Experimental Investigation on Damping of Layered and Welded Structure Beam

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Abstract— **In the present work, the mechanism of damping in layered and jointed structures with layered and welded been extensively studied. A lot of experiments have been conducted on a number of specimens with welded of various length and thickness to study its effect on the damping capacity of the layered and jointed structures and to establish the authenticity of the theory developed. Intensity of interface pressure, length and thickness of beam, number of layers, kinematic coefficient of friction at the interfaces and frequency and amplitude of excitation are found to play a major role on the damping capacity of such structures. This design concept of using layered structures with welded joints can be effectively utilized in trusses and frames, aircraft and aerospace structures, bridges, machine members, robots and many other applications where higher damping is required.**

Index Terms: **Slip Damping, welded Joint, Multiple Interfaces, Amplitude, Frequency, In-Plane Bending Stress, Dynamic Loading**

I. INTRODUCTION

Problems involving vibration occur in many areas of mechanical, civil and aerospace engineering. So as a structural member there is a critical need for development of reliable and practical mathematical models to predict the dynamic behavior of such built-up structures to control the vibration of structures at a desirable level. Engineering structures are generally fabricated using a variety of connections such as bolted, riveted, welded and bonded joints etc. Usually, such structures possess both low structural weight and damping. Unwanted vibrations with high amplitude can be the cause of the fatigue failures in machine elements and the reduction of their working life.

This situation calls for use of additional measures to improve the damping characteristics by dissipating more energy. The dynamics of mechanical joints is a topic of special interest due to their strong influence in the performance of the structure. Joints are inherently present in the assembled structures which con- tribute significantly to the slip damping in most of the fabricated structures. Further, the inclusion of these joints plays a significant role in the overall system behavior, particularly the damping level of the structures. Joints have a great potential for reducing the vibration levels of a structure thereby attracting the interest of many researchers. The mechanical engineers are concerned of energy such as heat. Dissipation of energy takes withmany unwanted vibrations in mechanical devices and replace at any time that the system vibrates.

In the present investigation, damping capacity of layered and jointed structures is to be evaluated from analytical expressions developed in the investigation and compared experimentally for aluminum cantilever beams under different - different conditions of excitation in order to establish the accuracy of the theory developed.

A. Damping

Term damping refers to the energy dissipation properties of a material. When a structure is subjected to an excitation by an external force then it vibrates in certain amplitude of vibration, it reduces as the external force is removed. This is due to some resistance offered to the structural member who may be internal or external. This resistance is termed as damping.

B. Classification of Damping-

Damping can be broadly divided into two classes depending on their sources.

1) Material Damping:

Damping due to dissipative mechanism working inside the material of the member is termed as material damping.

2) System Damping:

System damping involves configuration of distinguishable part arises from slip and boundary shear effects of mating surfaces. Energy dissipation during cyclic stress at an interface may occur as a result of dry sliding (coulomb friction), lubricated sliding (viscous forces) or cyclic strain in a separating adhesive (damping in visco-elastic layers between mating surfaces).

System damping to our need is classified as:

- Support damping.
- Damping due to sandwich construction.
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II. THEORETICAL ANALYSIS

2.1 theoretical analysis by classical energy approch

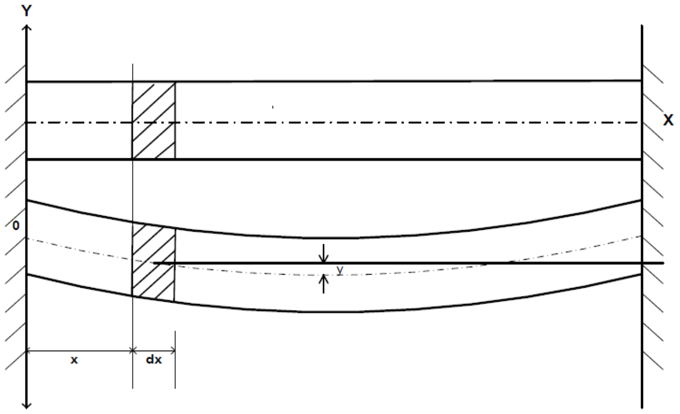

Figure1. Differential analysis of the fixed-fixed beam

The beam vibration is governed by the partial differential equations in terms of two variables for space function *x* and time function *t*. Therefore, the governing differential equation for the free transverse vibration of a beam is represented by:

$$EI\frac{d^4y}{dx^4} + \rho A\frac{d^2y}{dt^2} = 0$$

Where *E, I, ρ* and *A* are modulus of elasticity, second moment of area, mass density and cross-sectional area of the beam, respectively.

$$Y(x,t) = \begin{bmatrix} (\sin\lambda x - \sinh\lambda x) & (\cos\lambda L - \cosh\lambda L) \\ (\cos\lambda x - \cosh\lambda x) & (\sinh\lambda L - \sin\lambda L) \end{bmatrix} \begin{bmatrix} \dfrac{y\left(\frac{L}{2},0\right)}{X\left(\frac{L}{2}\right)} \end{bmatrix} \frac{\cos\omega_n t}{(\cos\lambda L - \cosh\lambda L)}$$

This is the generalized deflection equation at any section of a fixed-fixed beam.

2.2 Evaluation of Logarithmic decrement

Logarithmic decrement (δ), a measure of damping capacity, is defined as the natural logarithm of the ratio of two consecutive amplitudes in a given cycle.

$$\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right) \qquad (3.26)$$

Where x_0 = amplitude of vibration of first cycle
x_n = amplitude of vibration of last cycle
n = number of cycles

2.3 Determination of product of $\alpha \cdot \mu$

It is very difficult to assess the damping produced in the joints due to variations of the above two vital parameters (α and μ) under dynamic conditions. These two parameters are interdependent and if one is increasing, the other is decreasing and vice versa. However, their product ($\alpha \cdot \mu$) is found to be constant for a particular specimen. Thus, this product $\alpha \cdot \mu$ is found out as;

$$\alpha \cdot \mu = \frac{K_s\left(1 - e^{-2\delta}\right)y\left(\frac{L}{2},0\right)}{8bphe^{-2\delta}}$$

III. EXPERIMENTAL PROCEDURE

3.1 Specimen Details

The test specimens of different sizes are prepared from the stock of commercial mild steel flats. The two layered specimens are prepared by tack welding at the sides of the specimens. The distance between the tacks has been varied in steps. Further, specimens of various thicknesses and length are also prepared with thickness ratio of 1.0, 1.5 and 2.0 for conduct the experiments. This variation in beam length and width for a particular specimen affects the static bending stiffness as well as the natural frequency of vibration of the layered and welded beam specimens.

Thickness × width (mm × mm)	Number Of layers	Type of Specimen	Number of Tack welds	Length (mm)
(3+3) × 32.50 (4+4) × 32.50	2 2	Welded	10 10	520.00 540.00 600.00
(3+3) × 40.00 (4+4) × 40.00	2 2	Welded	20 20	520.00 540.00 600.00

Table 1. Mild steel specimen's details with thickness

Figure 2. Top view of mild steel specimens

3.2 experimental setup and description

Figure 3. Photographic view of the experimental set-up

The test rig includes the following instruments:

1. Power supply unit
2. Digital Storage Oscilloscope
3. Accelerometer/Vibration Pick-Up
4. Vibration Exciter (spring exciter)
5. Dial Gauge

3.3 Testing Procedure

The tests are performed in the prevailing laboratory environment. In order to perform the experiments, the specimens are rigidly mounted to the support as discussed earlier. At first, the Young's modulus of elasticity and static bending stiffness are measured by carrying out the static deflection tests. These measured values are subsequently used for the theoretical evaluation of logarithmic decrement of all the specimens. Later, the experimental logarithmic decrement will be calculated from the time history curve of decaying signals and frequency response curves, respectively. The detailed procedure to find out the above quantities is discussed in the succeeding sections.

3.3.1 Measurement of Young's Modulus of Elasticity (E)

As mentioned in the preceding paragraph, the Young's modulus of elasticity (E) of the specimen material is found out by conducting the static deflection tests. For this purpose, one sample of solid beam is selected from the same stock of mild steel flats. These specimens are mounted on the same experimental set-up rigidly so as to ensure perfect fixed-fixed conditions as mentioned earlier. Static loads (W) are applied at the mid-span and the corresponding deflections (Δ) are recorded. The Young's modulus for the specimen material is then determined using the expression $E = \frac{WL^3}{192 I \Delta}$ where L and I are the free length and moment of inertia of the fixed-fixed specimen.

The average of five readings is recorded from the tests from which the average value of Young's modulus for mild steel material is evaluated is 202.205Gpa.

3.3.2 Measurement of Static Bending Stiffness (k)

It is a well known fact that the stiffness of a jointed beam is always less compared to an equivalent solid one. It means that the incorporation of joints to assemble layers of beams is accompanied by a decrease in the stiffness. The amount of reduction in the stiffness is quantified by a factor called stiffness ratio which is defined as the ratio of the stiffness of a jointed beam (*k*) to that of an identical solid one (*k′*). The stiffness ratio is inversely related to the number of layers used in the jointed specimen. Its exact assessment carries much significance in the theoretical evaluation of damping capacity. The same static deflection tests as used in case of Young's modulus are performed to measure the actual stiffness (*k*) of a jointed specimen using the relation $K = \frac{W}{\Delta}$. However, the stiffness of an identical solid fixed-fixed beam is theoretically calculated from the expression $k' = \frac{192EI}{L^3}$. The average values of the stiffness ratios for two layered fixed-fixed welded beams has been calculated and presented in Tables as samples for mild steel respectively.

Table 2. Experimental reading of static deflection test for mild steel beam

Thickness × Width (mm × mm)	Length (mm)	Load (w) N	Deflection (Δ) mm
(3+3) × 32.50	600	125	1.432
		150	1.66
(4+4) × 32.50	600	125	0.57
		150	0.68
(2+3) × 32.50	560	125	1.99
		150	2.38
(4+6) × 32.50	560	125	0.24
		150	0.29
(2+4) × 32.50	520	125	0.91
		150	1.09
(3+6) × 32.50	520	125	0.26
		150	0.31

Table 3. Average stiffness ratio of two layered welded mild steel beam specimens

Thickness × Width (mm × mm)	Length (mm)	Static bending stiffness (N/mm)		Stiffness Ratio (*k/k'*)	Average Stiffness ratio
		Experimental (*k*)	Theoretical (*k'*)		
(3+3) × 32.50	600	88.8969	105.1460	0.8456	0.85495
(4+4) × 32.50	600	218.08	249.2351	0.8750	
(2+3) × 32.50	560	62.806	74.8409	0.8392	

(4+6) × 32.50	560	514.069	598.7294	0.8586	
(2+4) × 32.50	520	136.431	161.5247	0.8461	
(3+6) × 32.50	520	471.822	545.1444	0.8655	

The corresponding values of the average stiffness ratios for jointed beams consisting of varying thickness and lengths are given in Table 4.6 for mild steel specimens. It is found that the stiffness ratio decreases with the two layers of the jointed construction. These calculated stiffness ratios are used for determining the actual stiffness of jointed beams and further utilized for the theoretical evaluation of logarithmic decrement.

3.4 measurement of Damping

After evaluating the young's modulus of elasticity and static bending stiffness of mild steel specimens, the test are further conducted on the same set of specimens of mild steel for evaluating the damping capacity. In the present research, damping has been measured using the logarithmic decrement method based on the time domains.

3.4.1 Logarithmic damping measurement

From the literature survey, there are several techniques are used to quantify the level of damping. From that the logarithmic decrement is the most widely used time- response method. For damping measurement logarithmic decrement means for the rate at which the amplitude of free vibration decreases.

In this the beam is vibrated with small excitation level end moderate frequency range, this method produces good results for lightly damped linear system. In this method, the beam is vibrated with small excitation varying from 0.1 mm to 0.5 mm amplitude with spring loaded exciter at the mid span of the beam. The response of the given vibration amplitude is then sensed by contacting type accelerometer attached at the mid-span of the beam. The accelerometer is connected with digital storage oscilloscope. The damped frequency is read directly from the damped frequency (ω_n) is the same as that of the natural frequency.

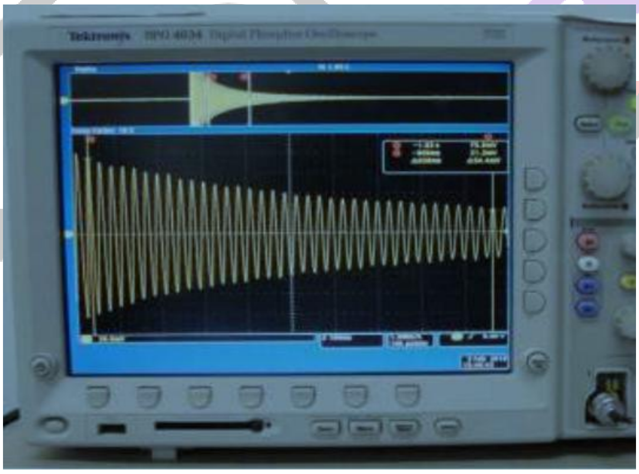

Figure 4. Photographic view of logarithmic decrement

From oscilloscope we take readings of the amplitudes of first cycle and last cycle and the number of cycle then with the expression $\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right)$ is used to find out the logarithmic decrement.

$$\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right) = \frac{1}{25}\ln\left(\frac{3.8}{3.1}\right)$$

$$= 8.143 \times 10^{-3}$$

$$= 0.008143$$

Table 4. Experimental reading from oscilloscope for excitation at amplitude of 0.1 mm

length (mm)	number of cycle	amplitude of first cycle x_0 (mv)	amplitude of last cycle x_n (mv)	logarithmic decrement $\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right)$
520	25	3.8	3.1	0.00814
560	22	3.7	3.06	0.008536
600	20	3.7	3.07	0.00993

IV. CONCLUSION

- The damping capacity of layered and tack welded beam increases with increase in the length of the beam.
- The damping capacity of layered and tack welded beam increases with increase in the initial amplitude of the beam.

REFRENCES

[1] B. K. Nanda, A. K. Behera, "Study on damping in layered and jointed structures with uniform pressure distribution at the interfaces" Journal of Sound and Vibration (1999) 226(4) 607-624.
[2] W. Chen, X. Deng, "Structural damping caused by micro-slip along frictional interfaces" International Journal of Mechanical Sciences 47 (2005) 1191–1211.
[3] B. K. Nanda, "Damping capacity of layered and jointed copper structures" Journal of Vibration and Control, Volume 12, Issue 6, June 2006, Pages 577-600.
[4] B.K. Nanda, "Study of the effect of bolt diameter and washer on damping in layered and jointed structures" Journal of Sound and Vibration 290 (2006) 1290–1314.
[5] Bhagat Singh, Bijoy Kumar Nanda, "Dynamic analysis of multilayered welded aluminium cantilever beams" Applied Acoustics 73 (2012) 1174–1184.
[6] Bhagat Singh, Bijoy Kumar Nanda, "Dynamic analysis of damping in layered and welded beams" Engineering Structures 48 (2013) 10–20.