THE EFFECTS OF BOLTED JOINTS ON DYNAMIC RESPONSE OF STRUCTURES

I. Zaman[1*], A. Khalid[1], B. Manshoor[1], S. Araby[2] and M. I. Ghazali[1]

[1]Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
*Email: izzuddin@uthm.edu.my
Phone : +607-453-8462; Fax : +607-453-6080
[2]School of Advanced Manufacturing & Mechanical Engineering,
University of South Australia, SA 5095, Australia

ABSTRACT

Joint is an universal fastening technology for structural members; in particular bolted joints are extensively used in mechanical structures due to its simple maintenance and low cost. However, the components of bolted joint are imperative because its failure could cost catastrophic and endanger lives. Hence, in this study, the effects of bolted joints on vibrating structures are investigated by determining the structural dynamics properties, such as mode shapes, damping ratios and natural frequencies, and these are compared with the monolithic structures (welding). Two approaches of experimental rigs are developed: a beam and a frame where both are subjected to dynamic loading. The analysis reveals the important of bolted joint in increasing the damping properties and minimizing the vibration magnitude of structure, therefore indicates the significant influence of bolted joints on the dynamic behaviour of the assembled structures. The outcome of this study provides a good model for predicting the experimental variable response in different types of structural joints.

Keywords: Beam, Frame, Joints, Modal parameters, Structural dynamics, Vibration

INTRODUCTION

Joints, in most engineering structures are considered vital part due to its functionality to unite and assemble the structural members. This result in using a choice of fastening techniques such as bolting, welding and riveting (Blake, 1985; Bickford and Nassar, 1998). Although joint is known to introduce flexibility to the structure, its behaviour when subjected to a dynamic loading is still not fully understood. In most cases, vibration is the most critical problem occurred in the mechanical structures which concerns to joint failure. The structural vibration causes the components to move in rapid linear motion, as a consequent produces a harmful effect mainly to the torque of joints. This awareness makes most people in particular structural engineers to realize the importance of joint especially in a giant construction where a failure instigates catastrophic and people death.

Until today, much knowledge and research about joints has been discovered and performed. For example, (Ahmadian and Jalali, 2007) identified the parameters of bolted joints in assembled structures through experiment and analytical solution. In their study, the lateral stiffness and torsional stiffness of assembled structures were identified using the first three natural frequencies whilst the damping coefficient was identified using a nonlinear response function. Similar study was performed by (Ma et al., 2001)

1

who compared the dynamics structure of beam with and without a joint through experimental approach. Three levels of joints tightening were distinguished to investigate non-linear effects and loosening effects occurred from the damping of joint. The experimental result indicated that this approach was found applicable to every bolted structure to know their parameters.

In order to accurately model the properties of joints, researchers calculated the frequency response function (FRF) data using the finite element analysis (Ren and Beards, 1994; Read and Hiser, 2004; Guo et al., 2012, Saxena et al., 2012). The assembly structure was divided into three systems: (i) first was substructure system, (ii) second was joint system and (iii) the third was the whole assembly system. Regardless it is difficult to get the accurate calculation because FRF data were contaminated by measurement errors. (Kim et al., 2007) introduced four finite element models of bolted joints, such as a solid bolt model, a coupled bolt model, a spider bolt model and a non-bolt model in order to investigate the accurateness of these modelling techniques. The models were analysed using ANSYS.

Although there are many research in the past have been devoted in the structural dynamics system, until today there are still lacking of studies in getting the accurate parameters of the bolted joints effects in particular. Aforementioned it is important to know and understand the behaviours of joint ant its effect on dynamic environments. Therefore, this study aims to evaluate and describe the effects of joints using the experimental rig testing. The experimental is carried out using modal testing—where impact hammer is excited through beams and frames structure in order to get the structural dynamic characteristics.

RESEARCH METHODOLOGY

Sample Preparation

There are two assembly structures were analysed in the study, which are a beam and frame structures. Both beam and frame were having two types; monolithic structure, where components are merged using welding method, and jointed structure, where components are merged using bolt and nut (See Figure 1). The structures were weighted equivalently to avoid errors. In the bolted structure, 12 mm diameter hexagon bolts were employed. Figure 2a shows the dimension of beam structure which given as $5.2 \times 2.5 \times 0.635$ cm while Figure 2b shows the dimension of frame structure at $26.7 \times 25.4 \times 0.635$ cm.
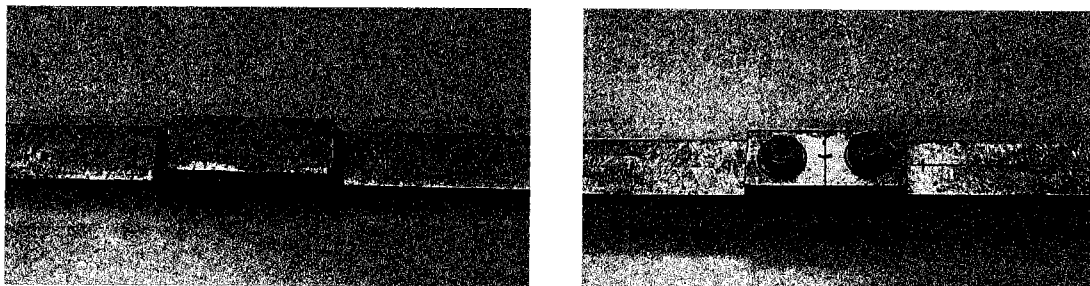

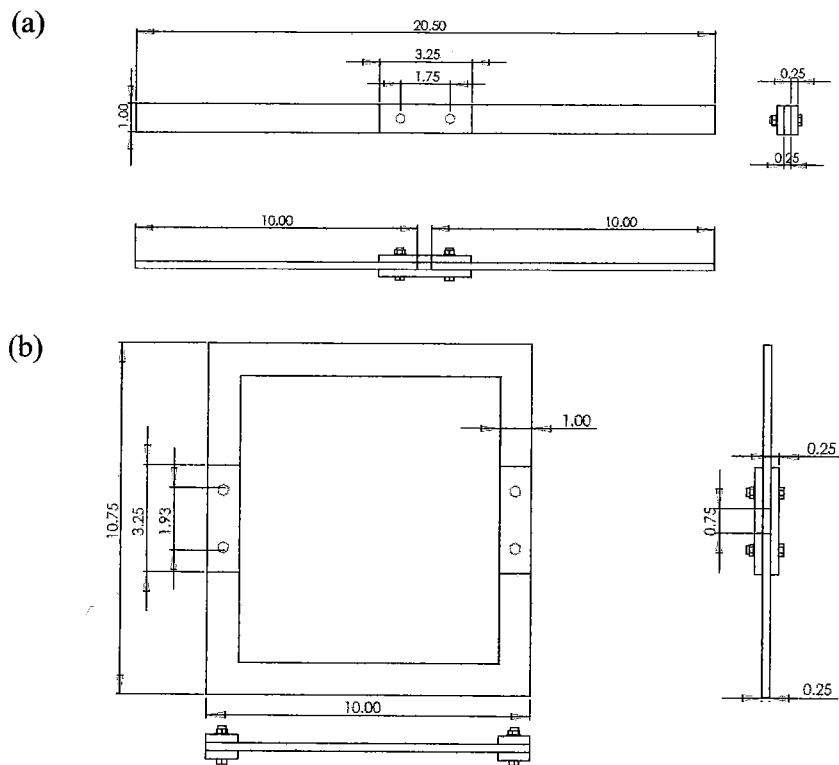Figure 1. Monolithic structure and bolted-joint structure.

Figure 2. Dimensions of (a) beam structure (b) frame structure from front, top and side view.

Design of Experiment

For the modal testing, the structure was suspended by 1 m length of elastic rope in order to stimulate a free-free boundary condition as shown in Figure 3. An impact hammer was used to excite the structure at all points (11 points for beam and 30 points for frame) and an accelerometer was fixed at point 1 to accept acceleration response from the structures. The force and acceleration data were collected through data analyser which later converting to FRF using Dynamic Signal Analyzer software.
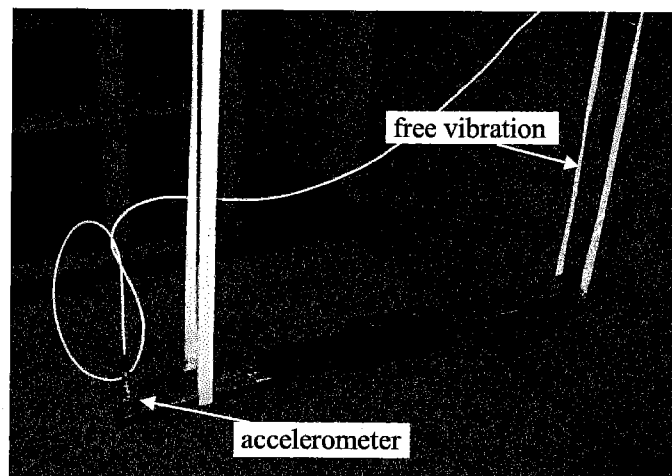

Figure 3. Typical experimental set-up for impact hammer test.

RESULTS AND DISCUSSION

Analysis of Beam

Table 1 tabulates the results of natural frequencies and damping ratios of each type of beams that obtained from experimental modal testing. It can be seen that the natural frequencies increase from each mode within the range of 0–2000 Hz. The bolt-jointed beam, however, shows reduction of natural frequencies about 1–15% compares to monolithic structure. By contrast, the damping ratios increased significantly in jointed beam, where the highest increment recorded was ~440% at mode three.

Table1. Structural dynamic properties of beams.

Mode	Monolithic beam		Jointed beam	
	Nat. freq. (Hz)	Damp. ratios	Nat. Freq (Hz)	Damp. ratios
1	189	1.77	159	1.75
2	444	0.224	437	0.166
3	1010	0.306	868	1.66
4	1420	0.222	1320	1.15

These results were further analysed using FRF where the graph log magnitudes were plotted against frequencies (see Figure 4a). It can be seen that the maximum peak in the third mode (1010 Hz) is shifted about 14%, and 7% for mode four (1420 Hz). Since the mass of both structures are similar, the only parameter that could affect natural frequency is stiffness. The stiffness of bolt-jointed beam was found smaller than monolithic beam due to the gaps at the lap joints. The magnitude of jointed beam was also found smaller where it decays about 77% and 85% for mode three and four, respectively. This result revealed that the bolted joints can reduce vibration in assembly structure and the hypothesis is supported by higher damping factor as shown in Table 1. Similar result was observed by (Ma et al., 2001) when they compared monolithic beam and jointed beam in their experiment. The corresponding mode shape of the beam at mode one is illustrated in Figure 5. It was found that the highest residue magnitude occurred at both end sides of the beam, where the lowest is observed in bolt-jointed beam.
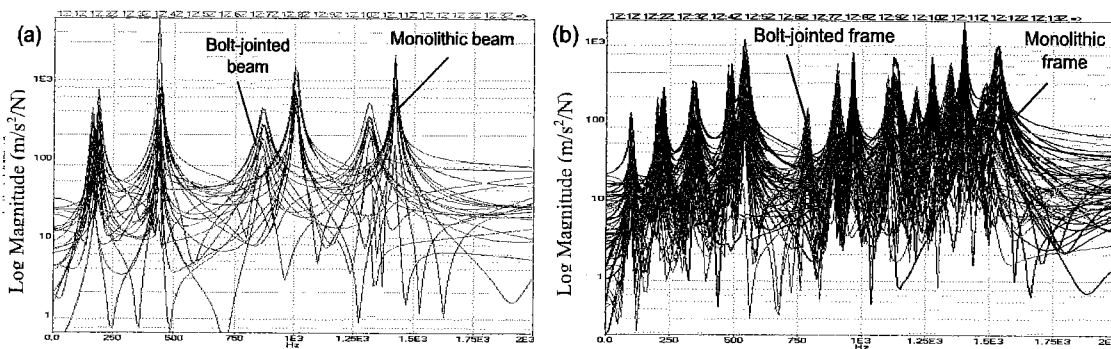

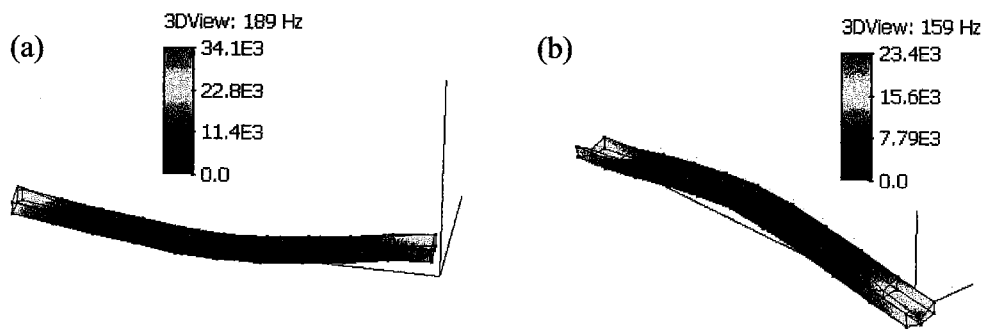Figure 4. Graph log magnitude vs. frequency for (a) beam and (b) frame.

Figure 5. Mode shape of (a) monolithic beam and (b) bolt-jointed beam.

Analysis of Frame

Figure 4b shows the FRF result of frames against frequencies. Similarly, bolt-jointed frame was compared to monolithic frame. There are ten mode were collected in range of 0 to 2000 Hz of frequency. The peaks are shifted for several modes where the joints are located. The first four peaks show almost similar phases, while the rest shows significantly different. Table 2 tabulates the dynamic properties of frames for the first four modes. It can be seen that bolt-jointed frame produces lower natural frequencies and higher damping ratios than monolithic frame. The average percentage increase of damping ratio recorded was ~290%. This can be further verified in Figure 4b, where the FRF of jointed frame is more stable and has lower amplitude from peak to peak. Figure 6 illustrates the mode shape of frames at first mode which observed as mode torsion.

Table2. Structural dynamic properties of frames.

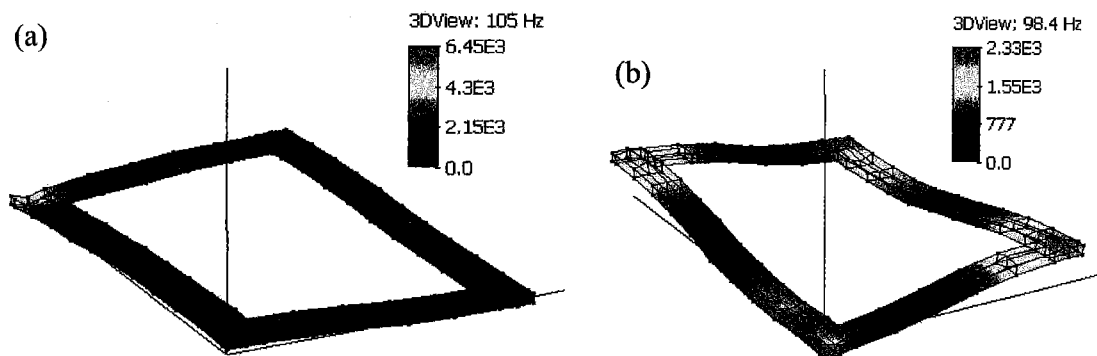| Mode	Monolithic frame		Jointed frame	
	Nat. freq. (Hz)	Damp. ratios	Nat. Freq (Hz)	Damp. ratios
1	105	0.231	98.4	0.819
2	221	0.255	199	1.000
3	343	0.254	328	0.906
4	486	0.17	476	0.476

Figure 6. Mode shape of (a) monolithic frame and (b) bolt-jointed frame.

CONCLUSION

This study investigated the effects of joints on dynamic response of assembly structures. The importance conclusions of this study are summarized as follows:
  i)   The addition of bolted joints decreases the structure' natural frequencies by adding additional mass to the structure.
  ii) The assembled structure using bolted joint significantly increases the damping ratio, thus this will immensely affect a complex structure.
  iii) The monolithic structures have higher stiffness compare to jointed structures.

ACKNOWLEDGEMENTS

REFERENCES

Ahmadian, H. and Jalali, H. 2007. Identification of Bolted Lap Joints Parameters in Assembled Structures. Journal of Mechanical Systems and Signal Processing, 21: 1041-1050.

Blakke A. 1985. Design of Mechanical Joints. New York: Marcell Dekker.

Bickford, J. H. and Nassar, S. 1998. Handbook Of Bolts and Bolted Joints. New York: Marcel Dekker.

Guo, T., Li, L., Cai, L. and Zhao, Y. 2012. Alternative Method for Identification of the Dynamic Properties of Bolted Joints. Journal of Mechanical Science and Technology, 26: 3017-3027

Kim, J., Yoon, J. C. and Kang, B. S. 2006. Finite Element Analysis and Modeling of Structure with Bolted Joints. Journal of Applied Mathematical Modelling, 31: 895-911.

Ma, X., Bergman, L. and Vakakis, A. 2001. Identification of Bolted Joints Through Laser Vibrometry. Journal of Sound and Vibration, 246: 441-460.

Ren, Y. amd Beards, C. F. 1994. Identification of Joint Properties of a Structure Using FRF Data. Journal of Sound and Vibration, 186: 567-587.

Reid, J. D. and Hiser, N. R. 2004. Detailed Modeling of Bolted Joints With Slippage. Journal of Finite Elements in Analysis and Design, 41: 547-562.

Saxena, M., Tripathi, K., Kanchwala, H. 2012. Investigation of Dynamic Response of Bolted Joint Test Rig Under Free Vibrations using FEA. International Journal of Applied Engineering Research, 7: 1359.

Webb, R.L. 1993. Principles of enhanced heat transfer. New York: John Wiley.