EXPERIMENTAL STUDIES ON THE ROLE OF BACKFILL AND PIPELINE CHARACTERISTICS IN THE APPLICATION OF ACOUSTIC LEAK LOCATION TO UNDERGROUND PIPELINES

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INTRODUCTION

In response to numerous releases of hazardous substances from leaks in underground storage tanks and pipelines, the EPA requires monitoring so that leaks are detected, located and repaired as quickly as possible. Acoustic leak location offers the possibility of locating leaks which have been identified by other methods but which are not appropriate for performing location. The successful application of acoustic leak location requires that existing data analysis approaches be improved so that the smallest leaks of interest be locatable with the widest possible sensor spacing. Part of developing such approaches requires that the physical conditions which affect the amplitude, frequency, and dispersion of the leak signal as it propagates between source and sensor be better understood.

ISU has been conducting work to assess the roles of pipeline propagation characteristics, non-leak noise, varied pipe backfill materials, sensor separation, pipe size and line configuration on the received leak signal. Earlier experimental work conducted at ISU has focused on the detection and capture of leak signals, the effect of pipeline hardware configurations on those signals, and the effect of leak hole geometry on leak signals. Included in these studies were experiments on sensor mounting hardware and mounting techniques, the effect of hole geometry, the effect of pipeline hardware (valves, couplings, etc.) on the propagation of leak signals, and, preliminarily, the role of backfill at the leak source on the amplitude of produced leak signals. These experiments were conducted on an Army-type double-walled line used for district heating purposes. The work was conducted during the spring of 1996, and a final report[1] of the results was delivered to the U.S. Army Civil Engineering Research Laboratory (USACERL) in April, 1996.

This paper contains the results of some follow-up experiments to the backfill portion of the CERL work. In this case, the studies were conducted on a 2" single-walled steel pipe very similar to the carrier pipe found in the Army double-walled line. The focus of this work was to determine the attenuation of leak signals in a fluid-filled pipeline and the effect of backfill material on the attenuation.

OBJECTIVES

Some disagreement exists within the acoustic emission and acoustic leak location communities regarding the importance of backfill, the material that surrounds a pipeline after it has been buried. Until now, it has been unclear what effect backfill material had on the attenuation of the signal as it propagates along the pipe. Some researchers have concluded that backfill has little effect on the leak signal, while others believe it plays a significant role. Since backfill effects could impact directly on signal strength and the distance a signal travels, and, as a consequence, the distance from which a leak can be detected, it is very important that these questions be answered. The objective of these experiments was to determine the attenuation of a repeatable signal in a fluid-filled pipe while buried in various backfill materials.

EXPERIMENTAL METHODS

All of the data reported here were taken on a 21 ft. section of schedule 40 galvanized steel pipe filled with water at ambient pressure. In order to conveniently change backfill materials, a large, mobile, wood box measuring approximately 2 ft. wide by 2 ft. high by 20 ft. long was constructed. The pipe was placed in the box, centered between the walls, and the box filled with the backfill of interest. The box supported the pipe at both ends and allowed for backfill materials to completely surround and bury the pipe. The pipe itself was placed in the box at a slight angle to insure that any air trapped in the pipe during the filling process would escape. A diagram of the box and pipe arrangement is shown in Figure 1.

Data were collected by driving a transducer to simulate a source at one end of the pipe and capturing the signal at the other end with a receiver. A Panametrics 500 kHz center-frequency, broadband transducer was used as the source, while an NDT 10-100 kHz transducer acted as the receiver. Both transducers were fixed perpendicular to the long axis of the pipe and coupled directly to the water through a thin rubber membrane stretch tight across the opening. Using this arrangement, energy was coupled to and received directly from the water in the pipe. Any difference in received signals, then, could be attributed directly to energy lost through the pipe wall and into the surrounding backfill material. Figure 2 shows a schematic of the sensor placement at one end of the pipe. Signals were generated using both a repeatable, high voltage pulser and a random white noise generator.

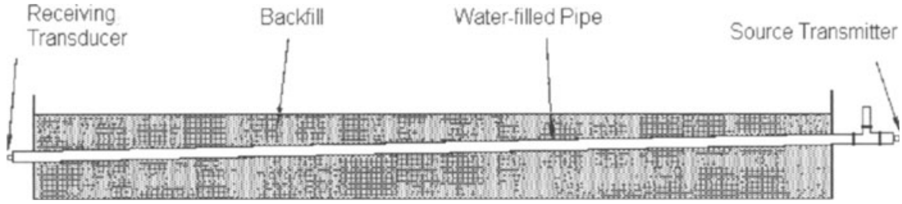

Figure 1: Backfill Experimental Apparatus.

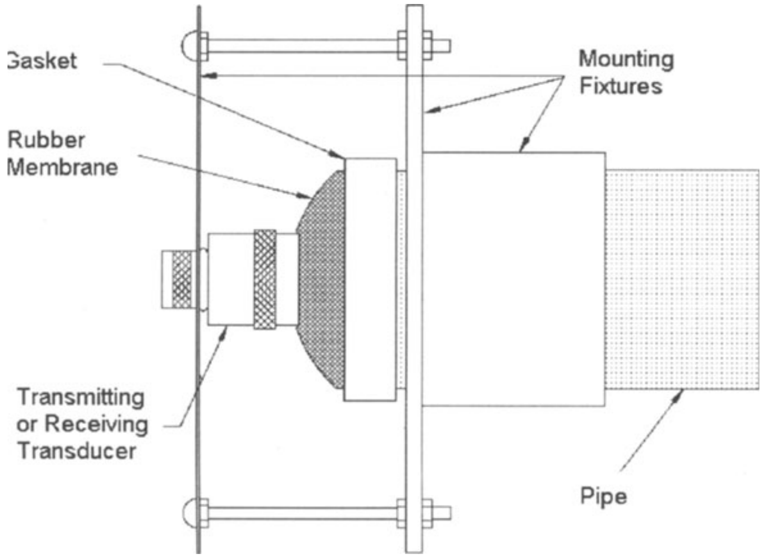

Figure 2: Transducer mounting setup.

Waveforms were bandpass filtered between 1-100 kHz using a Krohn-Hite analog filter to remove extraneous low-frequency background noise and match the high end of the calibrated range of the receiving transducer. At the same time, other work[2] (note Figures 5 and 6 below) has shown that very little leak noise energy is carried at frequencies higher than 100 kHz. Waveforms were digitized, averaged, and stored using an 8-bit Lecroy digital oscilloscope. For the pulse source, each collected data point represents the summed average of 25 sweeps of the leak (pulse) signal, while the white noise data represents the averaged frequency spectra of 20 waveforms.

To date, five variations on backfill materials have been studied. Data were collected using an air backfill (i.e. the pipe suspended freely in air) as a baseline, followed by water, wet sand, damp sand, and dry sand. Operating on the hypothesis that backfill will in fact effect the attenuation of a signal, these initial experiments used air and water backfills as examples of what were believed to be the extreme cases of low and high attenuation-producing backfills, respectively. The sand experiments were conducted to determine the effect of moisture content on a single material. Once sources have been procured, further experiments are planned using other common backfill materials, including dirt, clay, and gravel, all of varying moisture contents where possible.

RESULTS

The overall results of the experiments are illustrated in Figure 3, where the received frequency spectra are shown for each backfill. During these runs, the high voltage, short duration pulse was used as a repeatable source. The figure clearly shows that backfill material affects the strength of a received signal. For a pipe suspended in air with no other contacts but the supports, response varies from approximately -20 to -60 dB, with the greatest portion of the energy lying between 20 and 100 kHz. Keep in mind that the signal

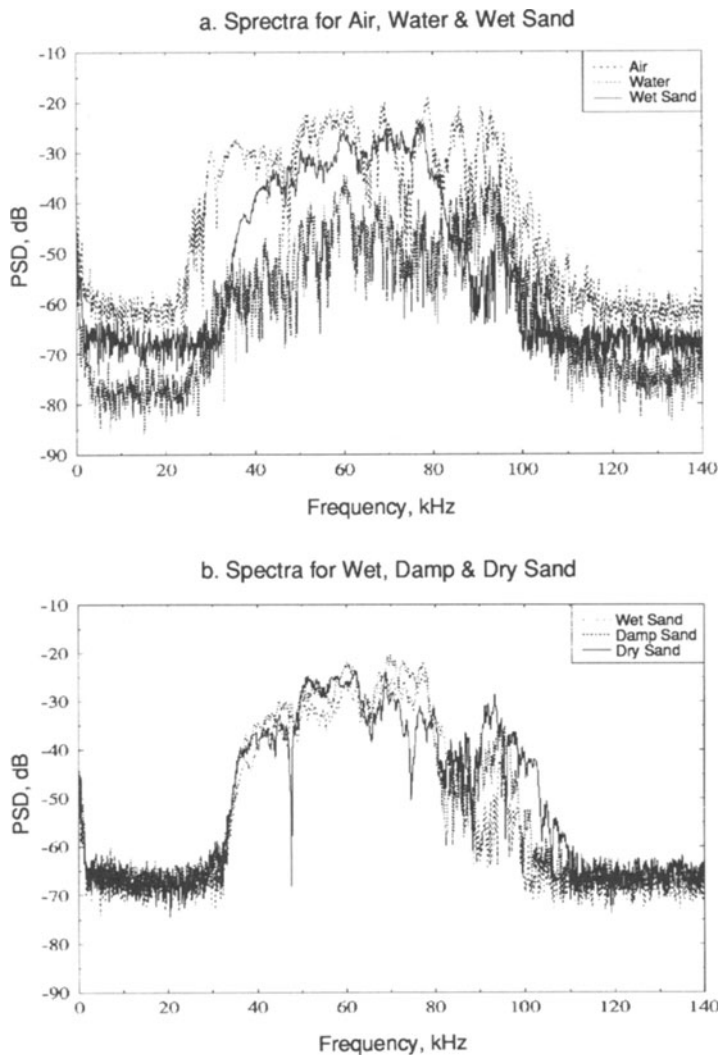

Figure 3: Received spectra as a function of backfill.

was bandpass filtered from 1-100 kHz. However, for a pipe immersed completely in water, as expected, the received signal strength drops significantly. In general, the signal from the water backfill is nearly 20 - 30 dB lower compared to the data with no (i.e. air) backfill.

There are several interesting features to note within the spectra representing the sand data. First, with only one clear exception, for wet sand between 85 and 95 kHz, the spectra for all sand conditions fall between that of air and water. The reason for the anomalous behavior has not yet been explained. As mentioned above, it was believed prior to these experiments that if backfill did in fact effect the attenuation of a signal, then air and water would represent the extreme cases. With that in mind, it should then be expected that other backfill materials would fall between the air and water spectra shown in Figure 3. The data bear this out. Second, the sand data shows that through the bandpassed region between 1 - 100 kHz, most of the energy transmitted along the pipe falls in the frequency band between approximately 30 and 95 kHz. Below 30 kHz, the signal is very flat and only 5 - 15 dB above the signal amplitude in water. Above 95 kHz the amplitude is decreasing and is eventually lost due to the filter. However, within that band the signal is very strong, with almost the same amplitude as the signal from the pipe suspended in air. Note that is also corresponds to the band of highest energy within the spectra from the water-immersed pipe. This would suggest that the energy in this band does not couple well through the pipe wall to the backfill, even when the backfill is the same as the fluid within the pipe.

These results also correspond well to data taken with real leak signals[1] captured during the CERL pipeline experiments. Figure 4 shows that the highest signal amplitudes of those signals were found to be in the frequency range between 25 and 45 kHz. The data also conform well to other work[2] in which both theoretical calculations and experimental results show that the dominant modes of propagation lie between 25 - 80 KHz, which is illustrated in Figures 5 and 6.

Finally, the data suggest that for sand, moisture content does not make much difference in the attenuation. In general, the data are close enough for all three cases, wet, damp, and dry, that it is not possible to determine with certainty that moisture content either significantly raises or lowers the attenuation in the pipe. In all cases, however, the sand data falls between that of air and water.

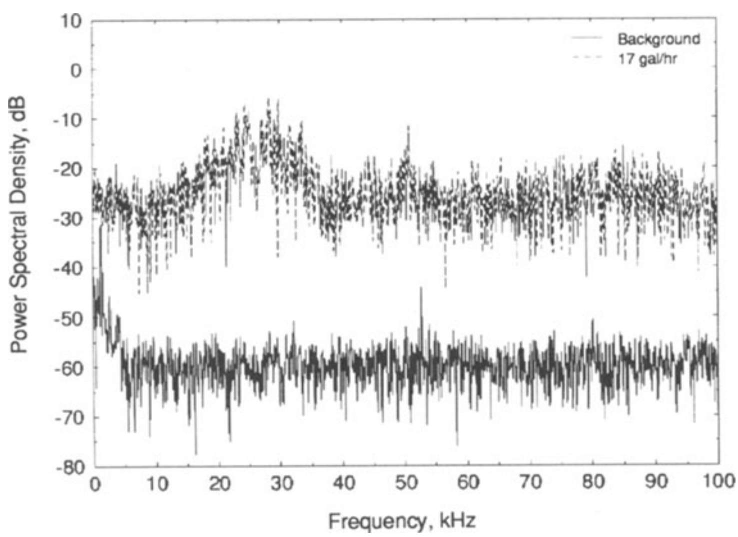

Figure 4: Spectra of leak signal produced by sand-covered leak source. Receiver approximately 20 ft. from source location[1].

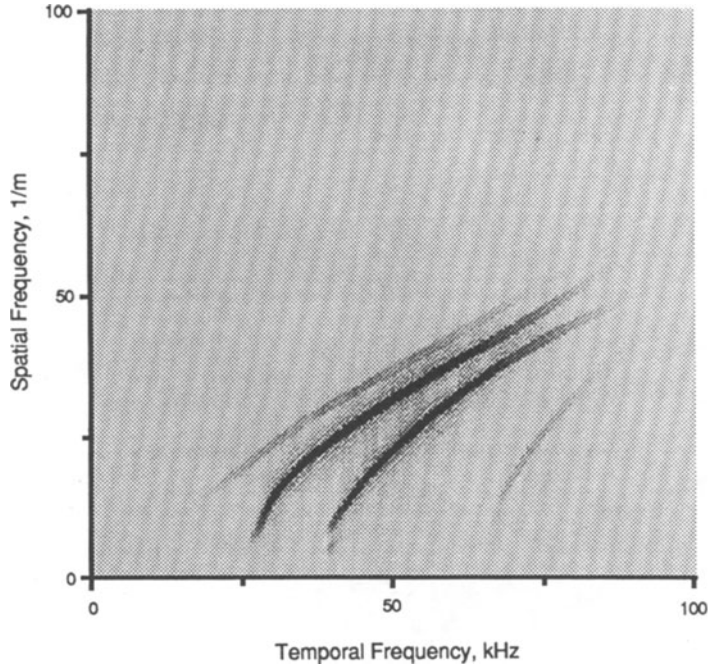

Figure 5: Axi-symmetric dispersion characteristics in a model pipeline (10 PD to source)[2].

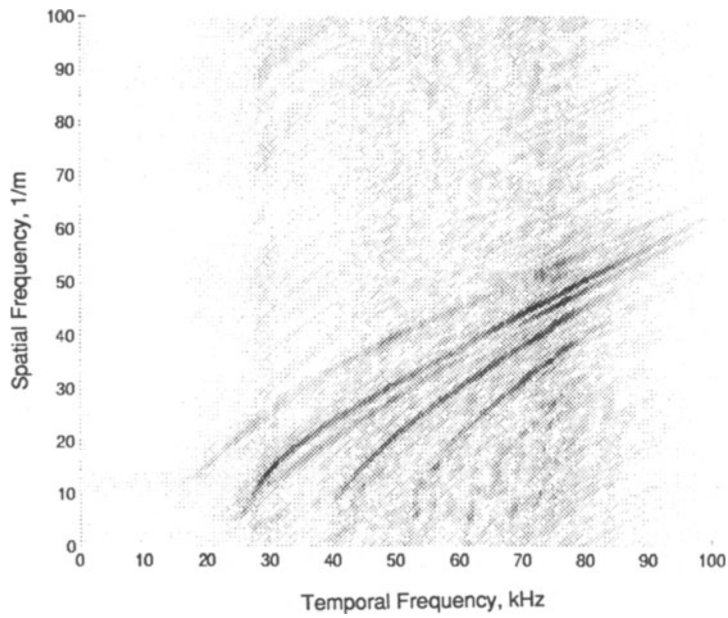

Figure 6: Dispersion characteristics of an experimental pipeline (10 PD to source)[2].

CONCLUSIONS

Preliminary data have been taken to determine the effect of backfill material on acoustic signal attenuation in fluid-filled pipelines. A baseline experiment of a pipe suspended in air (i.e. no backfill) was completed, followed by experiments using 100% water and sand of various moisture content. From the data, the following conclusions can be drawn:

1. The type of backfill material used to bury a fluid-filled pipe can have a significant effect on signal attenuation within the fluid of the pipe.

2. The cases of air (no backfill) and complete water immersion demonstrate the extreme cases of low and high levels of attenuation, respectively.

3. Most signal energy is the range 1 - 100 kHz propagates at frequencies above approximately 30 kHz.

4. For sand backfill, increasing moisture has a negligible effect on the overall attenuation in the pipe.

ACKNOWLEDGEMENTS

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