Testing the quality of geophone plants for 3-C land acquisition

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ABSTRACT

An experimental technique for characterizing geophone response is described. Using the technique, a number of different geophone plants are tested for quality. Surface-mounted cases and nail-style cases are compared using this technique. A novel way of quantifying geophone coupling is proposed. This method uses a pinging technique to transmit an impulse between two matched geophones. The transfer function (coupling) properties of the case may be computed by processing the output of both geophones. Based on early results using this technique, the nail-style cases have a superior coupling response than surface-mounted cases.

INTRODUCTION

Geophones, regardless of case design, require complete insertion into the ground in order to prevent a ground/case resonance from entering the signal band. This problem is accentuated in environments with poorly packed soils and sands. The effect of a poor geophone plant can be exacerbated if geophone groups are not utilized (a common practice in 3-C recording).

Multicomponent geophone cases typically belong to one of two categories. Surface-case designs consist of a geophone body which sits on top of the ground. Planting spikes improve coupling by penetrating into firmer soil at some depth. They also prevent the geophone from rotating. Geophones in the other category are shaped like a tapered or pointed cylinder. These so-called “nail” designs are typically planted into appropriately sized holes in the ground. In some circumstances, such as desert surveys, the ground may be soft enough for the geophones to be planted by force alone.

FIG. 1. Multicomponent surface geophone designs are typically surface-case styles (left) or nail styles (centre and right)

Earth coupling model for a surface-case 3-C geophone

The classic spring-dashpot model for a vertical geophone can be augmented to adequately describe geophones with horizontal components. Additional springs and dampers must be placed within the horizontal axis. Ideally, a 3-C geophone's base is fully in contact with the ground. This provides significant mechanical resistance to rotational swaying. If the geophone is not fully planted, the geophone is free to sway on its spike.

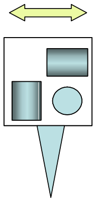


FIG. 2. A surface-mounted geophone case may sway from side-to-side if its base is not fully in contact with the ground.

Swaying of poorly planted 3-C geophones has been observed in the field. It is particularly noticeable if the geophone is tap-tested. A poorly planted geophone exhibits a very low frequency wobble when tapped horizontally with the soft pad of a finger. The severity of the swaying will be determined experimentally for a test geophone.

The investigators wanted to determine if the nail-style geophone cases had inherently better planting properties than the conventional surface-mounted geophone cases. Tap-test results indicate a reduction in swaying with nail-style cases. A test was devised to compare the nail case performance to a surface-style 3-C case.

Experiment

A spike-cased geophone was excited by hitting it with a small steel ball. This method, described by Hoover and O'Brien (1980) is known as "pinging". It enables measurement of the resonant frequency of a geophone through spectral analysis of it's ping response. The assumption is that a sharp hit with a steel ball is spectrally-equivalent to a perfectly impulsive source.

Krohn (1984) shows how geophone cases oscillate with the response characteristic of damped harmonic motion. We shall attempt to see if this motion is detectible and measurable separately from the geophone element's damped harmonic motion. If so, then it may be possible to compare the geophone case's inherent frequency response.

Apparatus

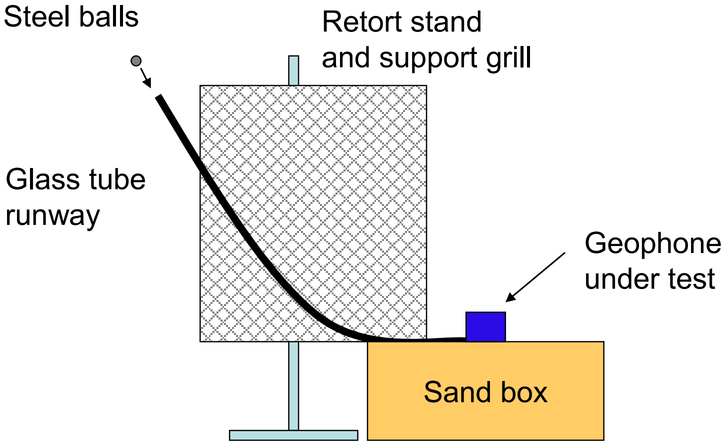


FIG. 3. A bent glass tube serves as a runway for a steel ball. The 5/32" diameter steel ball impacts the geophone horizontally with a controllable and repeatable force.

Steel ball bearings were used to ping the geophone. Two different ball bearing sizes were used: 3.96 mm (5/32") diameter and 4.75mm (3/16") diameter weighing 0.21 g and 0.42 g respectively. A 4 mm diameter glass tube was bent to a 135 degree angle with a sloped run of approximately 50 cm. The end of the glass tube was kept back from the geophone approximately 3 cm. The balls were allowed to ricochet off the geophone and onto the floor. To obtain the correct ball trajectory, the final 3 cm of ball travel was entirely through the air. Careful aiming of the glass tube produced a nearly-perfect horizontal ball-hit on the geophone. Care was taken to aim the balls so that they produced maximally-pure horizontal energy along the axis under test.

Data were recorded using a Geometrics R60 seismic recorder. The sample rate was 4000 Hz and data were acquired with no filters enabled. The instrument uses delta-sigma sampling and is capable of recording frequencies to 4/5 Nyquist in this configuration.

RESULTS

"Poor-plant" tests using PC-3D geophone cases

Oyo Geospace PC-3D and "Seismic Nail" geophone cases were used to test the effect of poor geophone planting technique. The PC-3D geophones were fitted with 10Hz GS-20DM geophone elements. The "Seismic Nail" geophones cases were fitted with GS-32CT 10 Hz geophone elements.

Figures 1 shows the time-domain ping response of the horizontal geophone elements. For the purpose of discussion, the horizontal geophone element which runs inline with the take-out is called the "inline" element while the perpendicular element will be called the "crossline" element.

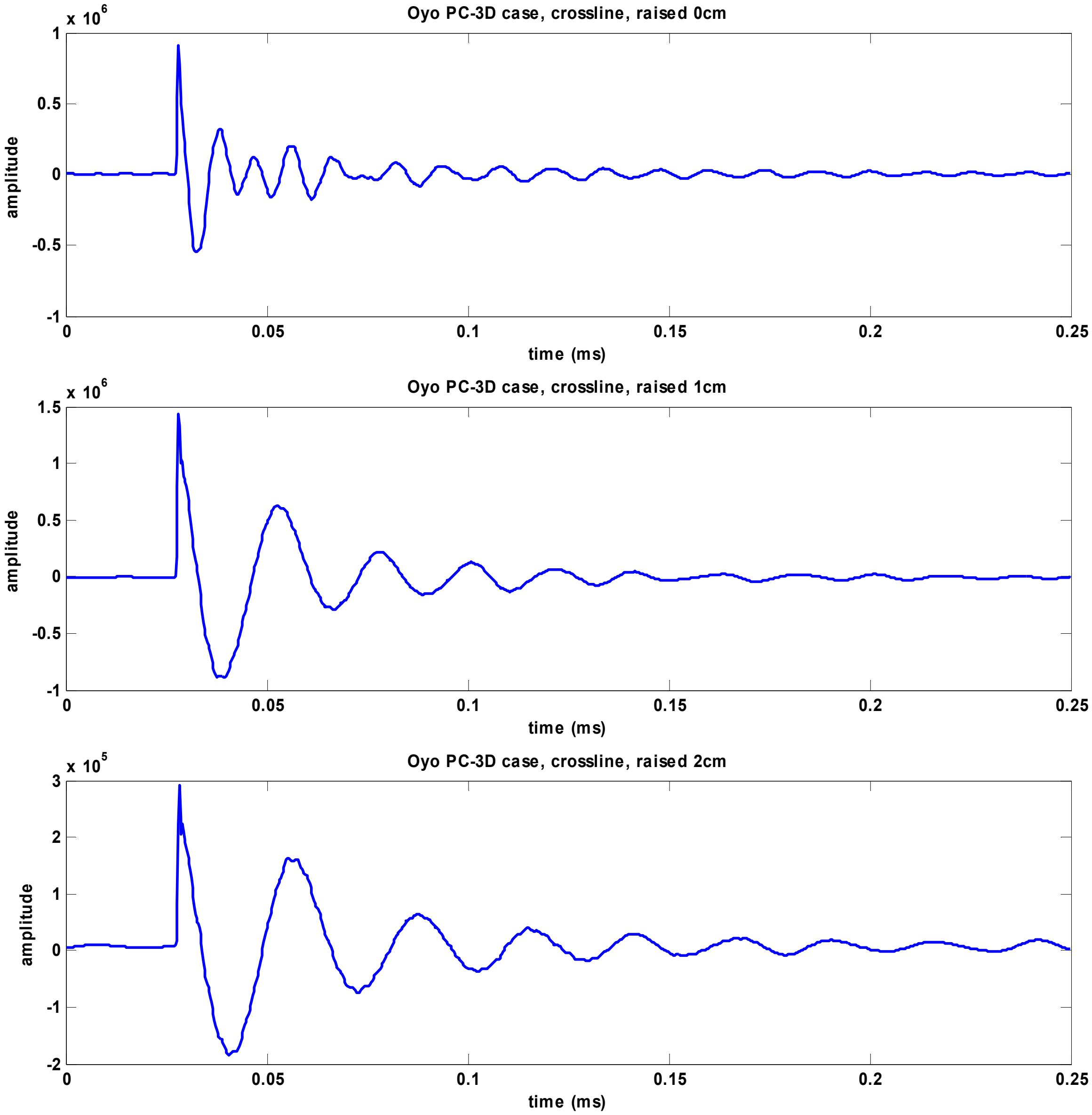


FIG. 4. The impulse response of a geophone changes as the geophone's base is raised above the ground. Representative traces showing a single "ping" are shown.

Horizontal impulse tests were performed with the geophone planted in a test bed of course sand. After repeating the test multiple times with the geophone planted firmly on the sand, the geophone was raised by 1 cm and the tests were repeated. In this configuration, the geophone base no longer touches the ground and it is free to sway. Spectral analysis of the impulse measurements (Figure 5) shows the sway frequency in the 30-50 Hz band. It is clear that this coupling resonance would interfere with field recordings under these conditions.

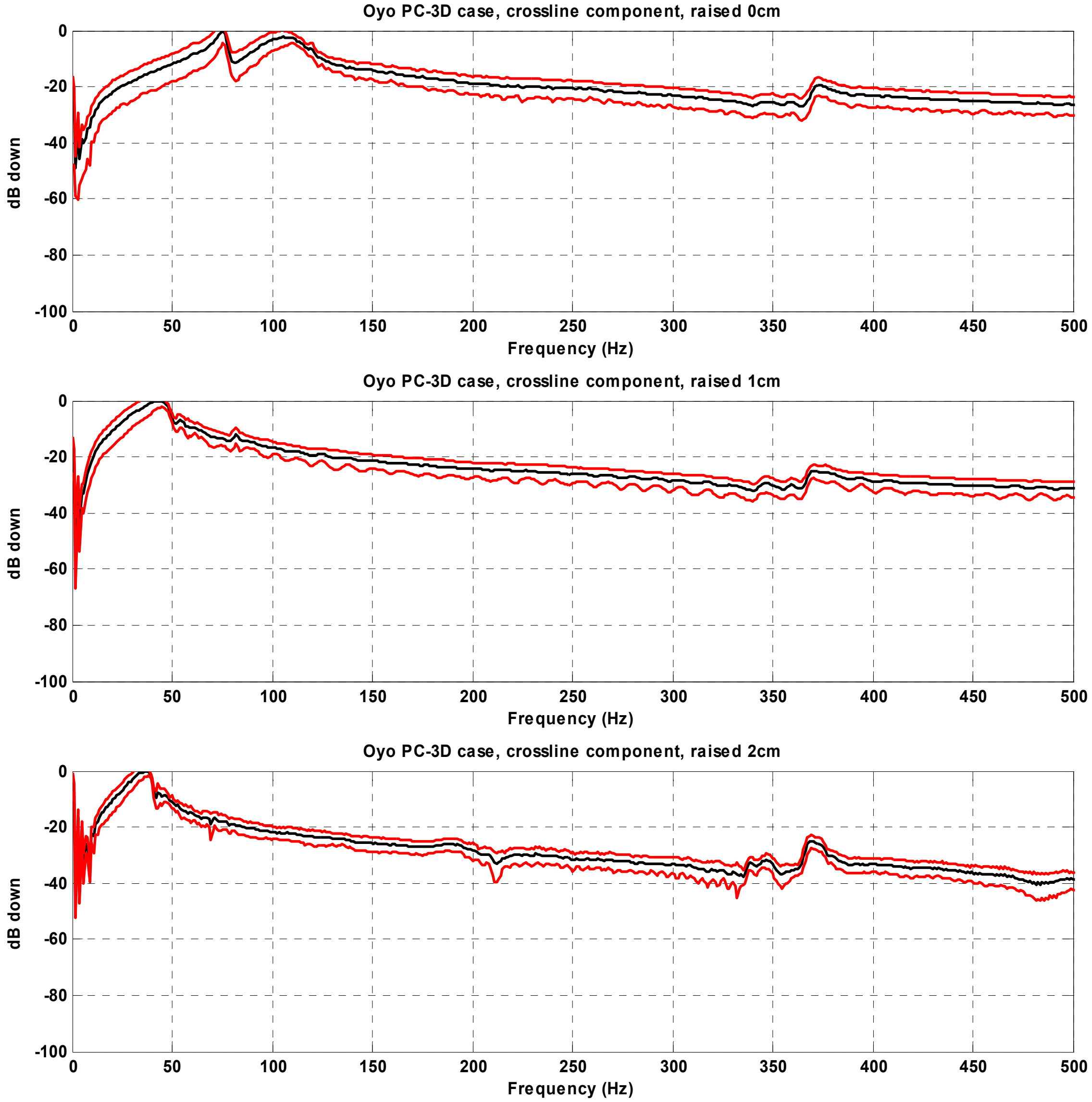
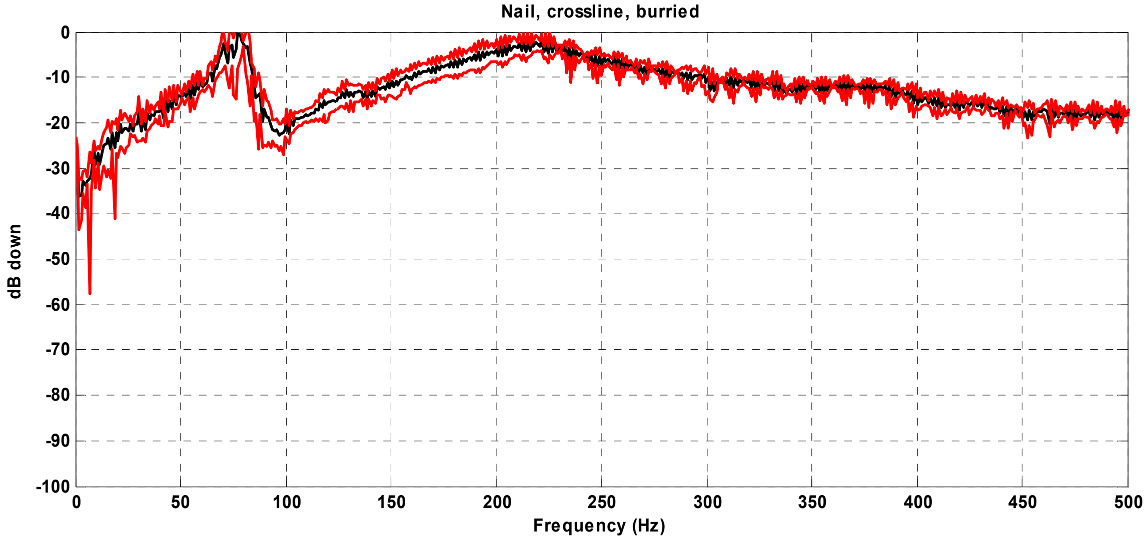


FIG 5. The power spectrum of the geophone ping tests show a resonance at 75 Hz and 105 Hz when the geophone is planted on course sand. If the geophone is improperly planted, the resonance drops to 45 and 40 Hz for elevations of 1 cm and 2 cm respectively. The strong impulse generates a clearly-visible spurious-frequency spike at 370 Hz. The mean of several measurements has been computed and plotted. A corridor of one standard-deviation radius is plotted to show the consistency of the data set.



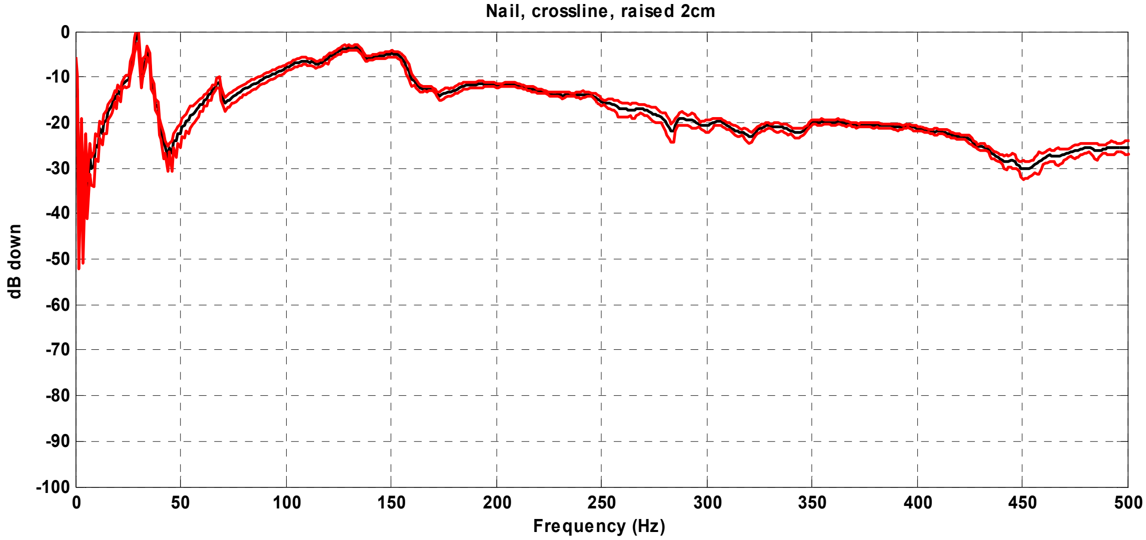


FIG. 6. Oyo Geospace "Seismic Nail" cases were tested in poor-plant conditions. The top figure shows the ping response of a fully-planted nail in course sand. The bottom figure shows the effect of leaving the top 2 cm of the case in free space. The red lines show the standard deviation excursion for the data set.

The seismic nail geophones were subjected to the same poor-plant test. Figure 6 shows a spectrum which, though broader, still contains a significant resonance at low frequency. It should be noted that the GS-32CT elements do not exhibit the same spurious frequency spike as was seen with the GS-20DM elements in the same test. In general the Nail case shows greater bandwidth under the same (miserable) plant conditions.

Krohn (1984) tests the resonant frequencies of different soil conditions. Our tests only employed one soil condition (loose, course, play sand). It was chosen because (1) it was easiest to work with and (2) any soil-to-case resonance would be exhibited well within the signal band of the geophone elements.

Table 1. Resonant frequencies for vertical geophones in different locations (from Krohn).

Location	*Resonant frequency Hz*
West texas	400
Friendswood clay	432
Friendswood topsoil	222
EPR grounds	305
Plowed Houston garden	110
Houson lawn near a garden	275

A novel approach to measuring geophone case response

The experimental method described could be extended to test geophone case response. By planting two identical geophones side-by-side, and pinging one geophone using a steel ball, it should be possible to receive the source waveform on the adjacent (receiver) geophone. In this experiment, all the source energy is coloured only by the geophone coupling properties of the source geophone (assuming that a perfect impulse is created with a steel-ball ping). Any case-induced transfer function is applied a second time as the wavefield enters the receiver geophone and makes its way to the geophone elements.

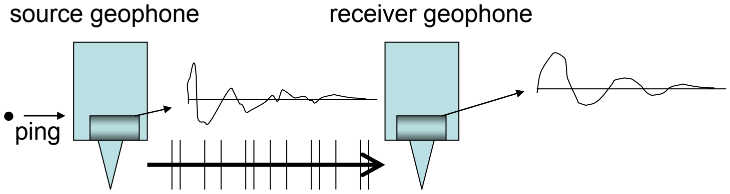


FIG. 7. A novel geophone case testing technique uses a source geophone to generate a wavefield in the ground. Both the source and receiver geophones' outputs are recorded. The difference signal between source and receiver must be attributable to a combination of the geophone coupling, the receiver's geophone's (element) response, and the wavefield degradation from source to receiver.

We could express the overall system with

$$
\begin{aligned}
x(t) &= \delta(t) \cdot T_{element1} \\
y(t) &= \delta(t) \cdot T_{case1} T_{soil} T_{element2} T_{case2}
\end{aligned}
\tag{1}
$$

where

$\delta(t)$ is and impulse applied to the side of the source geophone case.

x(t) is the signal recorded at the source geophone,

y(t) is the signal recorded at the receiver geophone

T_{case1} , T_{case2} are the transfer functions of the source and receiver geophone cases

$T_{element1}$ $T_{element2}$ are the transfer functions of the source and receiver elements

T_{soil} is the transfer function of the soil.

If we assume that $T_{element1} = T_{element2}$, and $T_{case1} = T_{case2}$, then the ratio of output to input,

$$\frac{y(t)}{x(t)} = T_{soil} T_{case}^2 . \tag{2}$$

If we assume the transfer function of the soil is linear, then the ratio of y(y) / x(t) is proportional to the square of the case's transfer:

$$T_{case} = k \sqrt{\frac{y(t)}{x(t)}} . \tag{3}$$

Some early work has been done to test this technique. Figure 8 shows the source, receiver power spectra for a horizontal ping traveling 13.5 cm through course sand. For this transmission test, an Oyo Geospace PC-3D geophone with a GS-20DM element was used as both source and receiver. Figure 9 shows the same test with the same geophone spacing (centre-to-centre) using a Oyo Geospace "Seismic Nail" case fitted with GS-32CT elements.

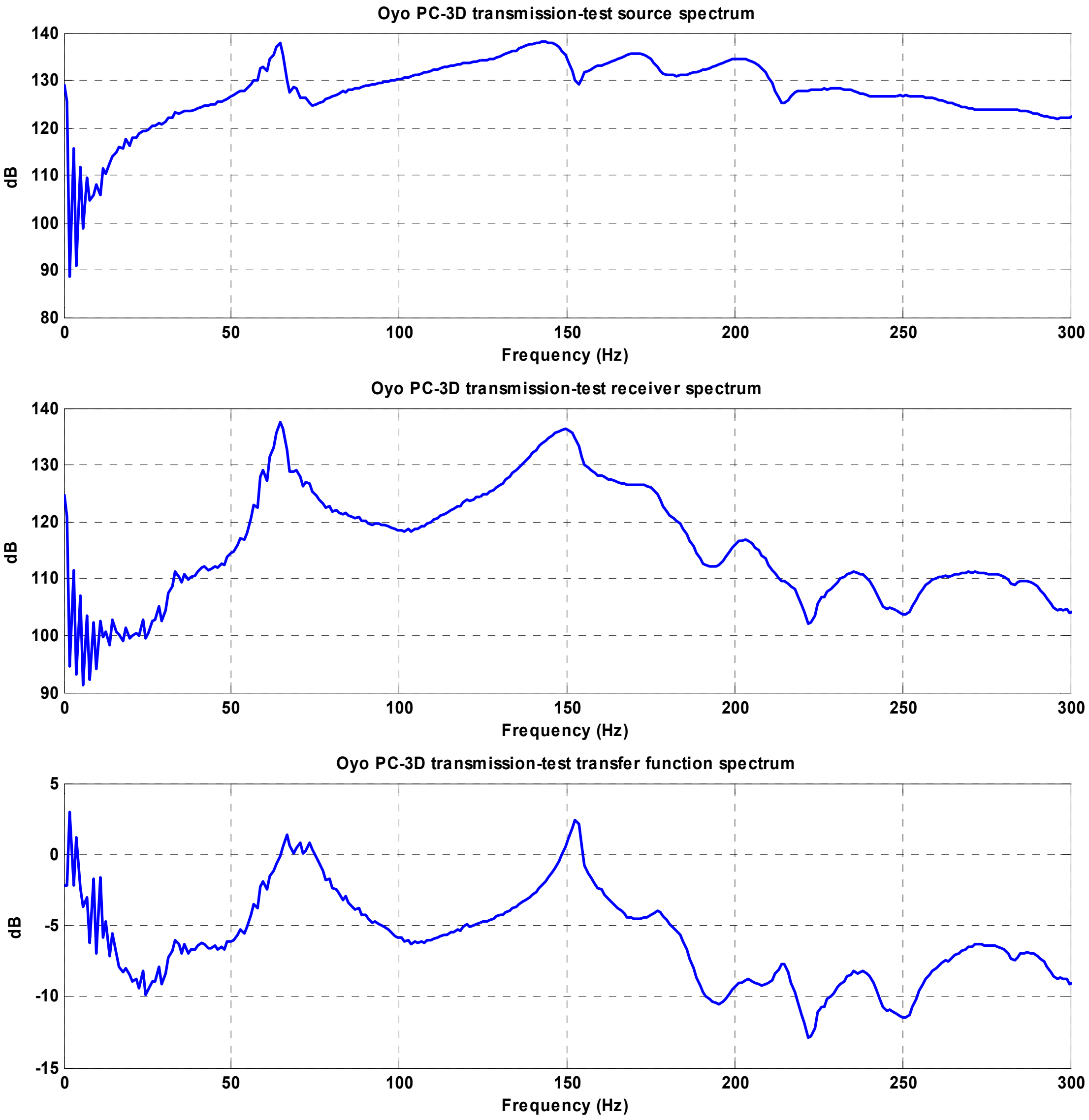


FIG. 8. A source geophone (an Oyo PC-3D case with GS-20DM elements) is pinged. A receiver geophone 13.5cm away records the ping. The output/input ratio is plotted as an approximation of the system's transfer function.

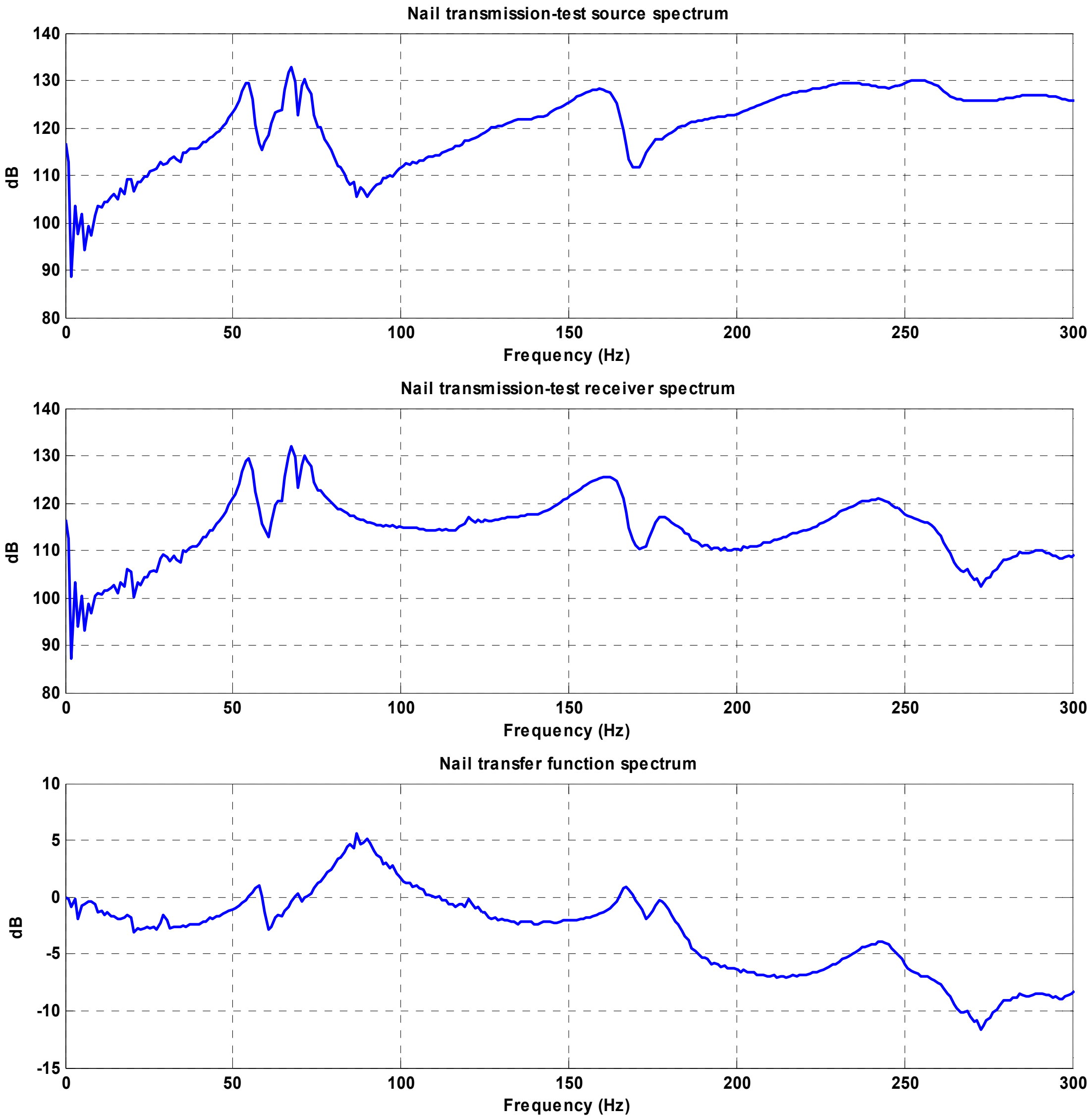


FIG. 10. A Oyo Geospace "Seismic Nail" case with GS-32CT elements is transmission-tested using a steel-ball ping on the source geophone. A receiver geophone records the ping after it travels through course sand. Geophones are spaced 13.5 cm apart centre-to-centre.

What is of interest in the two sets of experimental results is the relative flatness of the nail-case response in seismic band (8-150 Hz) as compared to the surface-case response. The surface case response indicates a 10 dB variation in within the signal band. By comparison, the nail case only deviates by 5 dB. Based on this set of data, the nail case seems to have a better response within the seismic data band.

Errors in the test require quantification in order to validate the result. It is believed that the greatest contributor to error is the small size of the test sandbox. It is highly likely that the wavefield is irregular as a result of the geophones' proximity to the sandbox edges. It would be worthwhile repeating the tests in a much larger sandbox. It may prove useful to perform the experiment in a field to remove sandbox-induced errors altogether. This will be the focus of future work.

CONCLUSIONS

An experimental technique for characterizing geophone response has been demonstrated. Using the technique, the effect of a poor geophone plant has been clearly illustrated. Geophones, regardless of case design, require complete insertion into the ground in order to prevent a ground/case resonance from entering the signal band. This problem is accentuated in environments with poorly packed soils and sands. The effect of a poor geophone plant can be exacerbated if geophone groups are not utilized (a common practice in 3-C recording).

A novel way of testing geophone coupling has been proposed. Though the technique suffers from many assumptions (such as a pure-linear transfer function for soil), it is able to supply an estimate of the case transfer function. Based on the dataset, the nail-style case provides much better response within the seismic signal band.

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