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PRACTICAL ASPECTS OF ACOUSTIC PLASTIC PIPE LOCATION

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ABSTRACT

Many gas distribution company operation and maintenance activities require precise knowledge of the location of buried plastic piping. Plastic pipe cannot be located if the tracer wire is gone or was never installed. Under sponsorship of the Southern California Gas Company, IGT successfully demonstrated an acoustic plastic pipe location technique and is developing the technique into a practical field instrument. An acoustic signal is injected directly into the gas at a service. The acoustic signal travels in the gas in the pipes, not in the pipe wall. As the acoustic wave travels along the pipe, some of the sound radiates from the pipe through the soil to the surface of the ground. An array of sensors on the surface of the ground perpendicular to the pipe detects the acoustic signal, thereby locating the pipe. Two different acoustic measurements are used. The first measurement locates the pipe to within ± 3-ft. Then the second technique determines the location of the pipe to within ± 6-in.

PRACTICAL ASPECTS OF ACOUSTIC PLASTIC PIPE LOCATION

THE NEED FOR A NEW LOCATOR

A plastic pipe locator based on a new locating principal is needed that accurately locates the pipe to within $\pm$ 1 foot. Many operation and maintenance activities performed by a gas distribution company require precise knowledge of the location of the gas main and/or service. These activities range from pipe location for the repair of a leak to the marking of pipe location as part of a one-call system. Accurate records are one method of knowing the location of piping. However, these records are not always sufficiently precise for field work. Thus, techniques for pipe location have always been an important need of the industry, with electromagnetic pipe locators filling this need for steel pipes for years. The use of plastic pipe has become very common. Electromagnetic pipe locators cannot find plastic pipe unless a tracer wire is buried next to or above the pipe. Often the tracer wire is broken, corroded or displaced. A broken tracer wire greatly reduces the effectiveness of the electromagnetic pipe locator.

OTHER APPROACHES WERE UNSUCCESSFULLY TRIED

Several organizations have sponsored a number of research projects to develop revolutionary new locators capable of "looking" into the ground to image more than just the pipe. Unfortunately, the techniques using ground probing radar (GPR) have not been universally successful because of the effects of moisture and high electrical conductivity of many soils; the technique works in some, but not all, soils. Acoustic imaging/holography techniques have also been unsuccessful.

Acoustic pipe locating techniques are attractive because the sound waves will propagate in all types of soil and pavement. In addition to the approach described in this paper, two other acoustic pipe locating techniques have been investigated. One technique attempts to use a surface transmitter to create continuous waves that reflect off the pipe to surface sensors located close to the transmitter. The second technique uses the same geometry of closely spaced transmitter and sensor. However, in this case an acoustic pulse or thump (containing all frequencies) is used to stimulate resonant pipe frequencies. The sensor is tuned to the resonant frequencies. Both of these techniques are very attractive because of the apparent simplicity of the concepts and because of the second case's apparent similarity to radar and sonar.

Neither of these acoustic approaches was successful because the transmitter also creates a large amount of surface waves in the vicinity of the sensor. The surface waves are very large in comparison to the acoustic signal returning from the pipe. In both cases the transmitted signal interference lingers on for such a long time that the returning signal from the pipe is obscured. That is, the total acoustic signal is so dominated by the contribution of the surface waves that it is very difficult to observe the pipe location signal even when sophisticated signal analysis techniques are used. In addition, acoustic coupling between a sensor and soil or pavement varies from sensor placement to sensor placement. These variations further complicate the detection of the small pipe detection signal.

ORIGIN OF THE TECHNIQUE

In order to develop an effective plastic pipe locator, IGT proposed an adaptation of the active sonic leak detection method for cast iron pipes patented by IGT researchers in the late 1950s for cast iron pipes[1-3] and later refined.[4-6] In the active leak detection method, sound was injected directly into cast iron pipe. The sound traveled inside the pipe and exited at any leak. The difficulty with the technique was that the sound also coupled into the pipe wall causing the entire pipe to vibrate. This created many false positive leak signals because the pipe itself was detected. Similar findings by the Applied Physics Laboratory of The Johns-Hopkins University[7-10] and British Gas[11] have confirmed the IGT work Because the active leak location technique keeps detecting the vibrating pipe, why not take advantage of this and optimize the technique for locating pipe?

Under sponsorship of the Southern California Gas Company,[12] IGT successfully demonstrated the proof-of-concept of an active acoustic plastic pipe location technique and is currently developing the technique into a practical field instrument. Work in this program is utilizing the pipe wall vibration created by the active acoustic method and is optimizing it for plastic pipe location. An important advantage of the active acoustic approach is that it significantly reduces the contribution of surface waves created at the signal injection point to the total signal, making it much easier to interpret the pipe location signal. Because the pipe locating sound wave travels faster in the natural gas inside the pipe than do the slower waves in the soil, the first signal received by the distant sensor is the desired pipe locating signal. By appropriately gating (turning on and off) the transmitter, the effects of the surface waves created at the signal injection point are eliminated. Because the acoustic signal is known, powerful signal extraction techniques can be used to minimize the effects of background noise such as vehicular traffic.

ACTIVE ACOUSTIC TECHNIQUE ACCURATELY LOCATES PLASTIC PIPE

This active acoustic technique for locating plastic pipe uses sensors at the surface of the ground to detect an acoustic signal injected into the gas stream. A known and specially selected acoustic signal is introduced into the plastic pipe with an acoustic speaker. As the acoustic wave travels along the pipe, some of the sound radiates from the pipe to the surface of the ground. An array of sensors is placed on the surface of the ground perpendicular to the suspected pipe location. These sensors detect the acoustic signal from the pipe and the instrument processes this data to determine the location of the pipe.

Two pipe location techniques were investigated: the amplitude and time-of-flight techniques. They differ in terms of the signal used to drive the speaker and in the physical quantity measured. The amplitude technique uses a continuous sine wave as the signal. One would expect that the sensor detecting the strongest signal should be directly over the pipe. Experiments have demonstrated that is not always the case. In one series of experiments, the speaker was driven with a single frequency. Many closely spaced frequencies in the range of 300 to 3,500 Hz were tested. At a few frequencies the peak amplitude versus sensor distance from the pipe was very sharp and directly over the known position of the pipe. At other frequencies more than one peak occurred and the largest peak was not over the pipe. This is demonstrated in Figure 1 where the pipe location signal is strongest over the 2 foot position rather than the actual location at the 4 foot mark. Also note that the curves are not symmetric about the true pipe location -- the readings at the 6 foot position are smaller than at 2 feet. In these and other cases the pipe is found to within only $\pm$ 3 feet. This is not sufficiently accurate for day-to-day applications which require $\pm$ 1 foot. This confusion in locating results is caused by interference patterns which depend on the frequency, the depth of the pipe, and velocity of sound in the soil. In principle if all of these quantities are known before hand, it should be possible to calculate an appropriate frequency. Unfortunately, they are not known before the pipe is located. It is also known that the coupling between the sensor and the ground varies with the placement of the sensor. Sometimes the signal amplitude detected by the sensor is smaller than the true value, further confusing interpretation of the results. Because of these and other factors, IGT believes that another acoustic pipe location method is required.

Thus, a second plastic pipe location method was developed which uses a burst of sound followed by a short period of quiet, rather than a continuous tone. Typically, the acoustic burst is composed of ten cycles of a single frequency. As with the amplitude method, some of the acoustic signal reaches the sensors in the array perpendicular to the pipe. The sensor closest to being directly over the pipe is the first to detect the arrival of the pulse.

Because the time of flight method measures the delay between when the burst is applied to the speaker or shaker and when it arrives at the sensor, it is much less susceptible to the coupling problems that affect the amplitude method. Poor coupling also effects the amplitude of the time-of-flight signal, but has very little effect on the time as long as the wave can still be detected. Figure 2 shows data obtained with the time-of-flight technique. The data in Figure 2 was collected on a

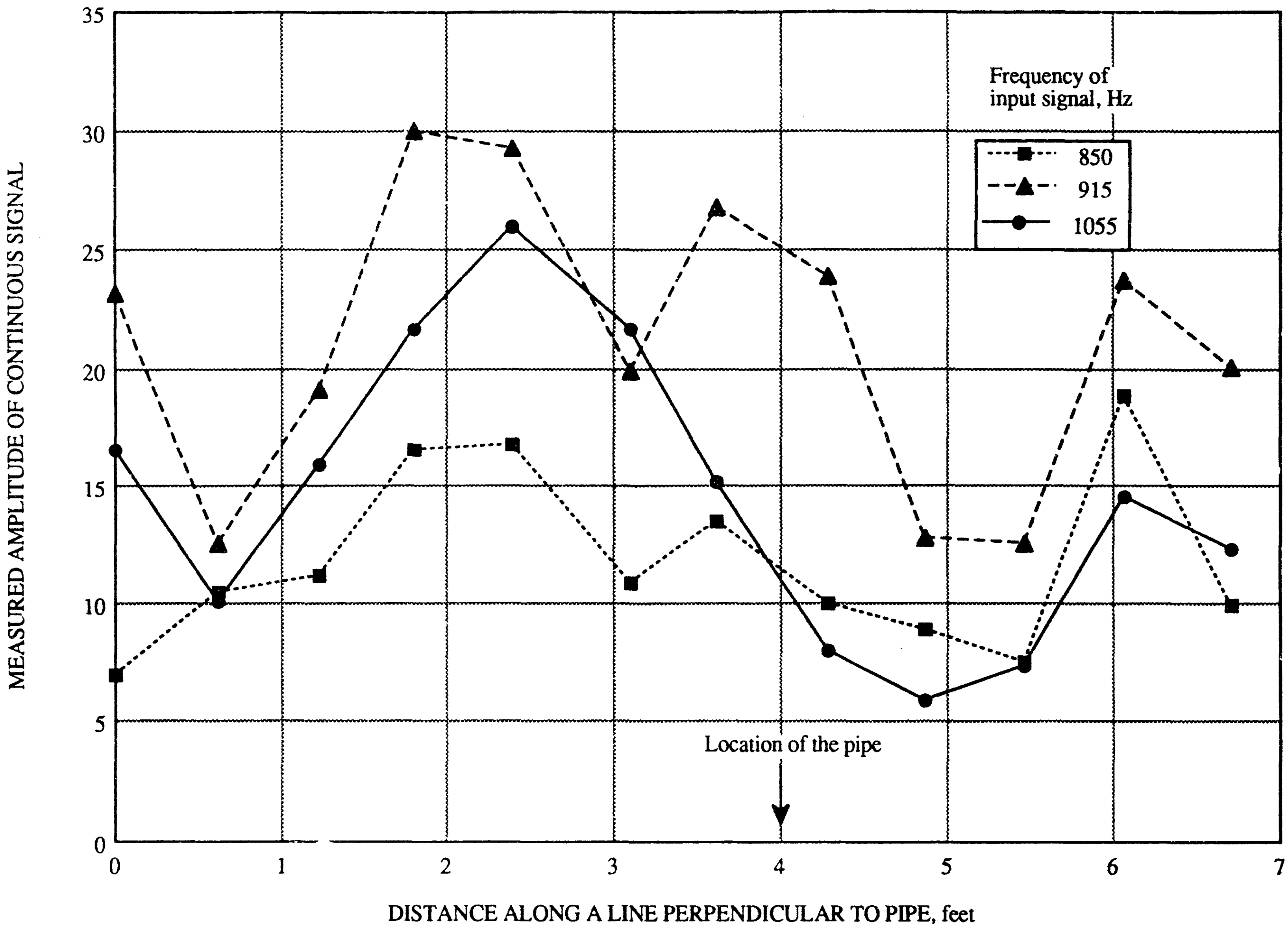

Figure 1. MEASURED AMPLITUDE VERSUS POSITION OF THE SENSOR FOR THREE CONTINUOUS SINEWAVES
Note: The pipe is located below the 4.0 position.

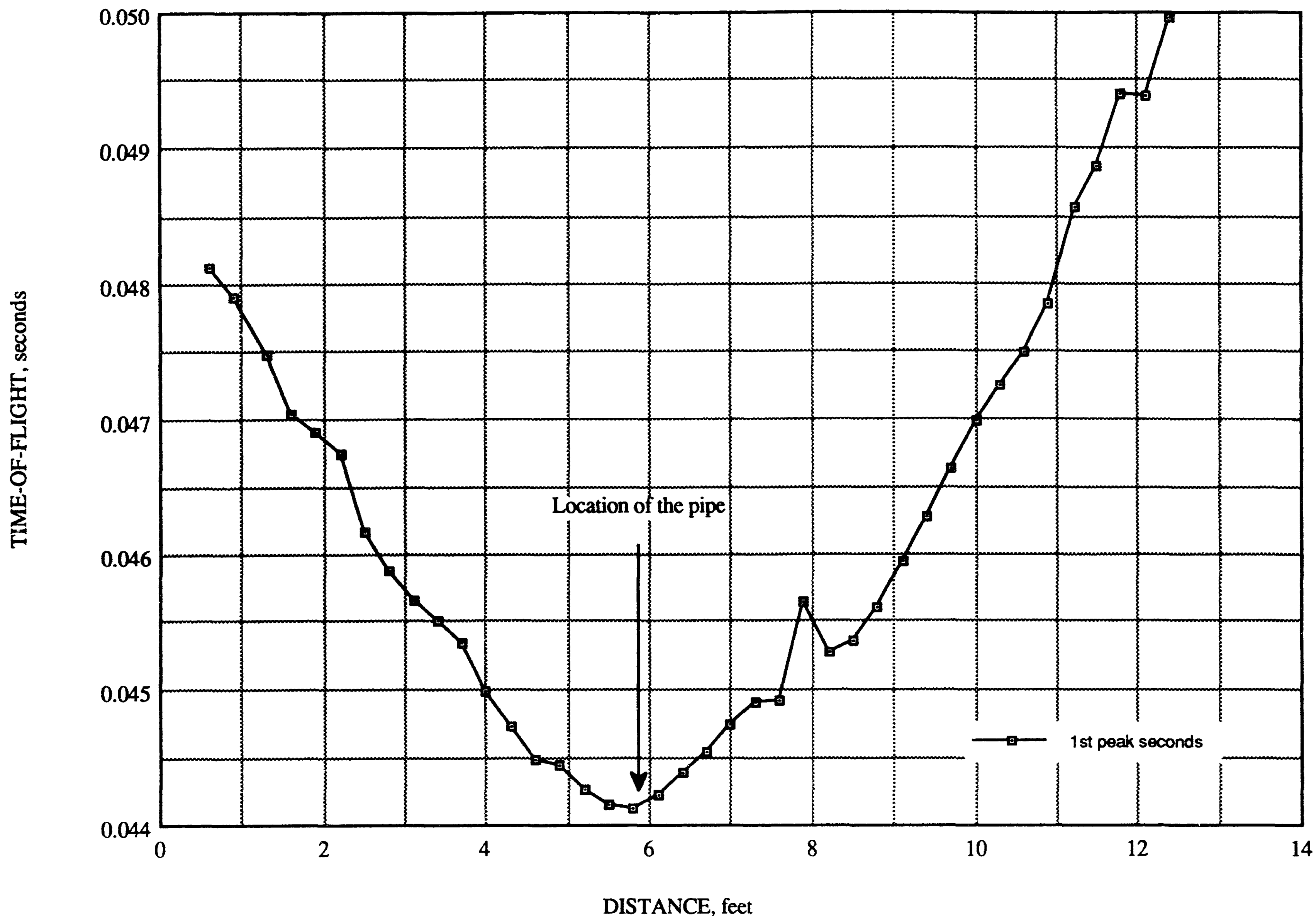

Figure 2. PIPE LOCATION USING THE TIME-OF-FLIGHT TECHNIQUE

different day and with a different starting position than the data in Figure 1. The lowest point on the curve is directly over the pipe with the pipe being located to within ± 6 in. Pipe location experiments were successfully repeated on many different days during all seasons at the IGT pipe farm. Soil conditions varied during these experiments from dry soil to very wet.

The time-of-flight technique has a disadvantage. Because only a few cycles of the waveform are used, the detected signal is weaker and thus, cannot be detected as far away from the main as the continuous signal. In some cases one may need to use a continuous signal to find the general pipe position before accurately locating it with the time-of-flight technique.

A patent on the technique of acoustically finding buried plastic pipe using the amplitude and time-of-flight methods was applied for and granted. U.S. Patent number 5,127,267 Acoustic Method for Locating Concealed Pipe was issued on July 7, 1992. This patent is owned by Southern California Gas. The patent teaches the use of the amplitude method for finding the general location of the pipe and the time-of-flight method for accurately locating the pipe.

DIRECT INJECTION OF THE ACOUSTIC SIGNAL INTO THE MAIN WORKS BEST

Practical use of the acoustic plastic pipe locator requires a method of getting the acoustic signal into the pipe that is easy to do in the field and provides enough signal to locate the pipe for a distance of a few hundred feet. A method that did not contact the gas in the pipe, or better yet does not touch the pipe, is the most desirable from an operating point of view. Approaches considered included a phased array of mechanical vibrators as a sound source (with no connection to the pipe), the use of a vibrator on a long probe, mechanical vibration of the service riser, and mechanical vibration of the main. The latter two were tried but were not very effective, probably because the sound propagates in the gas and not in the pipe wall. Vibrations of the pipe wall do not generate enough acoustic intensity to locate plastic pipe. For similar reasons, non-contact approaches would be even less effective. Experiments demonstrated that the most efficient (maximum range of pipe location from one single injection point) procedure for injecting the acoustic signal into the pipe is direct injection into the gas stream at the main using a loud speaker. From a day-to-day operations viewpoint, this approach is not very acceptable because it requires an excavation and hot-tapping of the pipe. Direct access to the gas inside the service is feasible and would have a much higher field acceptability.

The next most efficient method of injecting acoustic signal into the gas is to disconnect the service somewhere on the riser and attach the acoustic driver to the service. Because most services are smaller in diameter than the main, the attenuation through a given length of service is greater than for a corresponding length of main. There are also losses through the service connection, as well as, due to the change in direction from the service into the main. The proper choice of frequency can minimize these losses. We have not estimated the maximum range for pipe location with the signal injected at the service. However, we have located the pipe 180 feet away from the acoustic injection point on the service (the maximum distance possible in our test facility). The maximum range should be longer than this. SoCalGas has accepted direct coupling of the speaker to the service as an acceptable approach.

CRITICAL PARAMETERS WERE MEASURED IN A NEW TEST FACILITY

In order to develop a practical technique, several questions had to be answered.

- How does the sound propagate along the pipe: in the pipe wall or in the gas inside the pipe?
- How far can the sound propagate in the pipe?
- Does enough acoustic signal reach the ground surface to be detected?
- How should the acoustic signal be introduced into the pipe?
- What is the best pipe locating signal to use?
- What is the range of the technique?

An outdoor (all-weather) test facility was designed and built to facilitate rapid development of plastic pipe locating concepts under known, controlled, and reproducible conditions. The facility includes two manholes covered by two small instrument buildings. These permit below ground access to the piping. Figure 3 is a photograph of the 2 inch main; next to it is a 40 foot long 6-in. line connected by a 6 to 4-in. transition fitting 40 foot 4-in. pipe.

Two types of trenches, one 24 inches and the other a very wide 16 foot trench were connected end to end. All of the soil in the trenches was removed and replaced with two soil types: a heavy clay common in the Chicago area and pitcher's mound clay-- a manufactured soil made from clay and sand. The wide trench was excavated to a depth of 6 feet. The soils were filled in shallow 6-in. lifts and carefully compacted to a depth of 3 feet before the plastic pipe was laid. One plastic pipe (SDR11 PE2406 DuPont) 2 inches in diameter and 190 feet long was used for most of the experiments. Upon completion of the pipe installation the remainder of the soil was added and carefully compacted. The pipe in the narrow trench varies in depth from 2.0 to 6.0 feet. A paved road passes over the one end of the pipe. Two plastic services were installed, one at the far end of the 2-in. main. The 2-in. plastic pipe was instrumented with 7 buried accelerometer sets. Figure 4 shows one of the pipe accelerometer sets attached to the main 2-in. PE pipe. Moisture conditions of the soils varied throughout the seasons from dry soil to very wet soil. The water table was usually a few feet or more below the pipe.

Three features of the IGT pipe farm had special importance in this effort. The buried accelerometers attached to the 2-in. plastic pipe permitted detailed measurement of acoustic propagation along the pipe, as well as from the pipe to the ground surface. The two types of trenches (typical utility width and the very broad trench) permitted measurement and separation of any trench location effects from pipe location. In some cases, sound can be attenuated as it crosses the trench wall making it difficult to detect the sound outside of the trench. The active acoustic technique becomes in effect, a trench locator. Because some plastic pipe is installed with trenchless technologies, we wanted to be certain we are developing a pipe rather than a trench locator. The "manufactured" soil was used to make one portion of the facility as homogenous as possible. Thus, the results in Figure 1 were not caused by non-uniform soil.

SOUND TRAVELS IN GAS, NOT IN PIPE WALL RESULTS

One important question was whether the sound traveled in the plastic pipe wall, in the gas itself, or in a combination of both. The sensors mounted on the pipe wall were used to answer this question. A burst of sound was injected into the pipe. The sensors were monitored for the arrival of the acoustic waves. Because the velocity of sound in polyethylene plastic (7500 ft/sec) and methane (1417 ft/sec) or air (1130 ft/sec) are known, the time and relative amplitudes at which the sound burst(s) arrives would demonstrate the relative importance of each path. These measurements demonstrated that all of the detectable acoustic signal is propagating in the gas at the velocity of sound in the gas. No evidence of wave propagation along the PE pipe wall was found. These results were the same --

- whether the sound is injected directly into the gas with a speaker
- whether the sound is injected into the pipe wall with a vibrator.

The result that acoustic waves do not propagate along the plastic pipe wall does not mean that no propagation occurs in PE. The fact that acoustic signals are detected at the ground surface means that some sound is transmitted from the gas to the surface and, therefore, across the pipe wall.

The choice of what frequency is best to use for the active acoustic pipe locator was investigated. That is, is there one frequency, set of frequencies, or band of frequencies that is better to use than the others? Measurements of acoustic levels with sensors on the pipe wall have

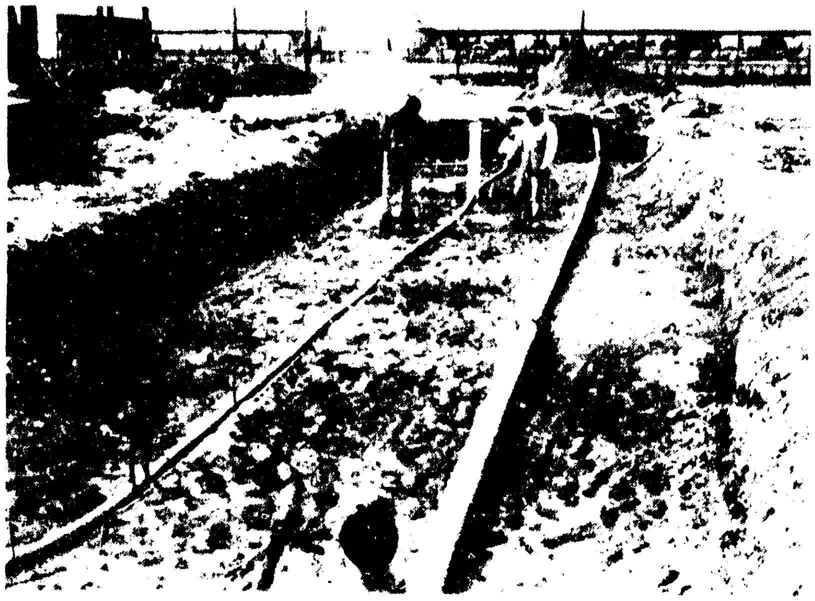

Figure 3. PHOTOGRAPH OF THE LARGE TRENCH LOOKING WEST
WITH THE 2-, 4-, AND 6-INCH PIPE

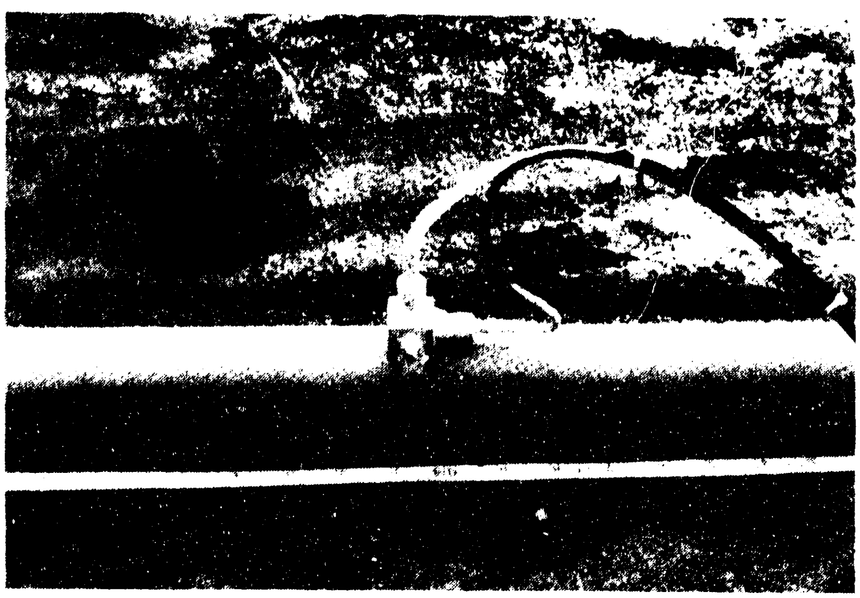

Figure 4. PHOTOGRAPH OF A PAIR OF ACCELEROMETERS MOUNTED ON THE
2-INCH LINE

not identified any frequencies (up to 3500 Hz) that are especially good or prohibitively bad to use. That is, there are not any sharply resonant features in the spectrum that occur in every pipe location situation to use or avoid. (We are defining sharply resonant as 2 or more orders of magnitude.)

However, in each pipe location case there will be a set of frequencies that will produce better results than others because of the length of the service, the details of the service main coupling tee, coupling of the sound to the soil, soil acoustic attenuation, spatial resolution, and possibly pipe diameter. At some frequencies standing waves are produced in the service. At these frequencies very little sound is propagated into the main. Sound does travel into the main at other frequencies. The plastic pipe locator can be designed to automatically scan through a set of frequencies and select an optimum frequency for the specific conditions.

We often use a frequency near 1000 Hz as a compromise between improved noise rejection and locating resolution and range of the technique.

The next question was to estimate the range of application of the technique. There are conflicting requirements for a successful acoustic pipe locating technique. Enough sound must couple through the wall to be detectable at the surface of the ground and that energy must be provided by the acoustic signal in the gas. On the other hand, if the acoustic energy couples through the wall too quickly, the distance between signal injection points becomes too short to be practical. Of course, not all of the acoustic energy lost from the gas results in signal at the surface of the ground.

The attenuation of sound in the gas in the pipe was measured as a function of acoustic frequency. Similar measurements were made on the attenuation of sound in soil. These values were used to estimate the range of the technique for direct signal injection into a 2-in. main (rather than the service) at a frequency of 1000 Hz. The range was calculated to be approximately 800 feet. Sound in a larger diameter pipe will propagate further; also sound at lower frequencies will propagate farther. Conversely, acoustic reflections from tees and services will reduce the range of the technique.

SENSOR ON A TRIPOD MAKES TECHNIQUE EASIER TO USE

The choice of sensors is critical to the technical success of the method and to the acceptance of field crews for day-to-day use. Measurements in the early portion of the program successfully used a sensor mounted on a short spike. Because much piping is located under pavement, it would be most convenient to place the sensors on top of the pavement. A sensor mounted on a triangular base has been used by others in the past as an acoustic sensor. The mass of the triangular base and the spacing of the legs are known to be important parameters affecting the coupling of sound from the pavement into the sensor. Other factors that may affect the choice of sensor and sensor base may depend on soil type and condition (compaction and moisture content).

The design of the sensor tripod base is important as it effects the overall sensitivity and the frequency response of the sensor/base combination. Several authors have modeled the complex interaction of a sensor resting on the surface of the ground. The literature was used to select trial base diameters, base material, and thickness.

Tests demonstrated that for plastic pipe location needs, a tripod sensor can be used on pavement with little or no loss in sensitivity. Measurements were made on clay soils, and on asphalt. As expected from theory, the smaller the circular base the larger the frequency response of the accelerometer. All of the accelerometers on circular bases had a better frequency response below 500 Hz than the accelerometer on the spike. Conversely, above 500 Hz, the accelerometer on a spike was better. Of the circular bases, the 3" diameter gave the best response; however, the long electrical cable attached to the accelerometer makes the sensor and 3" base too unstable. (It tends to fall over.) The 4" diameter base is sufficiently stable for practical use and gives nearly as good sensitivity and frequency response. It was selected and has been successfully used on both soil and asphalt pavement to locate the plastic pipe. Two sets of sensor bases will be used in the field trials, an accelerometer on a tripod and an accelerometer on a short spike.

A sensor with improved signal-to-noise ratio is possible and would benefit the technique by insuring that the results would be even more reliable. Such a sensor is under development in the Advanced Acoustic Distribution Instruments program of the IGT Sustaining Membership Program (SMP). The unique feature of this sensor is that it should be less sensitive to low frequency background noise and more sensitive to the pipe location signals. If this sensor is successfully developed, it should be used for the plastic pipe locator.

FIELD TRIALS ARE NEXT

The next steps are to complete the refinement of the technique by having a microcomputer do the data interpretation as to the location of the pipe and to display the results in an easy to understand format. When this is complete the instrumentation will be taken to Southern California Gas Company for field trails in the summer of 1993.

SUMMARY

The active acoustic plastic pipe locating technique has successfully passed the proof-of-concept stage and the instrumentation and technique are being refined for testing in the field. The pipe located to within ± 6 in. and pipe location experiments have been successfully repeated on many different days during all seasons at the PE pipe field facility.

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