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Modeling acoustic landmine detection using a soil-plate oscillator

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Abstract:
In laboratory acoustic landmine detection experiments a plastic cylindrical drum-like simulant is buried in a soil (or sand) tank. Airborne sound, generated from two subwoofer loudspeakers (located above the soil), drive the soil particles and subsequent particle vibration over the compliant top plate of the simulant. Measurements of tuning curve soil surface vibration particle velocity vs. frequency are recorded for various scan locations across the soil surface in an effort to profile the buried simulant. Measurements of resonances "off the target" are also included in this study. The results can be modeled using a soil-plate-oscillator (SPO) apparatus. The SPO involves a vertical thick-wall cylindrical column of granular medium (sand, soil, pebbles, light density edible granular material like wheat germ or even uncooked brown rice) that is supported by a thin circular elastic (acrylic) plate (8 inch diam, 1/8 inch thick) that is rigidly clamped at the bottom of the column. A small accelerometer placed on the granular surface (or a laser Doppler vibrometer) measures tuning curve results across the surface using a sweep spectrum analyzer. Profiles are compared for both the SPO and the simulant in an effort to model the results in the later – more complicated case.

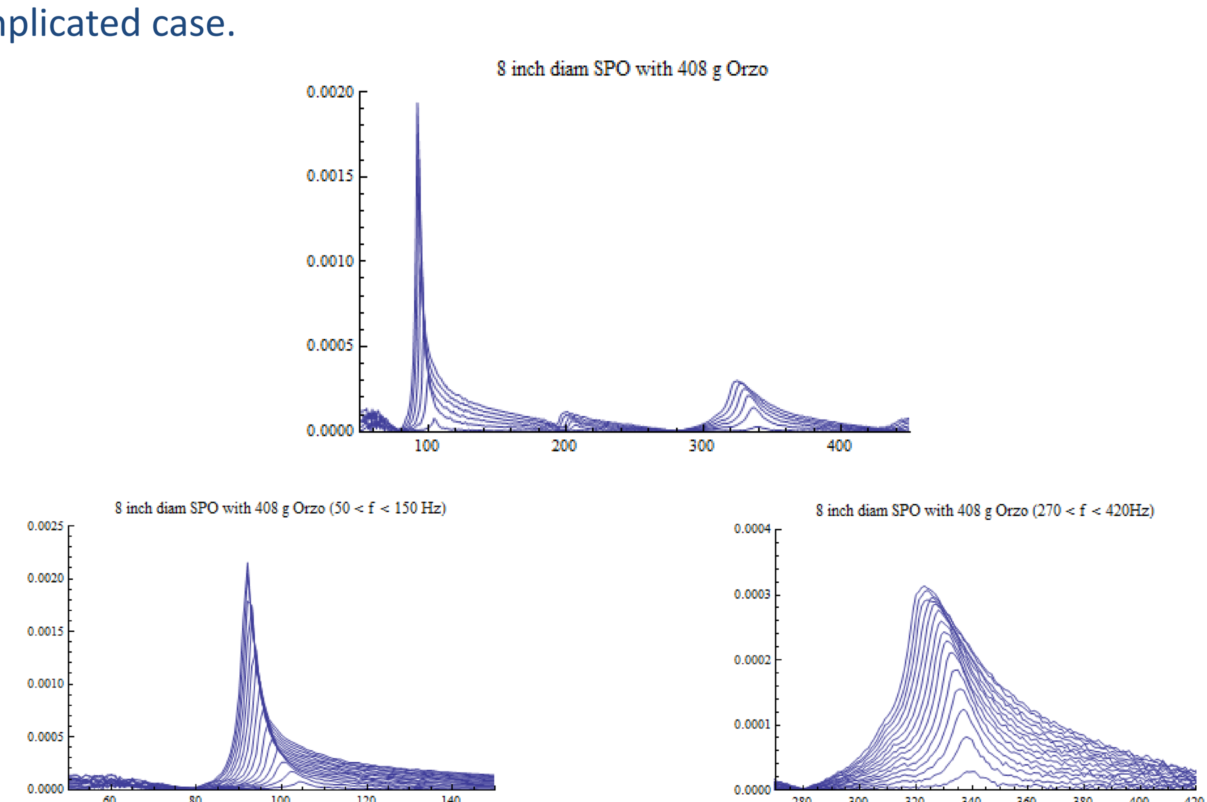
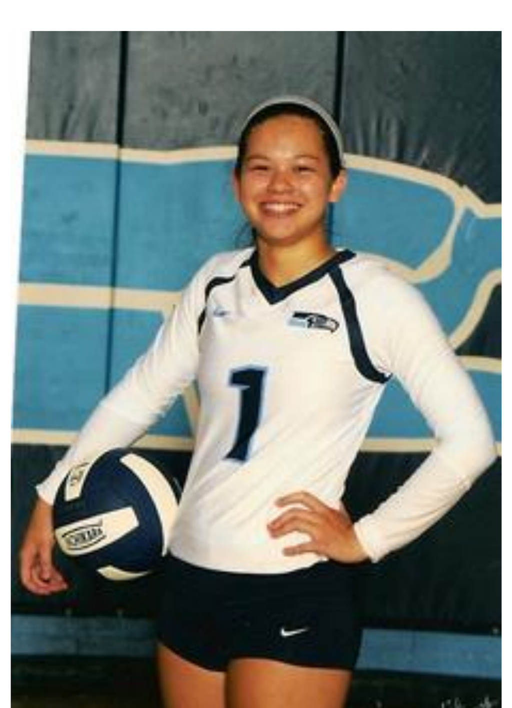
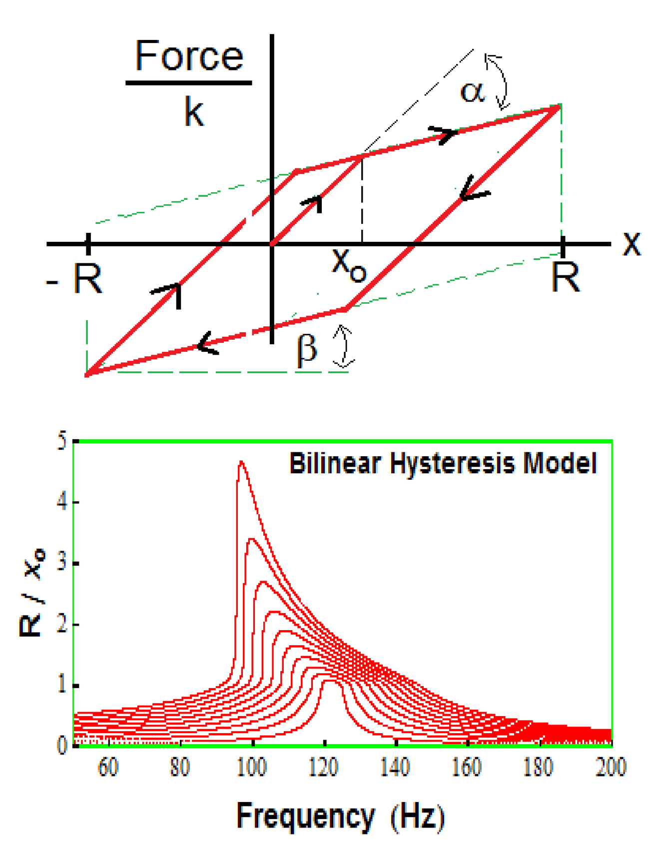


Figure 1. A set of tuning curve responses of a Soil Plate Oscillator (SPO) filled with 408 g of uncooked orzo. The clamped acrylic 1/8 inch plate is 8 inch in diam and has a clamped mass of 108 g. The underside of the plate has an accelerometer attached to a rare earth magnet which is driven by an amplified swept sine signal connected to an AC coil (placed under the plate). The accel. signal goes into a charge amplifier that is connected to the Agilent 35670A dynamic analyzer. Near the fundamental 100 Hz resonance the tuning curve exhibit a nonlinear "softening" with an upward curvature, while near 340 Hz (a higher mode resonance) the tuning curve exhibits a nonlinear "softening" with a downward curvature.



Miahnna Nyguen enters the U.S. Naval Academy this Fall 2016 as a Midshipman Fourth Class "Plebe" (as a freshman)



A bilinear hysteresis model can be used to predict the nonlinear tuning curve upward curvature behavior . See Ref. 1.

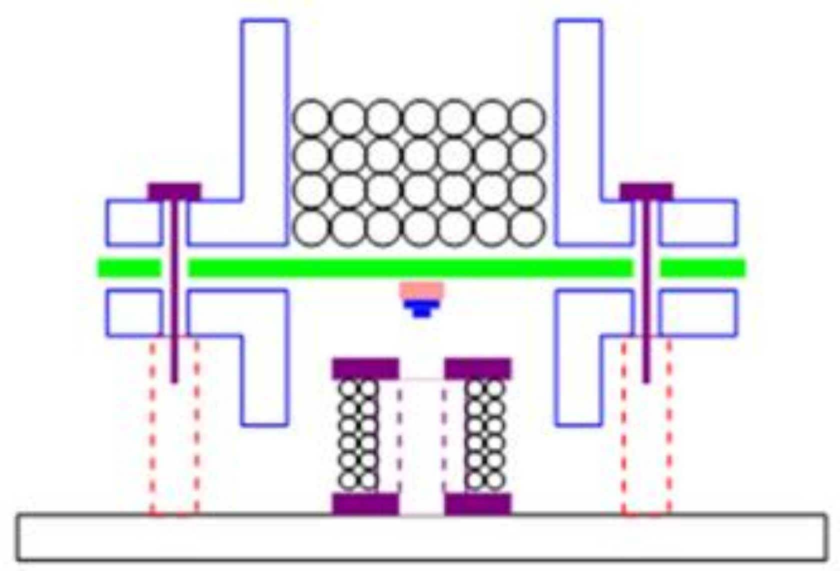


Figure 2. Cross-section of the Soil Plate Oscillator (SPO), that is driven from underneath the clamped acrylic plate by a swept sinusoidal signal going to the AC coil. This drives the magnet with the accelerometer attached to measure the frequency response. Drawing by Emily Santos.

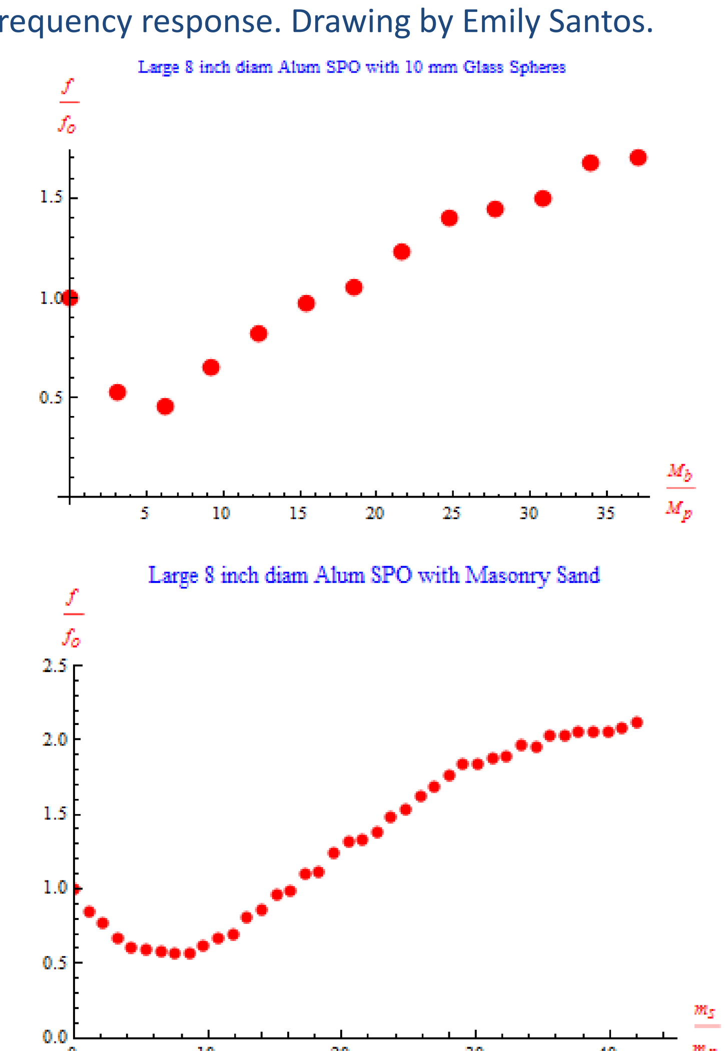


Figure 8. The normalized resonant frequency vs. (A) 10 mm glass bead loading or (B) masonry sand loading exhibits first a decrease in resonant frequency followed by an notable increase. This is due to the elastic "disk" layer of the granular medium having a more dominant increase in its effective lumped spring constant K [which is proportional to the cube of its thickness (or mass)] while the granular mass loading increases linearly. The plate mass is M_p = 108 grams.

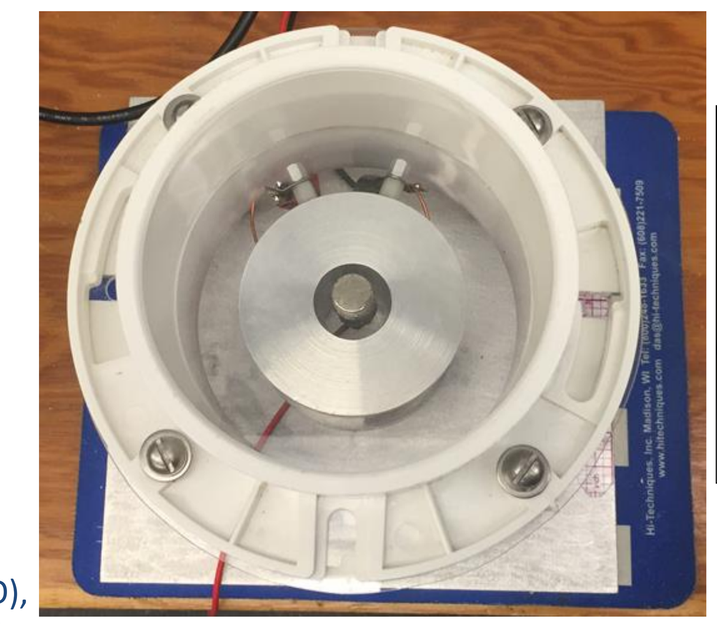


Figure 3. A 4.5 inch diam SPO made from PVC flanges and a 1/8 inch thick acrylic circular clamped plate. AC coil, rare earth magnets and accelerometer is on underside of plate.

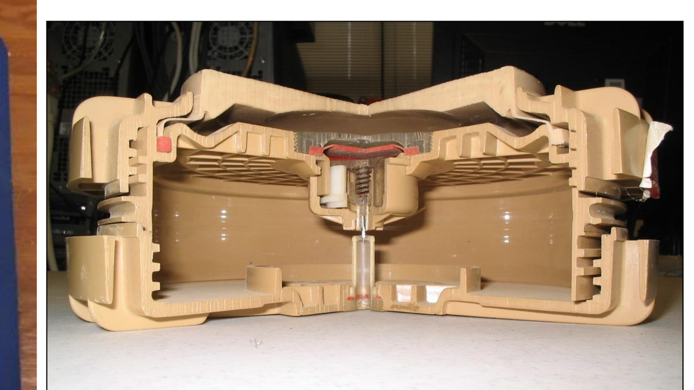


Figure 4. Cross-section of VS - 1.6 plastic "inert" landmine, 8.5 inch diam by 3.5 inches in height.

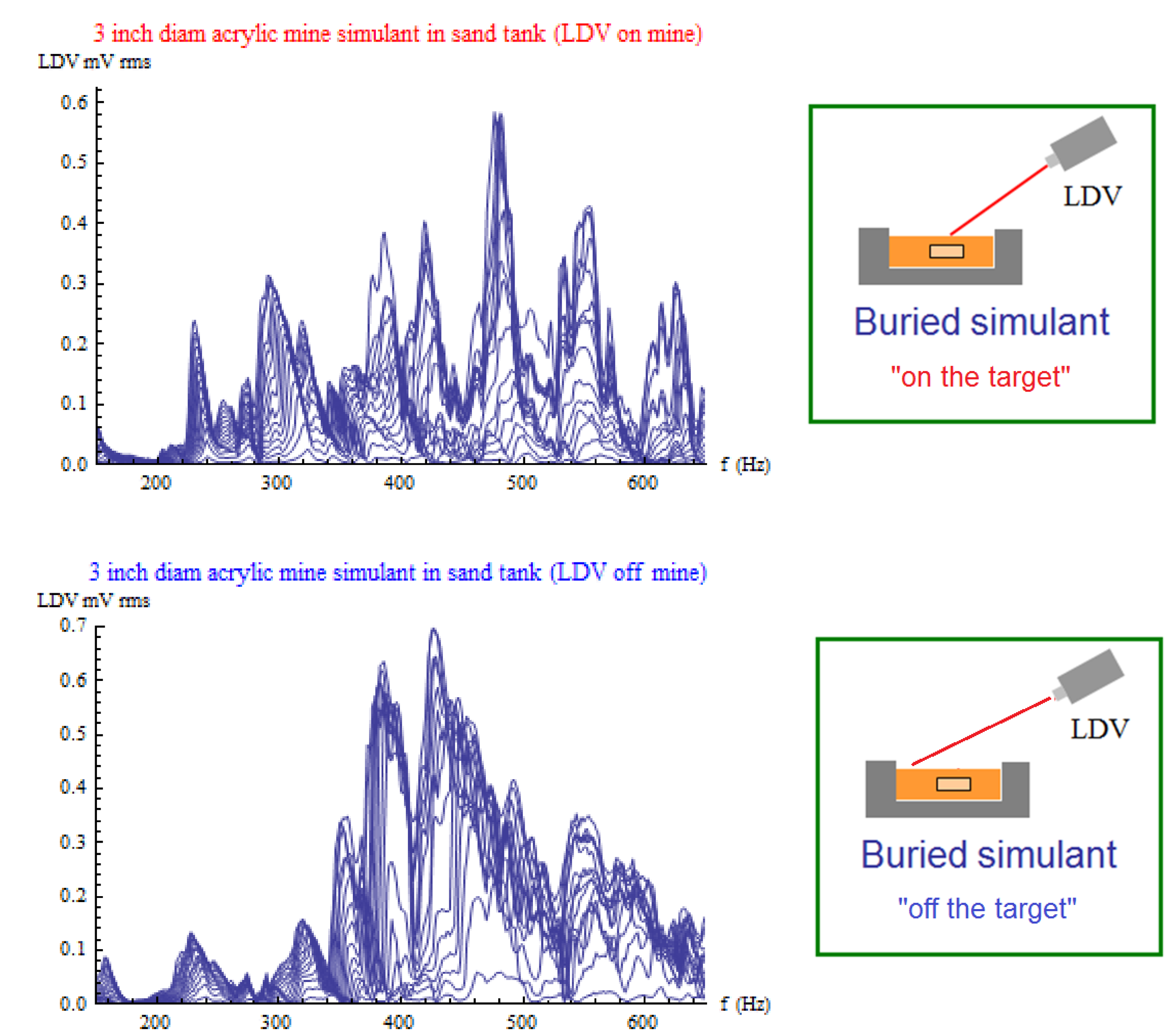


Figure 9. LDV surface velocity measurement for "on the target" and "off the target particle velocity response vs. frequency. The mine is 1.5 inches in radius. and has a height of 2 inches. The "off target "location is at the position x = - 4.5 inches from the center. The concrete soil box is 12 inches by 12 inches by 3.5 inches deep.

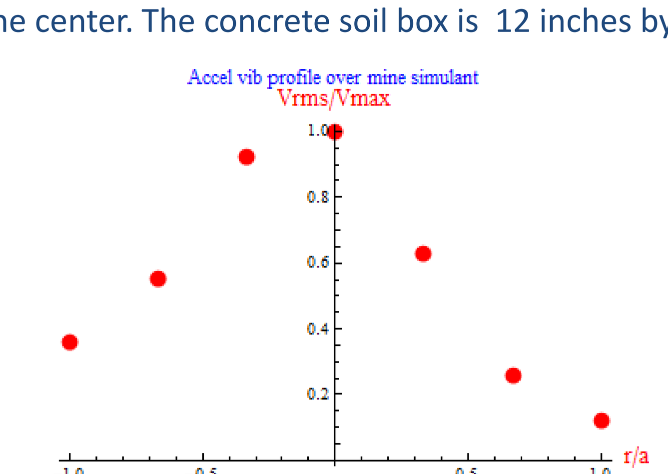


Figure 10. Accelerometer vibration measurement of the sand over the 1.5 inch radius buried acrylic mine simulant (in the soil box). Measurement taken near 300 Hz.

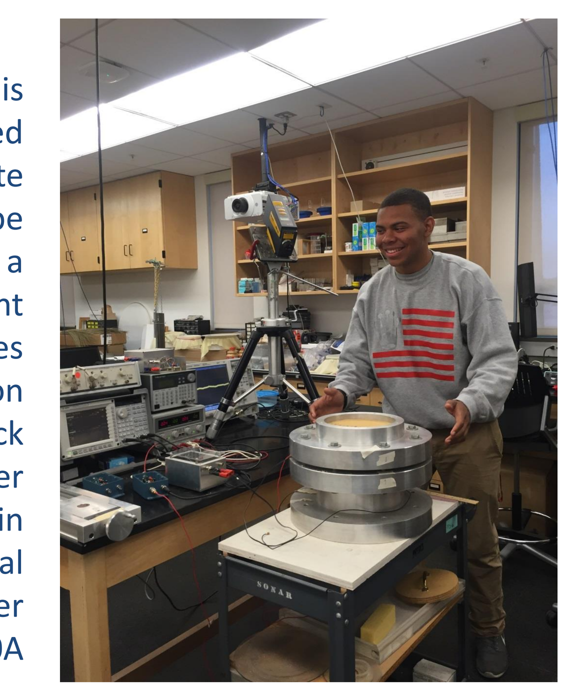


Figure 5. The 8 inch diam SPO is filled with 3440 grams of sifted masonry sand. The clamped plate mass is 108 grams. The SPO can be driven from the underside by a swept sinusoidal amplified current going to AC coil. The coil field drives the rare earth magnets located on the underside of the 1/8 inch thick acrylic plate. The accelerometer fastened to the magnet (1 cm in diam) generates a response signal that goes into a charge amplifier and then to the Agilent 35670A dynamic spectrum analyzer.

The 8 inch diam SPO is made from aluminum. It can be driven from above by two 8 inch sub-woofers. The Laser Doppler vibrometer (Polytec 100) measures the soil surface vibration.

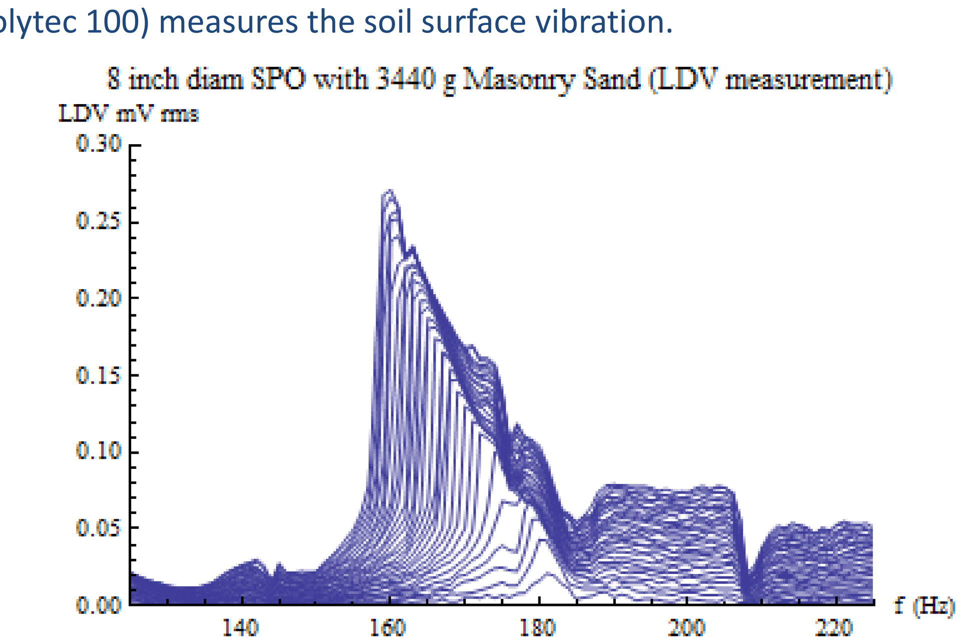


Figure 6. Nonlinear tuning curve response off the sand surface vibration on axis. Notice the linear backbone peak ridge.

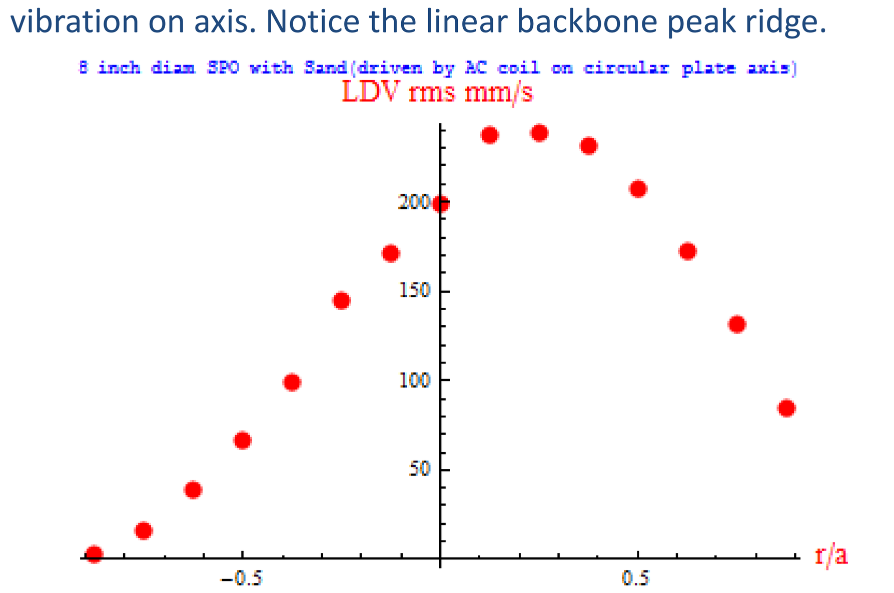


Figure 7. The LDV response near 160 Hz across the sand surface.

References & Related Material:
1. T. K. Caughey, Transactions of the ASME, J. Applied Mech., 27, (1960), 640-643.
2. L. A. Ostrovsky and P. A. Johnson, "Dynamic Nonlinearity Elasticity and geomaterials,"Revista Del Nouvo Cinmento, 24, serie 4, No. 7, 1-46 (2001).
3. M. S. Korman, D. V. Duong and A. E. Kalsbeck, A.I.P. Conference Proceedings, 20th ISNA, Ecully, France, 29 June-3 July 2015, "Electrodynamic Soil Plate Oscillator: Modeling Nonlinear Mesoscopic Elastic Behavior and Hysteresis in Nonlinear Acoustic Landmine Detection," (080003-1 to 8).