6-25-2017

Detection of Structural Bolt Detorquing Using Direct Stethoscope Measurement

Joe Guarino
Boise State University

Robert Hamilton
Boise State University

Proceedings of Meetings on Acoustics

Volume 30 http://acousticalsociety.org/

Acoustics `17 Boston

173rd Meeting of Acoustical Society of America and 8th Forum Acusticum
Boston, Massachusetts
25-29 June 2017

Structural Acoustics and Vibration: Paper 4aSAc3

Detection of structural bolt detorquing using direct stethoscope measurement

Joe Guarino
Mechanical and Biomedical Engineering, Boise State University, Boise, Idaho, 83725; jguarino@boisestate.edu

Robert Hamilton
Civil Engineering Department, Boise State University, Boise, Idaho, 83725; RHamilton@boisestate.edu

A method for detecting loosened bolts in a structural joint based upon open-loop acoustic measurement is presented. The acoustic measurement is taken directly on the bolt head. The response of the bolt to a proximal hammer impact is evaluated and characterized using wavelet decomposition of the signal measured from the bolt head. Data were also taken from an accelerometer mounted longitudinally and transversely on the bolt head. Results from the stethoscope and the accelerometer are presented from a set of structural bolts in several conditions of preload and looseness. A stethoscope applied to the loose bolt and a proximal bolt during impact recorded a marked difference between tight, finger tight, and loose bolts. The study could enable a quick and simple method for detecting and evaluating detorqued bolts in structural joints.

Introduction

Detecting loose bolts in a structural connection is an important area of study in the field of structural-health monitoring (SHM). Many non-destructive evaluation (NDE) methods for detecting damage and looseness in joints and bolts have been investigated. Accelerometer-based methods are exemplified by Jaques and Adams (2012)[1], using an array of impact and sensor locations to detect loose bolts in lap joints and panels. Esmaeel et al. (2012)[2] published a study of a bolted flange in a pipeline that was degraded by progressively loosening bolts. The structure was impacted with a hammer and the dynamic response was measured by an array of piezoelectric sensors. Results indicated that the bolt looseness could be detected and quantified. Amerini and Meo (2011)[3] presented a method for determining degrees of bolt looseness using acoustic ultrasonography (AU), over a wide range of frequencies. Among their findings, Amerini and Meo reported differences in PSD spectra between states of looseness in the frequency range of 1 to 7 kHz, using sensors attached to a bolted plate. Milanese et al. (2008)[4] presented a method for detecting progressively-loosened bolts using an output-only model based upon measurements taken from fiber-optic strain sensors attached to the bolts. Nichols et al. (2007)[5] used bolt-mounted fiber-optic strain sensors to detect a loose bolted joint using ambient vibrations, without the need for baseline data. Guarino and Hamilton (2015)[6] presented an output-only method for detecting loose bolts in a bolted flange connection, using an electronic stethoscope applied to the bolted beams.

The authors explore a simple and inexpensive method for determining degrees of looseness of a specific bolt in a bolted flange, based upon direct measurement of the bolt head. We present an output-only method using an electronic stethoscope and processing software that is free at this time. We compare response spectra from the stethoscope and from an accelerometer mounted on the bolt head in both normal and transverse directions. Measurements were taken from the head of the loosened bolt and the head of a proximal bolt that remained tight.

Methods

A bolted flange connecting a horizontal, standard W 27 X 84 I-beam to a vertical steel column in a full-sized space frame was used in our study, as shown in Figure 1a. Impact was from a spud wrench swung by hand, striking a point midway between the heads of bolts 7 and 5. The impact point is shown in Figures 1a and 1b. The beam and columns are A36 structural steel, and the bolts are SAE Grade 5 (ASTM A325), 0.75 inches in diameter and 2.83 inches long (nominal).

Figure 1a. Connection and impact point

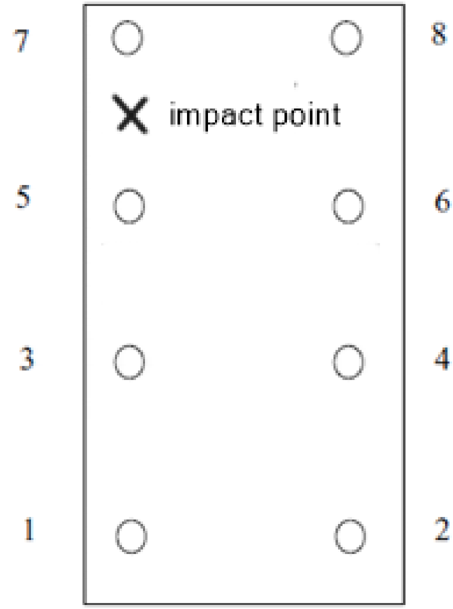


Figure 1b. ***End view of connection plate showing bolt locations and impact point***

Measurements were taken using a common electronic stethoscope and an accelerometer. The stethoscope is a Rhythm ds32a Digital Stethoscope, from Thinklabs, Inc.[7]. The Rhythm ds32a is an electronic stethoscope that filters and records acoustic data when applied and activated. The listening piece incorporates a flexible material that is placed in contact with the surface. The back of the flexible material moves in an electric field within the listening piece, creating a measurable electric signal that is further processed by the stethoscope to closely simulate the response of a common analog stethoscope. Like an analog stethoscope, the frequency response of the Rhythm ds32a can be "tuned" to be more sensitive to lower frequencies by increasing the pressure against the surface; however, this tuning property has virtually no effect in the Rhythm ds32a above 1000 Hz [8,9] . The diaphragm piece of the stethoscope is larger than the bolt heads. Firm pressure was applied to the diaphragm piece to ensure good contact with the bolt head. All data were processed and displayed using Audacity ® acoustic processing software, which could be downloaded at no cost at the time of this study[10].

We wished to evaluate the effect of a proximal loose bolt on a tight bolt. Therefore, measurements were taken at the tops of bolts five and seven for three conditions:

1. All bolts tight
2. Bolt 7 finger tight
3. Bolt 7 loose.

Bolt tightness was defined using the turn-of-the-nut method following RCSC Specifications for Structural Joints Using ASTM A325 or A490 Bolts[11] .

All measurements were taken from the top of bolts 5 and 7, for three different conditions of tightness of bolt 7. The eighteen different measurements are described below in Table 1.

Table 1. Description of Measurements

Bolt 7 Tight	**Bolt 7 Finger Tight**	**Bolt 7 Loose**
Accelerometer normal bolt 5	Accelerometer normal bolt 5	Accelerometer normal bolt 5
Accelerometer transverse bolt 5	Accelerometer transverse bolt 5	Accelerometer transverse bolt 5
Accelerometer normal bolt 7	Accelerometer normal bolt 7	Accelerometer normal bolt 7
Accelerometer transverse bolt 7	Accelerometer transverse bolt 7	Accelerometer transverse bolt 7
Stethoscope bolt 5	Stethoscope bolt 5	Stethoscope bolt 5
Stethoscope bolt 7	Stethoscope bolt 7	Stethoscope bolt 7

Data were recorded on a laptop computer and displayed using Audacity ® acoustic processing software. The sampling rate was 44 KHz, and a Hanning window was used. Data records were trimmed and spectrograms were created for each record. No other post processing was performed. However, we note that the Thinklabs stethoscope incorporates filtering that rolls off quite sharply beyond 1000 Hz.

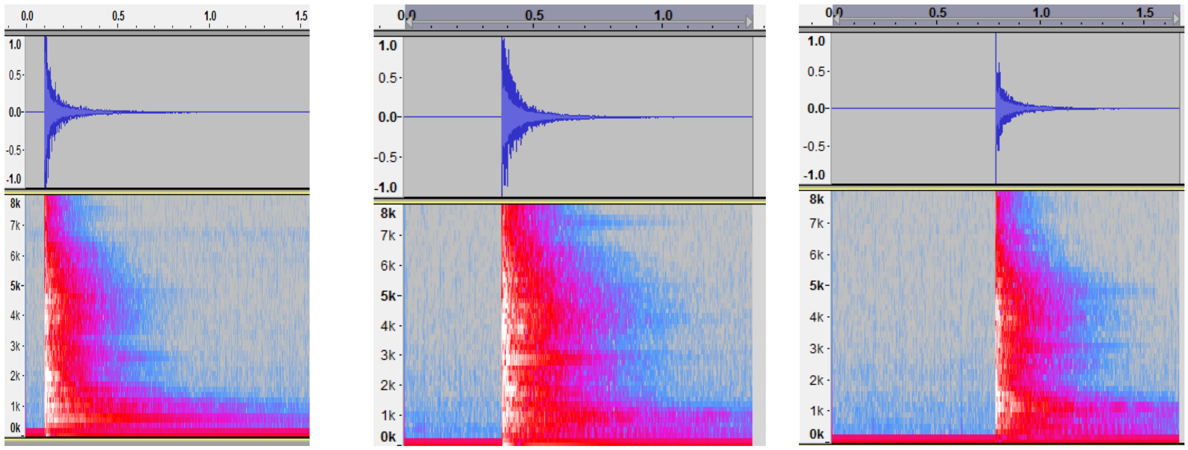
Results

Time records and spectrograms are shown in Figures 2, 3, and 4 for accelerometer in the normal direction (axial to the bolt), accelerometer in the transverse direction, and the stethoscope. Measurements were taken from bolt 5 (always tight, proximal to bolt 7), and bolt 7. Bolt 7 was in the three conditions of tight, finger tight, and loose.

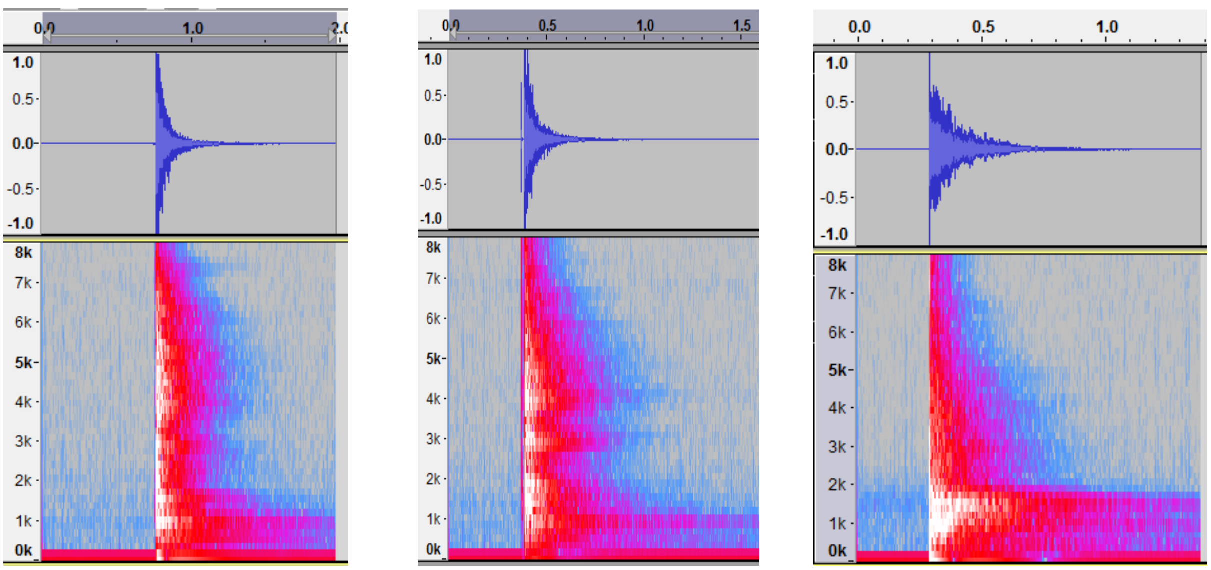
Spectra associated with accelerometer measurements were studied in the frequency range of 1000 to 8000 Hz, corresponding to our interest in the audible range as measured by the stethoscope. Spectrograms from the normal accelerometer measurements in figure 2 showed the same general spectral distribution, with perhaps subtle differences. Spectrograms from transverse accelerometer measurements in figure 3 showed a more discernible difference in the case of the measurement taken from bolt 7 in the loose condition.

Spectrograms from stethoscope measurements in figure 4 show clear differences that are gradational with bolt looseness. Measurements from bolt 5 (the proximal bolt) show a segmented spectrum with a cluster of components that gradually increase in frequency as bolt 7 is loosened. Measurements from bolt 7 (the gradually loosened bolt) show a cluster of components that decrease in frequency as bolt 7 is loosened.

Bolt 7 Tight | **Bolt 7 Finger Tight** | **Bolt 7 Loose**



Accelerometer on Bolt 5 normal orientation | Accelerometer on Bolt 5 normal orientation | Accelerometer on Bolt 5 normal orientation



Accelerometer on Bolt 7 normal orientation | Accelerometer on Bolt 7 normal orientation | Accelerometer on Bolt 7 normal orientation

Figure 2. Accelerometer in normal direction

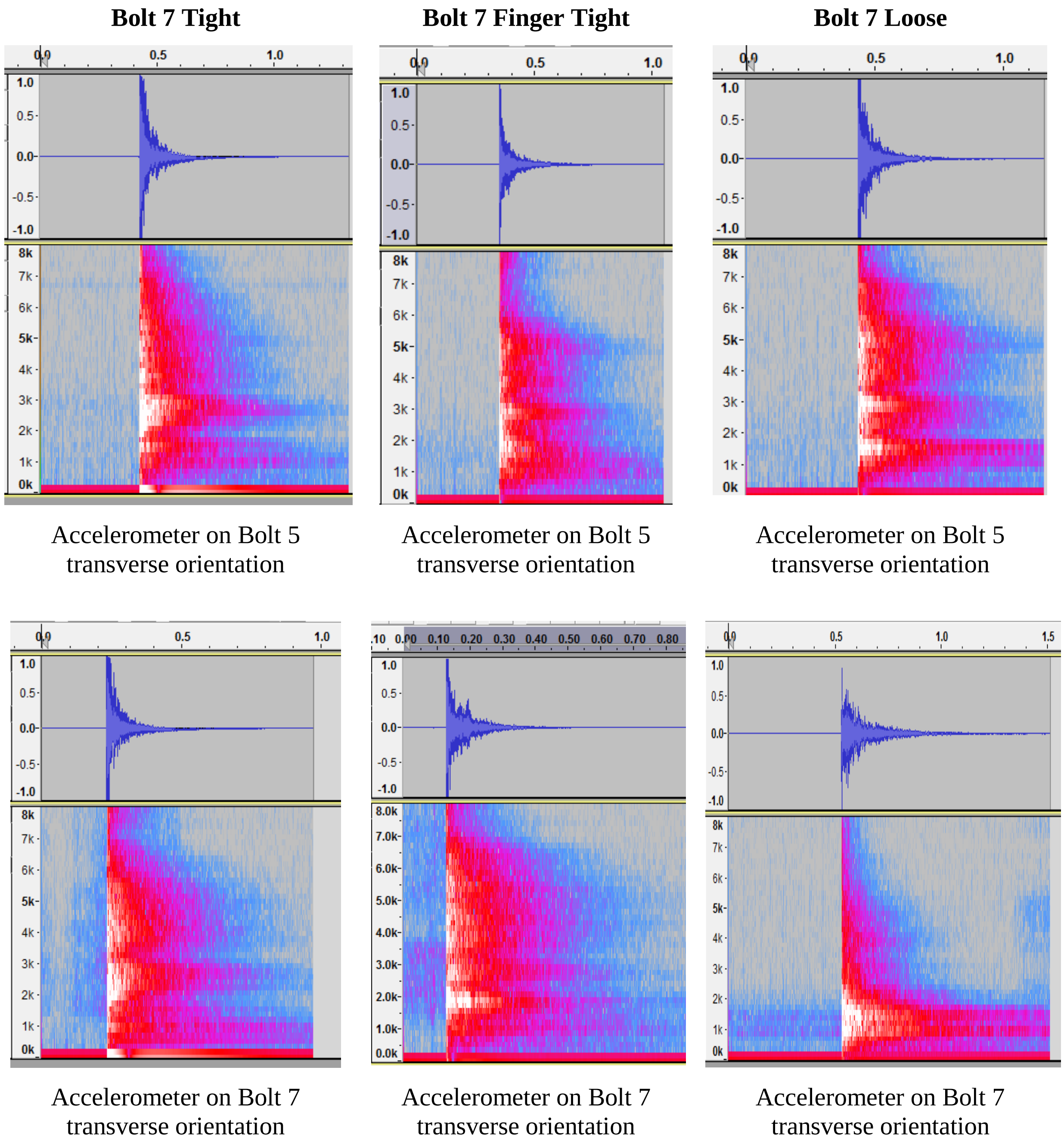


Figure 3. Accelerometer in transverse direction

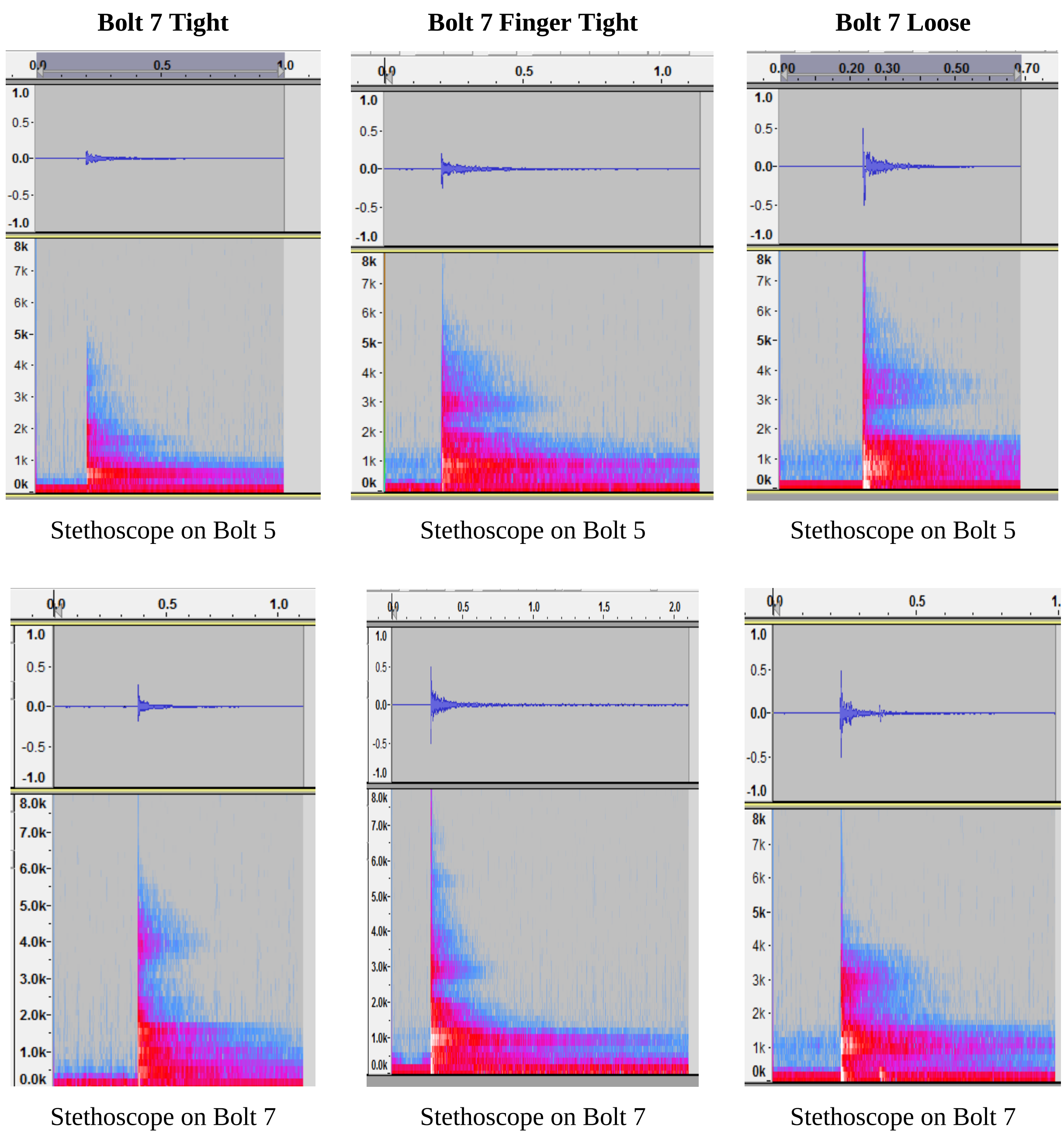


Figure 4. Stethoscope measurements

Conclusions

The electronic stethoscope provided the best differentiation in response to three different degrees of bolt looseness, in the frequency range that we studied. There are likely to be differences in the measurements taken from the accelerometer that would be revealed under more sophisticated analysis of a broader frequency range. In our frequency range, the transverse accelerometer orientation provided somewhat more differentiation than the normal orientation. Spectra from the stethoscope provided clear differences that were gradational associated with the three degrees of bolt looseness. However, changes in the spectra from the stethoscope applied to the proximal bolt were almost the reverse of changes in the spectra from the stethoscope applied to the loosened bolt. Further study is needed to elucidate the physics and specificity with regard to the response of the stethoscope. However, we conclude that an effective method for detecting bolt looseness can be developed using an inexpensive electronic stethoscope and simple processing software.

References

1. J. Jaques and D.E. Adams, “Using Impact Modulation to Detect Loose Bolts in a Satellite,” In: Adams D., Kerschen G., Carrella A. (eds) Topics in Nonlinear Dynamics, Volume 3. Conference Proceedings of the Society for Experimental Mechanics Series. Springer, New York, NY, 2012

2. Esmaeel, R. A., J. Briand, F. Taheri, “Computational simulation and experimental verification of a new vibration-based structural health monitoring approach using piezoelectric sensors,” *Structural Health Monitoring* 2012 11:237 , Sage publications

3. F. Amerini and M. Meo, “Structural health monitoring of bolted joints using linear and nonlinear acoustic/ultrasound methods,” *Structural Health Monitoring*, 10(6):659-672, 2011.

4. A. Milanese, P. Marzocca, J.M. Nichols, M. Seaver, and S.T. Trickey, “Modeling and detection of joint loosening using output-only broad-band vibration data,” *Structural Health Monitoring*, 7(4):309–328, 2008.

5. J.M. Nichols, S.T. Trickey, M. Seaver, S.R. Motley, and E.D. Eisner, “Using ambient vibrations to detect loosening of a composite-to-metal bolted joint in the presence of strong temperature fluctuations,” *Journal of Vibration and Acoustics*, 129(6):710 – 717, 2007.

6. Guarino, Joe, and R. Hamilton, “Stethoscope-based detection of detorqued bolts using impact-induced acoustic emissions,” Proceedings of Meetings on Acoustics (POMA), V. 22, 065001 (2015), Acoustical Society of America

7. Thinklabs One Digital Stethoscope: Filtering, (Filter Frequency Response vs. Gap), www.thinklabs.com/#1filtering/c9w9

8. Rhythm ds32a Digital Stethoscope, Thinklabs Inc., 6571 South Pontiac Court, Centennial, Colorado 80111 USA

9. Finkelstein, Eli, "The Ulitmate Acoustic Stethoscope Review," *For Us Docs*, www.forusdocs.com , July 1, 2008

10. Audacity ® 2.0.6 , Audacity Team, available from SourceForge.net

11. Specification for Structural Joints Using ASTM A325 or A490 Bolts, Publication Number S348 (2M205), Research Council on Structural Connections, c/o American Institute of Steel Construction, Inc., One East Wacker Drie, Suite 3100, Chicago, Illinois 60601-2001, June 30, 2004