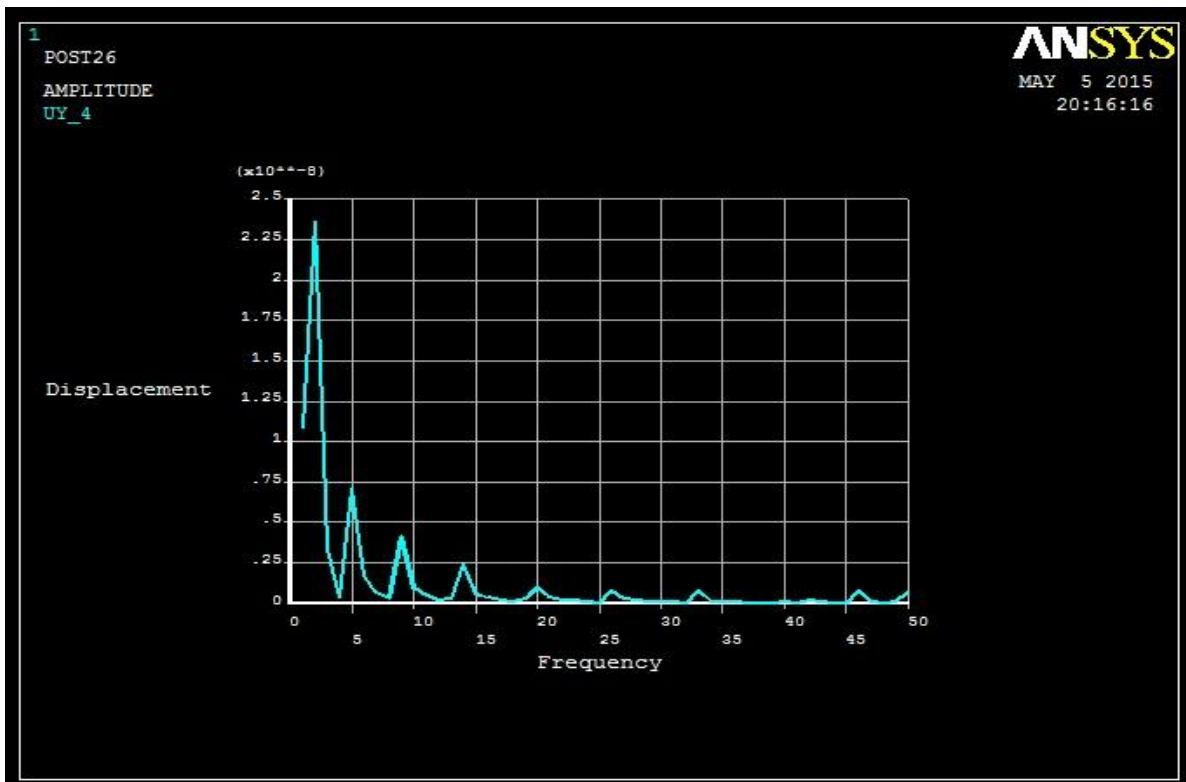


Fig.14: FEA Results of riveted cantilever beam

VIII. COMPARISON OF EXPERIMENTAL & FEA RESULTS OF RIVETED CANTILEVER BEAM

The rivets beam of thickness 1.0, 1.5, 2.0 is analyzed for increasing number of rivets from 8 to 11. The overall length of beam increases are pitch between two consecutive rivets is kept. These beam is excited for 1mm, 2mm, 3mm of excitation using spring loaded exciter.

The data obtained from FFT Analyzer are imported in MATLAB software for determining the damping ratio. The data obtained from FEA Analysis are also imported in the software for calculating damping ratio.

TABLE 3: Experimental and FEA Results of specimens

Sr. No.	Width×Thickness (mm×mm)	Number of Rivets	Damping ratio (ξ)					
			Experimental			FEA		
			1mm	2mm	3mm	1mm	2mm	3mm
Thickness ratio =1.0								
1.	40× (3+3)mm	8	0.472	0.423	0.3606	0.45	0.405	0.35
2.		9	0.4788	0.429	0.393	0.445	0.4	0.38
3.		10	0.4825	0.459	0.4	0.47	0.42	0.39
4.		11	0.4905	0.466	0.412	0.48	0.43	0.4
Thickness ratio =1.5								
1.	40× (3.6+2.4)mm	8	0.374	0.349	0.335	0.37	0.33	0.31
2.		9	0.407	0.383	0.356	0.39	0.36	0.335
3.		10	0.434	0.405	0.388	0.42	0.38	0.36
4.		11	0.449	0.426	0.4	0.43	0.42	0.38
Thickness ratio =2.0								
1.	40× (4+2)mm	8	0.3603	0.335	0.321	0.35	0.31	0.3
2.		9	0.372	0.364	0.338	0.365	0.34	0.315
3.		10	0.377	0.367	0.357	0.365	0.35	0.34
4.		11	0.388	0.3796	0.366	0.375	0.355	0.355

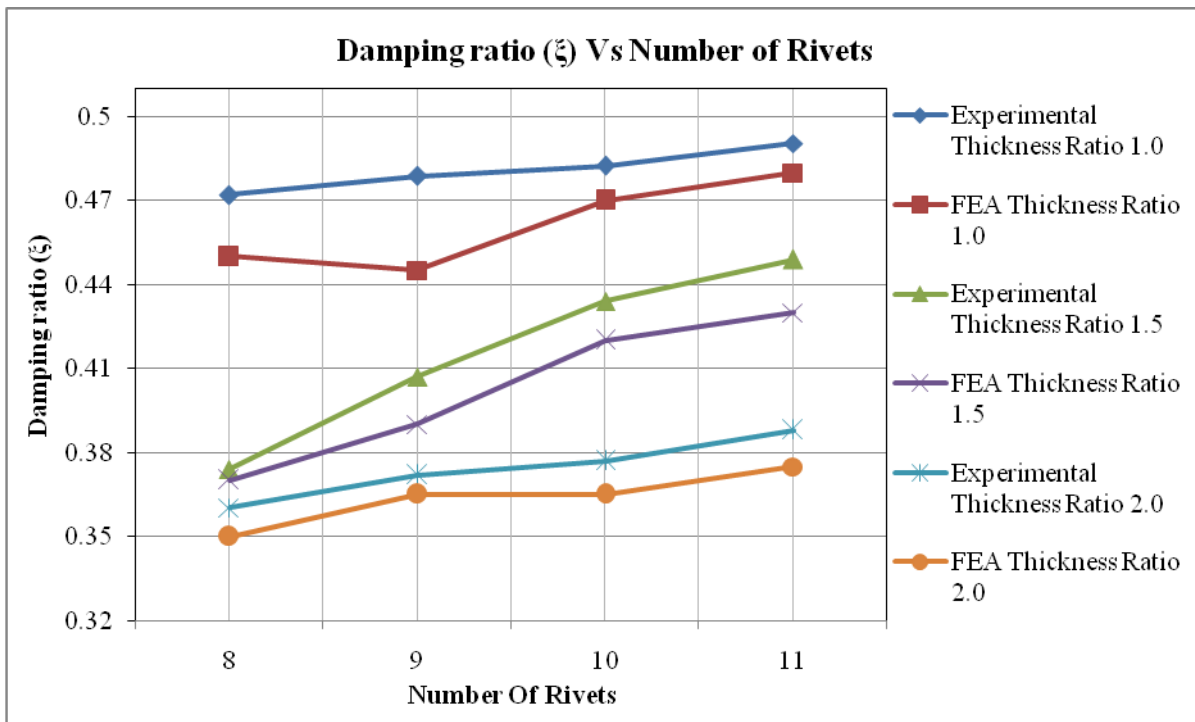


Fig.15: Experimental and FEA Results of damping ratio for Excitation 1mm with influencing parameter:- Number of Rivets

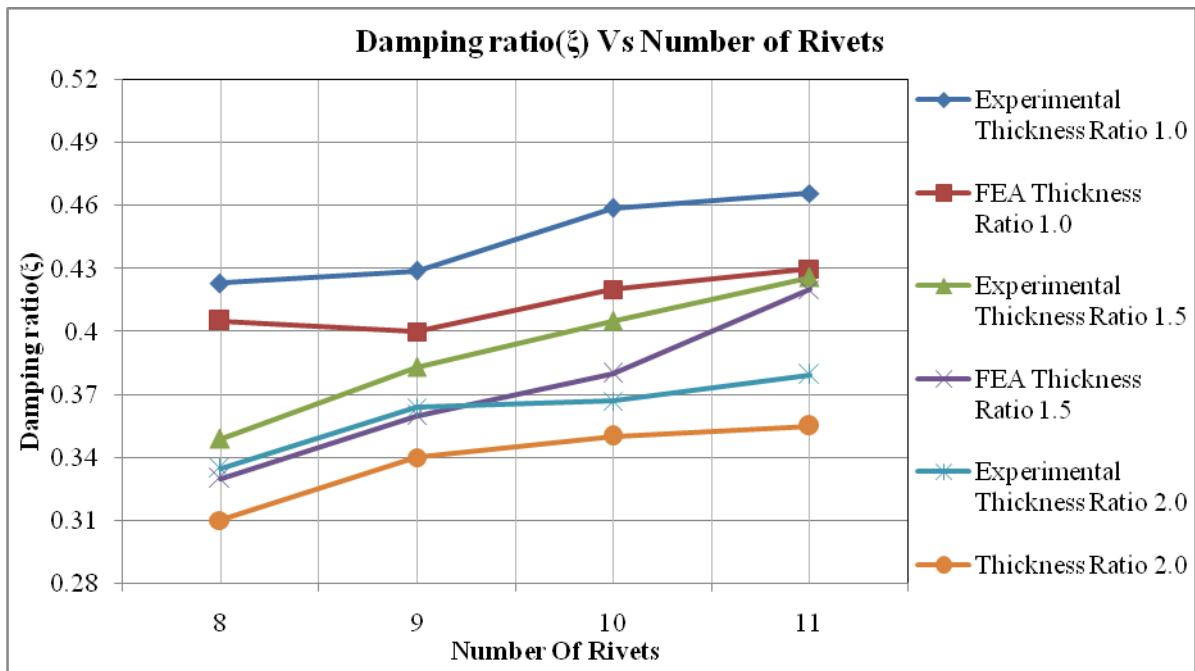


Fig.16: Experimental and FEA Results of damping ratio for Excitation 2mm with influencing parameter: - Number of Rivets

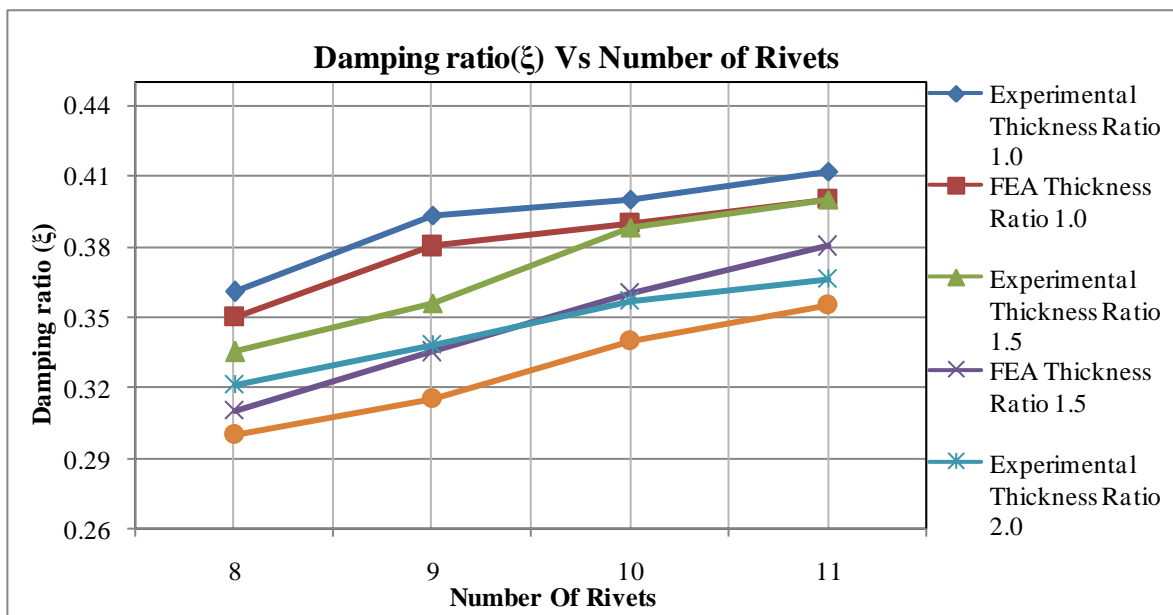


Fig.17: Experimental and FEA Results of damping ratio for Excitation 3mm with influencing parameter: - Number of Rivets

IX. CONCLUSIONS

The aim of this paper was to analyze the influence of joints and their functional parameters on the vibration characteristics of built-up structures.

Effect of number of rivets: - The increase in dynamic slip is due using more number of rivets. Moreover, the energy dissipation is enhanced as the contact area of the interface undergoing micro-slip increases with the specimen length. The net effect of all these improves the damping with an increase in the cantilever length.

It is found from analysis that the thickness ratio of 1.0 yields maximum damping of jointed structures. This damping will further increase with the use of more number of layers with the same overall beam thickness due to more friction layers which produces higher energy loss at the interfaces.

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