MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Acoustic Landmine Detection: Laboratory Experiments using Airborne Sound

Lusby, Ava[1]
South River High School STEM
210 Central Avenue East
Edgewater, MD 21037

Lusby, Thomas[2]
United States Naval Academy Center for Academic Excellence
Annapolis, MD 21402

Korman, Murray[3]
United States Naval Academy Physics Department
572-C Holloway Road
Annapolis, MD 21402

ABSTRACT

Acoustic-to-seismic coupling methodology has been established to detect small plastic anti-personnel and anti-tank landmines buried in roadbeds. Experiments performed at the U.S. Naval Academy examined the detection of larger landmine simulants, up to 60 cm in diameter. A 30 cm circular landmine simulant (cylindrical aluminum frame and bottom plate, acrylic top plate) was buried to a four-inch depth in an open concrete tank filled with dry-sifted masonry sand. Airborne sound waves from 50 to 450 Hz were generated by amplifying the Agilent dynamic signal analyzer's swept tone to drive two large subwoofers, located 60 cm above the soil tank. The resulting soil vibrations were measured with a laser Doppler vibrometer and recorded by the analyzer. Reflecting discs were positioned in 1 cm increments across the center of a 57 cm square tank to collect particle velocity response vs. frequency data. Soil velocity vs. position graphs were compiled to measure the mode shape at 200 different fixed frequencies. Several radially symmetric mode shapes were identified that help to determine peak resonant frequencies of the coupled sand-landmine simulant system. In the future, similar methodology will be used to test acoustic landmine detection in alternate mediums, including dry or wetted pea sized gravel.

Keywords: Nonlinear, Tuning Curve, Landmine, Resonance, Vibration
I-INCE Classification of Subject Number: 76

1. INTRODUCTION

One of the main purposes of acoustic detection is to locate landmines in war zones, or in past war zones. Over 26,000 people are killed every year due to the estimated 60-70 million undetected land mines across the globe. Current landmine detection methods such as ground-penetrating radar are not effective at detecting non-metallic objects. With an increasing presence of plastic landmines in war zones, alternative detection techniques need to be explored. Acoustic detection has a distinct advantage for landmine detection in that non-metallic as well as metallic objects can be detected.

Acoustic imaging techniques take advantage of the concept that all objects or collections of objects (systems) have natural resonant frequencies. When the frequency of a generated sound wave matches a natural resonant frequency of the system, the system will react with increasing vibrational motion. In the case of this research, the system is comprised of a drum-like landmine simulant buried under a depth of sand. As the sound waves penetrate the soil, the soil particles and the drum will vibrate. When the sound waves match a natural frequency of the system, constructive interference will result in a measurable increase in soil motion.

Acoustic imaging techniques have been used to successfully detect smaller landmines, but more research is needed on larger objects. A related study done by M.S. Korman of the U.S. Naval Academy [3] measured how sound amplitude affected the resonant frequency of a small VS-50 landmine. Results of the amplitude effect are shown in the tuning curve (Figure 1) below. The system exhibited nonlinear behavior in that a higher sound amplitude resulted in a lower resonant frequency. We hope to apply similar acoustic detection techniques to larger objects. See references [1-8] for further discussion of related topics.

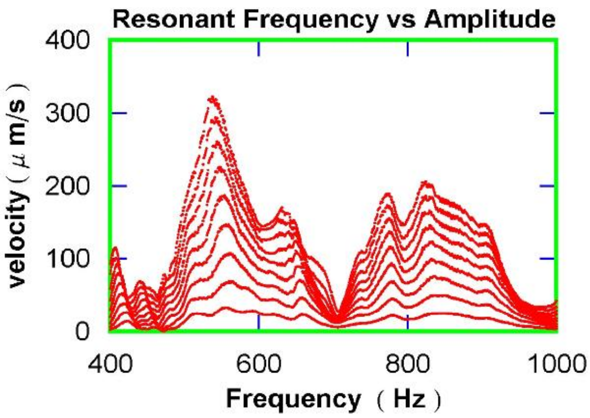

Figure 1: Frequency vs. velocity amplitude

2. EXPERIMENTAL OVERVIEW AND SETUP

A 30-cm diameter landmine simulant was used in our experiments. The drum-like simulant (Figure 2) was constructed with a ⅜” thick acrylic top plate, ¼” thick aluminum bottom plate, and 2” thick aluminium cylindrical ring. The concrete soil box used to bury the simulant is 57 cm square x 21 cm tall with 7.5 cm thick walls. Masonry sand was used to fill the soil box.

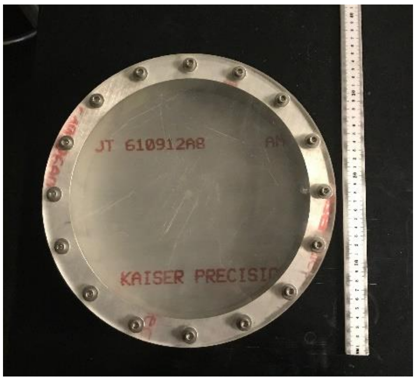

Figure 2: Landmine simulant- 30cm diameter, ⅜” thick acrylic top plate, ¼” thick bottom plate, 2” thick aluminum ring

An Agilent dynamic signal analyzer generates and controls the frequency of the sound signal, the signal is amplified and sent to two sub-woofer loud speakers to produce the sound wave. The loud speakers are positioned 60 cm directly above the soil box. The velocity of the soil surface was measured using a Polytec PDV100 laser Doppler vibrometer (LDV). One-quarter inch reflective discs were positioned one cm apart across the center of the soil box to serve as reliable reflecting surfaces for the LDV beam. The dynamic signal analyzer also recorded the LDV frequency response as a rms voltage. Figures 3 and 4 show the experimental setup.

Figure 3: Laser Doppler vibrometer setup with soil box, speakers, amplifiers.

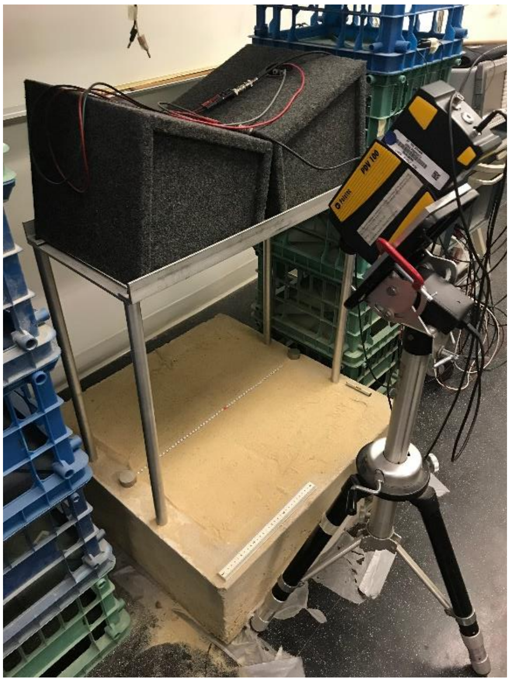

Figure 4: Laser Doppler vibrometer beam on center disc

For this research, we first explored the frequency response and tuning curve at the center of an un-buried landmine simulant. Secondly, the resonant frequencies across the soil tank alone were characterised. We then explored the resonant frequencies across the soil tank with the landmine simulant buried to a depth of four inches. Finally, we characterised the effect of sound amplitude on the frequency response at the center of the soil tank alone and at the center of the soil tank with the buried landmine simulant.

3. EXPERIMENTAL RESULTS

3.1 Experiment 1: LDV tuning curves of landmine simulant on lab bench

Our first experiment was to characterise the frequency response at the center of the acrylic top-plate landmine simulant. A reflective disk was placed at the center of top-plate to provide a reliable reflective surface for the LDV. Frequency response was recorded in 2 Hz increments from 250 Hz – 750Hz. The signal analyzer recorded the rms output voltage of the LDV. The acoustic pressure drive level (sound volume) was incrementally adjusted after each sweep to generate a family of 23 tuning curves. (Figure 5) The tuning curves indicate a slight nonlinearity in the frequency response. The resonant frequencies increase slightly with increased volume. The landmine simulant has a fundamental natural frequency at approximately 540 Hz.

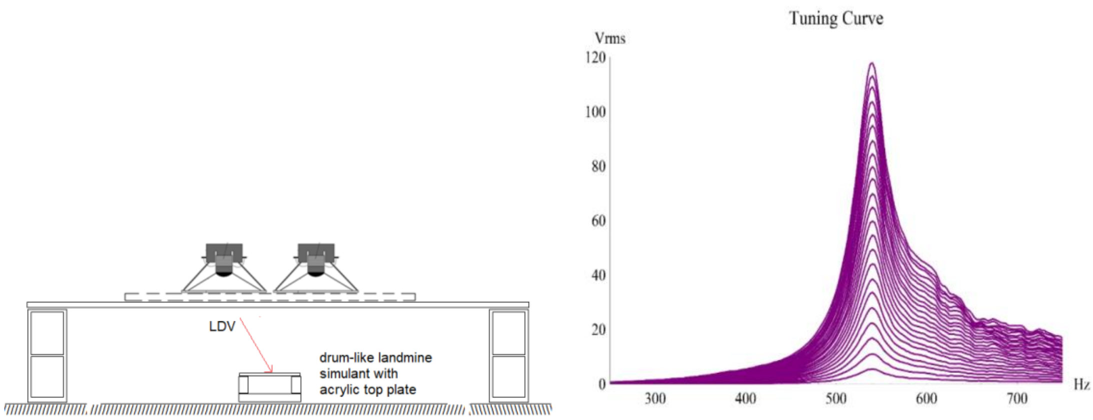

Figure 5: (a) Experimental setup schematic to measure the tuning curve response vs. frequency of the landmine simulant. (b) Tuning curve measurements exhibit a slight nonlinear behaviour where the resonant frequency slightly increases with drive amplitude. The LDV beam is located on the center of the acrylic top plate for all of the tuning curve measurements shown above.

3.2 Experiment 2: LDV measurements across a soil tank in the absence of the buried landmine simulant

In the second experiment we explored the resonant frequencies across the soil tank filled with sand and without the landmine simulant. Reflective discs were placed one cm apart across the center of the soil tank. LDV data was collected at each disc for frequency sweeps of 50-450 Hz. Figure 6 shows the experimental setup schematics for both the soil box without the simulant and the soil box with the simulant.

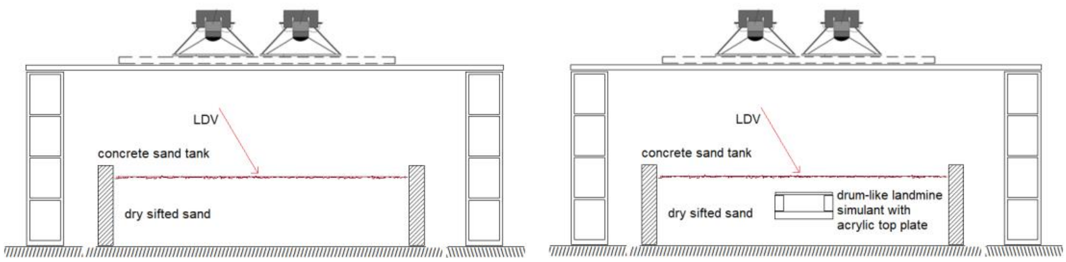

Figure 6: (a) LDV particle velocity vibration measurement across the soil surface of the sand tank in the absence of the buried landmine simulant. (b) LDV particle velocity vibration measurement across the soil surface of the sand tank in the presence of the buried landmine simulant.

Several vibration modes are shown in the following figures. Figure 7 shows a fundamental resonant peak at 162-164 Hz with maximum velocity near the center of the soil tank. Figure 8 shows radial vibration mode at 212-214 Hz. Figure 9 shows a mode with non-azimuthal symmetry.

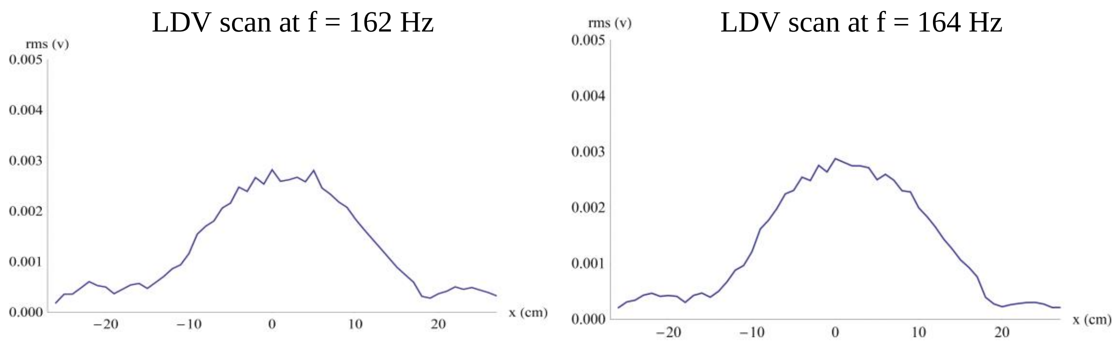

Figure 7 : Resonant peak at 162-164 Hz for soil tank without simulant.

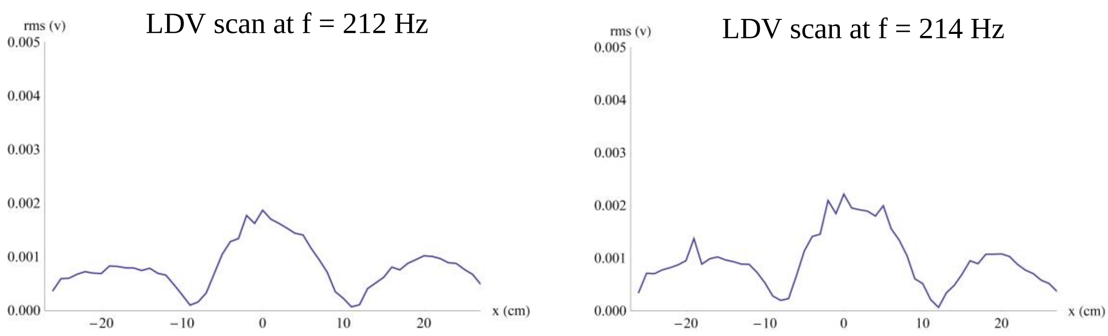

Figure 8: Resonant peaks at 212-214 Hz for soil tank without simulant

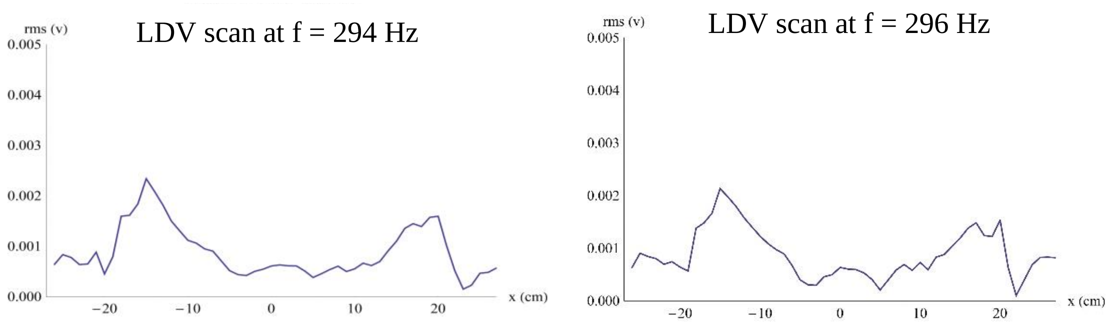

Figure 9: Resonant peaks at 294-296 Hz for soil tank without simulant. These peaks are exhibiting non-azimuthal symmetry in the vibration pattern.

3.3 Experiment 3: LDV measurements across soil tank in presence of buried landmine simulant at 4 inch depth

The next experiment was to repeat the experiment above with the landmine simulant buried under 4 inches of masonry sand. Various distinct, symmentric mode shapes were apparent in the data. Figure 10 shows that at f = 84-86 Hz, a fundamental resonant frequency is causing the landmine simulant to vibrate with the maximum deflection in the center. The significant decrease in the fundamental resonant frequency of the buried simulant is expected due to the increased mass on the top-plate. The graph (Figure 11) at 130 Hz shows a different vibration pattern, or modal structure in the simulant. In this mode, the center of the drum remains relatively stationary while the maximum vibration occurs approximately 14 cm from either side of the center. Figure 12 shows another mode at f = 154-156 Hz that peaks directly over the center of the simulant but is slightly asymmetric.

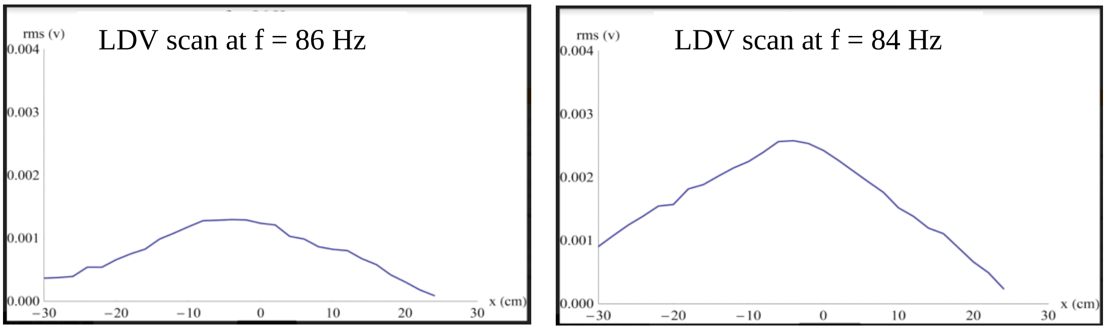

Figure 10: a fundamental resonant peak of the buried landmine simulant system.

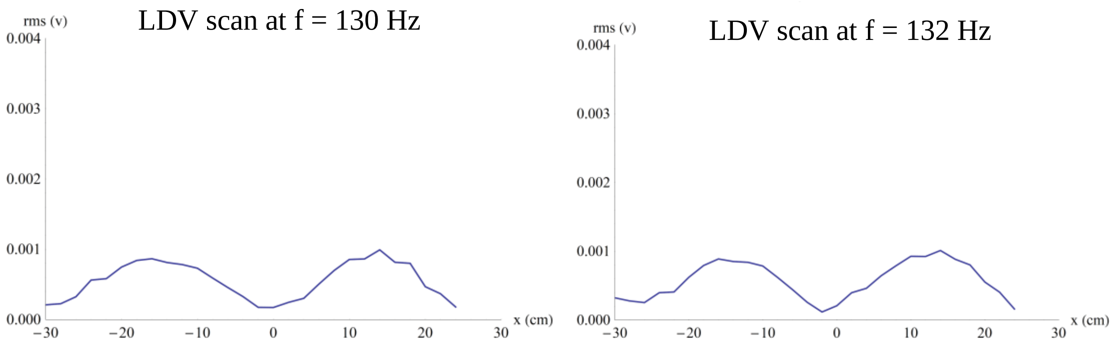

Figure 11: Modal structure of this resonant peak shows drum center remaining relatively still.

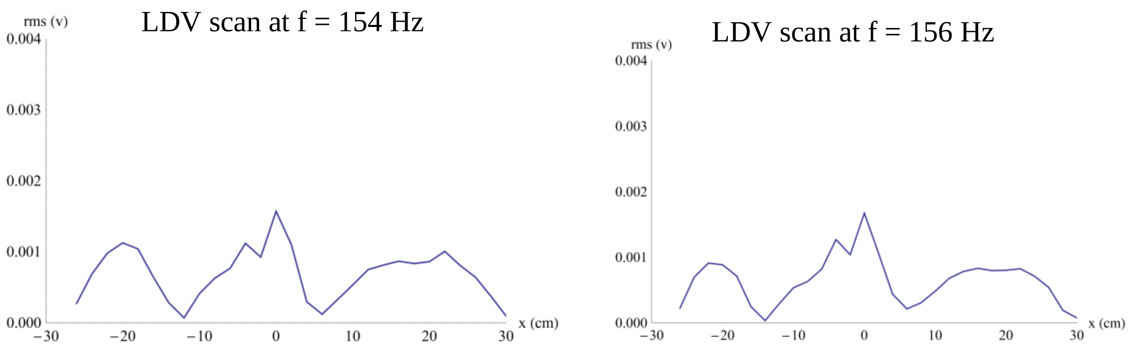

Figure 12: resonant peaks at 154-156 Hz

3.4 Experiment 4: Tuning curves on the center of buried landmine simulant

In the next experiment, we generated tuning curves to investigate the effect of sound amplitude on the frequency response at the center of the soil box with the simulant buried to a depth of 4 inches. Figure 13 shows the result of this experiment. Analysis of the curves show a slight decrease in the resonant frequencies as the sound amplitude is increased. Thus the system behaves nonlinearly with increasing sound volume.

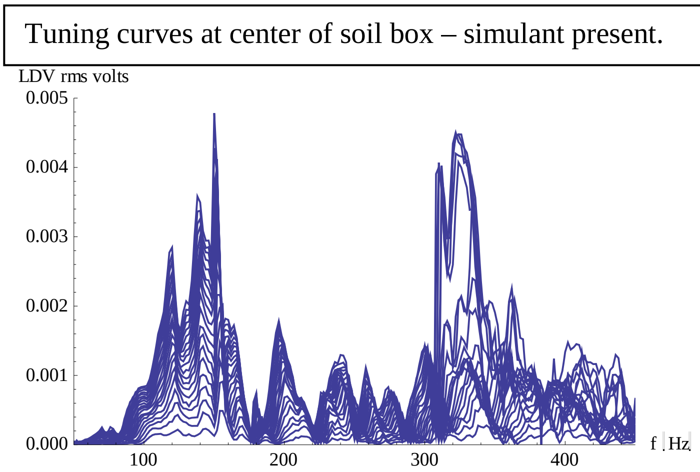

Figure 13: Effect of sound amplitude on frequency response of soil tank/simulant system.

3.5 Experiment 5: Tuning curves at center of soil tank in the absence of landmine simulant

In the final experiment, we generated tuning curves to investigate the effect of sound amplitude on the frequency response at the center of the soil box without the landmine simulant. Figure 14 shows the result of this experiment. As in the tuning curves for the soil tank with the simulant, the resonant frequencies behave nonlinearly, with increasing amplitude the resonant frequencies decrease. Experiment 1 showed an increase in resonant frequencies with sound volume for the simulant alone, while experiment 4 showed a decrease in resonant frequencies with sound volume. This experiment demonstrates that the effect of the soil to decrease the resonant frequencies with sound volume is the dominant effect.

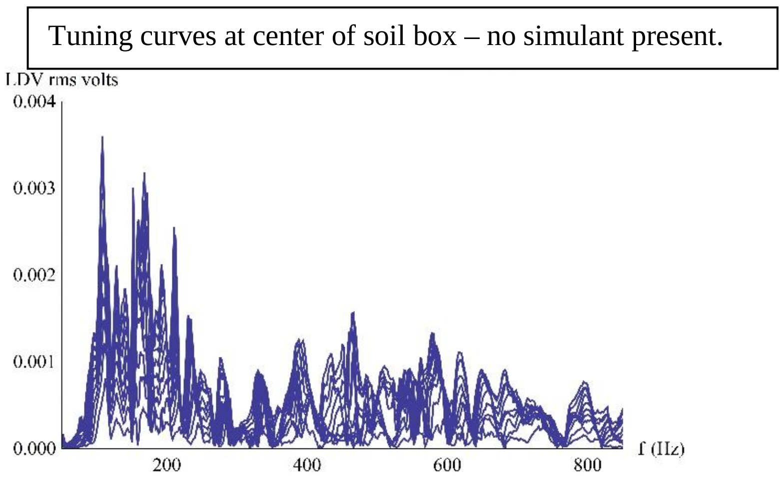

Figure 14: Effect of sound amplitude on frequency response of soil tank – without buried simulant

4. CONCLUSIONS

We successfully measured distinct symmetric mode shapes in a soil tank with and without a buried 30 cm wide landmine simulant. The nonlinear resonant behavior of the landmine simulant buried under 4 inches of masonry sand was demonstrated. The tuning curves generated show that the resonant frequencies decrease with increasing sound amplitude. More detailed quantitative analysis is needed to determine if a nonlinear detection contrast (NDC) method could be used with our data to reliable show the presence of a buried landmine. Other future work with the large landmine simulant will be to characterize frequency responses while buried under various materials and conditions such as dry and wetted pea-sized gravel.

5. ACKNOWLEDGEMENTS

I'd like to acknowledge the U.S. Naval Academy for allowing me access to all the facilities in the Physics dept. I am extremely thankful to Professor Korman for all his guidance and assistance in this research project.

6. REFERENCES

1. Sabatier, J. M., & Xiang, N. (2001). An investigation of acoustic-to-seismic coupling to detect buried antitank landmines. *IEEE Transactions on Geoscience and Remote Sensing, 39* (6), 1146-1154. doi:10.1109/36.927429

2. Xiang, N., & Sabatier, J. M. (2003). An experimental study on antipersonnel landmine detection using acoustic-to-seismic coupling. *The Journal of the Acoustical Society of America, 113*(3), 1333-1341. doi:10.1121/1.1543554

3. Korman, M. S., & Sabatier, J. M. (2004) Nonlinear Acoustic Techniques For Landmine Detection. The Journal of the Acoustical Society of America, 116 (6), 3354-3369. doi:10.1121/1.1814119

4. Aranchuk, V., Lal, A., Hess, C., & Sabatier, J. M. (2006). Multi-beam laser doppler vibrometer for landmine detection. *Optical Engineering, 45*(10), 104302. doi:10.1117/1.2358975

5. Sabatier, J. M., & Xiang, N. (1999). Physics of acoustic-to-seismic coupling and detection of buried objects. *The Journal of the Acoustical Society of America, 105*(2), 1383. doi:10.1121/1.426537

6. Alberts, W. C. K., Sabatier, J. M., & Waxler, R. (2006). Resonance frequency shift saturation in land mine burial simulation experiments. *The Journal of the Acoustical Society of America, 120*(4), 1881. doi:10.1121/1.2338294

7. Detecting land mines with sound. (2007, January 23). Retrieved February 22, 2016, from http://phys.org/news/2007-01-detecting-land-mines-with-sound.html

8. Donskoy, D. (2008). Nonlinear seismo-acoustic landmine detection. *The Journal of the Acoustical Society of America* **123**, 3042 (2008); https://doi.org/10.1121/1.2932728