Abstract
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.

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.

The study of damping mechanism and its improvement in structures has become significant in effectively controlling the undesirable effects of vibration with simultaneously aiming at
enhancing the damping capacity. As the available damping in the structural members is inadequate, various techniques have been adopted in practice to improve the damping capacity of structures. These techniques are:

(i) Use of constrained/unconstrained viscoelastic layers,
(ii) Fabrication of multi-layered sandwich construction,
(iii) Insertion of special high elastic inserts

In the alternative, cast structures can be used, but unfortunately, these are more expensive to manufacture and as a result, the deployment 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 aforesaid parameters on the damping rate of such structures is investigated and discussed in this study.

Many structures are built up by connecting structural members through joints. Due to very low material damping of built-up structures, sufficient damping has to come from the joints. In structures made up of bolted members, up to 90% of the damping can be supplied by the joints themselves. The damping of a structure is experimentally measured either by time or frequency domain methods. In case of the former, the damping is estimated in terms of logarithmic decrement using the free decay signal. This method is generally applied to lightly damp linear systems excited at lower amplitude and frequency. Many researchers have conveniently used this technique for estimating damping.

Damping

Damping is a phenomenon by which mechanical energy is dissipated (usually converted as thermal energy) in dynamic systems. It is the energy dissipation property of a material or system under cyclic stress. 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 which may be internal or external. This resistance is termed as damping.

The study of damping has been taken up primarily in four major areas like Materials science, Structural mechanics, Vibration control and Inspection methods. The energy of the vibrating system is dissipated by various mechanisms and generally more than one mechanism may be present, concurrently. For convenience, damping in vibrating mechanical systems is classified depending on the main routes of energy dissipation as follows:

1. Material damping
2. Structural damping and
3. Fluid damping

Bolted Joints
A bolt is a short cylindrical bar with a head at one end. The amount or energy loss for a bolted joint depends on the materials, surface finish, contact area, bolt tension, lubrication, fretting corrosion etc. The joint becomes stiffer with less damping as the bolt torque increases.

**Advantages of Bolted joints**
- Bolted joint can be designed to take tension loads, unlike riveting.
- Bolts are easy. Welding takes a lot of skill and a lot of time, particularly if you are going to inspect the weld for flaws after its completed.
- Bolted joint are more reliable than welded joint in applications which are subjected to vibrations and impact forces.
- It offers much better joint quality than a screw, mostly because the threads are more tightly controlled.
- The heat required for welding causes warping and affects the structure of heat treated components. The parts assembled by Bolted joint are free from such thermal effects.
- When the Bolted joint is dismantled, the connected components are less damaged compared with those welded joint.

**Drawbacks of Bolted joints**
1) The bolted joint can become loose over a time as the nut backs off or a material creeps.
2) The bolted joints require access to both sides of the joints.
3) The corrosion between the bolt and parent material should be considered.
4) The overall cost of Bolted joint is more than that of welded joint due to increased metal consumption and higher labour cost.
5) Bolted assemblies have more weight than welded assemblies due to strap plates and bolts.

**2. 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:
- 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.
- Damping capacity is higher in bolted joints and least in welded joints. Hence in order to overcome this drawbacks a beam with Bolted joints are used.

**3. EXPERIMENTAL METHODOLOGY**
**Preparation of Specimens**
The specimen of mild material is prepared from different sizes of bolts. Bolts of 6mm, 8mm, and 10mm diameter are used to prepare specimens of different sizes with a constant pressure acting while bolting specimen with a constant torque of 30N-m. The pitch between two bolts is kept same. The width and length of the specimens are also taken from the bolt
diameter and beam thickness ratio as per the zone of influence. For example, pitch distance between two consecutive bolts and width of specimens are kept as 3.5 times the diameter of the bolt for beam thickness ratios of 1.0, 1.5 and 2.0. The analyses are based on the assumptions of Euler-Bernoulli beam theory as the dimensions of test specimens satisfy the criterion of thin beam theory and the beam is vibrated at low frequency.

Figure 1: Photographs of specimens with Bolt diameter 10mm used for experimentation

Figure 2: Photographs of specimens with bolt diameter 8mm used for experimentation

Figure 3: Photographs of specimens with bolt diameter 6mm used for experimentation
Table 1: Details of mild steel specimens for the thickness ratio 1.0

<table>
<thead>
<tr>
<th>Width<em>thickness (mm</em>mm)</th>
<th>Number of Layers</th>
<th>Type of specimen</th>
<th>Diameter of bolt (mm)</th>
<th>Number of Bolt</th>
<th>Beam Span (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40*(3+3)</td>
<td>2</td>
<td>Jointed</td>
<td>10</td>
<td>10</td>
<td>330</td>
</tr>
<tr>
<td>40*(4+4+4)</td>
<td>3</td>
<td>Jointed</td>
<td>10</td>
<td>10</td>
<td>330</td>
</tr>
<tr>
<td>40*(3+3+3+3)</td>
<td>4</td>
<td>Jointed</td>
<td>10</td>
<td>10</td>
<td>330</td>
</tr>
<tr>
<td>30*(3+3)</td>
<td>2</td>
<td>Jointed</td>
<td>8</td>
<td>10</td>
<td>330</td>
</tr>
<tr>
<td>25*(3+3)</td>
<td>2</td>
<td>Jointed</td>
<td>6</td>
<td>10</td>
<td>330</td>
</tr>
</tbody>
</table>

Table 2: Details of mild steel specimens used for the thickness ratio 1.5

<table>
<thead>
<tr>
<th>Width<em>thickness (mm</em>mm)</th>
<th>Number of Layers</th>
<th>Type of specimen</th>
<th>Diameter of bolt (mm)</th>
<th>Number of Bolt</th>
<th>Beam Span (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40*(3.6+2.4)</td>
<td>2</td>
<td>Jointed</td>
<td>10</td>
<td>10</td>
<td>330</td>
</tr>
</tbody>
</table>

Table 3: Details of mild steel specimens used for the thickness ratio 2.0

<table>
<thead>
<tr>
<th>Width<em>thickness (mm</em>mm)</th>
<th>Number of Layers</th>
<th>Type of specimen</th>
<th>Diameter of bolt (mm)</th>
<th>Number of Bolt</th>
<th>Beam Span (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40*(4+2)</td>
<td>2</td>
<td>Jointed</td>
<td>10</td>
<td>10</td>
<td>330</td>
</tr>
</tbody>
</table>

4. EXPERIMENTAL SETUP

The experimental set-up consists of a framework which is fabricated from steel C-channel sections by welding. The frame is grouted to a heavy and rigid concrete base by means of foundation bolts and it has the provision of slotted guide ways to accommodate the beams of different lengths. The frame has the provision to hold the fixed end of the cantilever beam specimens tightly and rigidly in order to ensure perfect cantilever condition. This clamping is achieved using a mechanical vice. The vice working on the screw-jack principle consists of a base plate and a spindle with internal and external threading, respectively. An arm is attached to this spindle at the upper end. On rotating the arm, it moves axially downward and imparts the necessary clamping force to the base plate thereby holding the specimen to achieve a perfect cantilever condition. The base plate prevents the rotation of the specimens while applying the fixed end load. A spring loaded exciter is used to initiate vibration at the free end of the specimens

- Spring Loaded Exciter
- Accelerometer
- OROS 4 Channel FFT Analyzer
- Bolted beam
- Dial Indicator
- Computer

Figure 4: Experimental set-up for cantilever beam
5. RESULTS AND DISCUSSION

5.1 Effect of Diameter on damping ratio ($\xi$)

By keeping the overall thickness of the beam constant the Bolted beam are constructed for varying number of diameter. Considering this influencing parameter the beam is analyzed for 3 mm and 6 mm excitation.

Table 4: Experimental Results of damping ratio with increasing number of Diameter.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Width<em>Thickness (mm</em>mm)</th>
<th>Diameter (mm)</th>
<th>Experimental Damping Ratio($\xi$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3 mm</td>
<td>6mm</td>
</tr>
<tr>
<td>1</td>
<td>40(3+3)</td>
<td>10</td>
<td>0.515</td>
</tr>
<tr>
<td>2</td>
<td>30(3+3)</td>
<td>8</td>
<td>0.493</td>
</tr>
<tr>
<td>3</td>
<td>25(3+3)</td>
<td>6</td>
<td>0.4524</td>
</tr>
</tbody>
</table>

Figure 5: Damping ratio versus Bolt Diameter graph

5.2 Effect of Thickness Ratio on damping ratio ($\xi$)

By performing experiments on Bolted beam for different diameter of bolts it can be observed that the damping ratio ($\xi$) increases as diameter of bolts is increased from 6mm to 10mm. The Bolted beam is excited for 3mm and 6mm. As excitation increases the damping ratio goes on decreasing.

Table 5: Experimental Results of damping ratio with Thickness Ratio

<table>
<thead>
<tr>
<th>Thickness Ratio</th>
<th>Width<em>Thickness (mm</em>mm)</th>
<th>Diameter (mm)</th>
<th>Experimental Damping Ratio($\xi$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3 mm</td>
<td>6mm</td>
</tr>
<tr>
<td>1.0</td>
<td>40(3+3)</td>
<td>10</td>
<td>0.515</td>
</tr>
<tr>
<td>1.5</td>
<td>40(3.6+2.4)</td>
<td>10</td>
<td>0.4837</td>
</tr>
<tr>
<td>2.0</td>
<td>40(4+2)</td>
<td>10</td>
<td>0.444</td>
</tr>
</tbody>
</table>
5.3 Effect of Number of Layers on damping ratio (ξ)

By keeping the overall thickness of the beam constant the Bolted beam are constructed for varying number of layers. Considering this influencing parameter the beam is analyzed for 2 mm excitation.

Table 6: Experimental Results of damping ratio with increasing number of Layers

<table>
<thead>
<tr>
<th>Number of Layer</th>
<th>Width<em>Thickness (mm</em>mm)</th>
<th>Diameter (mm)</th>
<th>Experimental Damping Ratio(ξ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>40*6</td>
<td>-</td>
<td>0.3806 0.379</td>
</tr>
<tr>
<td>Solid</td>
<td>40*(12)</td>
<td>-</td>
<td>0.4098 0.402</td>
</tr>
<tr>
<td>2</td>
<td>40*(6+6)</td>
<td>10</td>
<td>0.426 0.415</td>
</tr>
<tr>
<td>3</td>
<td>40*(4+4+4)</td>
<td>10</td>
<td>0.476 0.458</td>
</tr>
<tr>
<td>4</td>
<td>40*(3+3+3+3)</td>
<td>10</td>
<td>0.526 0.508</td>
</tr>
</tbody>
</table>

Figure 7: Damping ratio versus Number of layers graph
6. CONCLUSION

Damping ratio ($\xi$) of solid and bolted cantilever beam is experimentally presented. For Bolted beam different influencing parameter:- diameter of bolts, thickness ratio, number of layers. The following conclusion is obtained from experimental results.

1) **Effect of diameter of bolt**: The preload on bolts is increased by the use of bolts of larger diameter, thereby increasing the normal force and the energy loss at the interfaces. But the energy dissipation due to interface friction occurs at a higher rate compared to the input energy, thereby causing a net increase damping ratio.

2) **Effect of beam thickness ratio**: Experimental shows that damping ratio increases in jointed as compared to solid one keeping overall beam thickness constant. It is observed that damping ratio is greater in jointed structure having smaller thickness ratio. By using structure of equal thickness damping can be increased.

3) **Effect of number of layers**: As discussed earlier, 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 compared to the solid beam of same overall thickness due to more friction interfaces which produces higher energy loss at the interfaces.

**Future Scope:**

The experimental results can be validated by FEA analysis. These results can be validated by using Ansys software.

7 REFERENCES


To Cite This Paper