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CAVEAT EMPTOR
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A BUYER'S GUIDE TO PILE INTEGRITY TESTING

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INTRODUCTION

During recent years, the integrity testing of piles has made considerable progress. With the availability of portable and powerful computers, practically all integrity testing equipment is now digital. Using sophisticated software for data acquisition and analysis, today's testing systems can provide owners with important information regarding both the length and integrity of piles and drilled shafts.

This sophistication carries a price: Very few clients, including experienced engineers, do understand the strange-looking graphs adorning the reports they get. In fact, most of them will never ask, some because they are too busy to care and others because they are ashamed to show their ignorance. This situation is well exploited by a few shrewd operators of test equipment. Facing strong competition and falling revenues, they simplify their task and cut their expenses by the following means:

1. Using old equipment until it falls apart, and then some,
2. Hiring under-qualified personnel,
3. Staying on site as little as possible,
4. Eliminating the analysis and evaluation stage altogether,
5. Confirming as-made lengths and reporting no defects.

While most pile testing laboratories do provide high quality service, the minority that practices the above techniques can give the whole industry a bad name. It is important, therefore, to educate clients in the principles of integrity testing methods, show them

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examples of how they can be abused and teach them how to distinguish between highly qualified, honest pile-testing professionals and so-called “cowboys”.

This paper provides some typical examples of both sonic and ultrasonic test results. For each example, the paper shows how the above methods are applied in practice and how data was manipulated. It concludes by strongly recommending that all engineers representing clients on piling projects have at least a basic understanding of integrity testing methods, their capabilities and their limitations. The principle of “Caveat emptor”, or “Buyers beware” will serve them well.

The examples quoted in this paper were obtained by various firms and with different instruments. The criticism expressed by the author is not directed at those instruments. They are all adequate, and when operated by qualified personnel and under suitable conditions can provide meaningful information. It is the operators who cheat their clients and abuse the instruments who have to be exposed and banished from sites.

THE SONIC METHOD

The sonic method has been in use for more than two decades (van Koten & Middendorp 1980), and is undoubtedly the most widespread of integrity testing techniques. Recently it has been standardized in Europe and in North America (ASTM 1996). The method is based on hitting the pile head with a hammer and reading the waves reflected from the toe and from significant changes in the cross section. Current testing instruments, all computerized, treat the signals and display them in the form of a reflectogram (Figure 1). When given the assumed length, most instruments will search and identify the toe reflection, mark it with a cursor and print the length. The operator may override this determination by moving the cursor manually. To compensate for soil friction, every reflectogram has to be amplified. The common technique is to apply exponentially increasing amplification that starts from 1 at zero depth and reaches a maximum at the toe. For slender piles in hard soils, amplification in the order of a few hundreds is usually required.
Because of ever-present noise, obtaining a high quality reflectogram with a clear toe reflection is not always easy. The following section elaborates on this key subject.

![Figure 1: A quality reflectogram](image)

**NOISE IN SONIC TESTING**

Noise is the enemy of all physical measurements, and its magnitude in relation to the measured signal is of utmost importance. In the sonic test, there are numerous sources of noise, namely:

1. Surface (Rayleigh) waves created by the hammer blow are reflected from the pile head boundaries, causing high-frequency noise.
2. Often a short piece of casing is used at the top of a pile during concreting and later pulled out, resulting in a sudden decrease of the cross section at the bottom of the casing. This decrease creates regularly repetitive reflections that (except for the first one) appear as medium-frequency noise.
3. Trimming of the pile tops usually leaves a rough surface. When a concrete protrusion is hit with the hammer, it may break and create random noise.
4. Careless hammer blows which may hit reinforcement bars may also produce high-frequency noise.
5. When the top of the pile is not trimmed enough, or not at all, it may produce pure noise that will result in a reflectogram with a wavy form.

Noise should always be reduced to the minimum level. Regular noise (Items 1 and 2) may sometimes be treated by mathematical filtering. Random noise (Items 3 and 4) is reduced by averaging a larger number of blows. Testing an unprepared pile (Item 5) is a waste of time, so whenever one is identified, the test should be repeated after proper trimming. This often entails another site visit, something that can play havoc with the economics of the job.
Therefore, unscrupulous operators prefer not to eliminate the wave, but rather ride it.

Following is an example of this method, encountered by the author.

RIDING THE WAVES

For irresponsible operators, noise in an asset that can be exploited. A noisy reflectogram (Figure 2) is always easy to obtain – all it takes are a few careless blows on an ill-prepared surface. “Interpretation” in such a case is also simple: Place the cursor on one of the many minima points on the graph that is closest to the assumed length. The difference will usually be less than the accepted 10 percent (Turner 1997) and everybody involved will be happy.

When an over-inquisitive client asks why a certain trough was preferred over others looking much the same, the standard answer is “It was determined by the computer”.

![Image of a wavy reflectogram](image)

Figure 2: A wavy reflectogram

POURING OIL OVER THE WATER

Other operators may prefer the opposite technique by depressing noise altogether. This can be done by using little or no amplification, combined with maximum filtering. This may produce nice, smooth “reflectograms” (Figure 3) with much room for improvisation. While Figure 3 provides little information about the integrity of the concrete piles “tested”, it tells a lot about the integrity of the operator. The points of most interest are:
1. From a depth of 2 m downward, both “reflectograms” are rather smooth and featureless, with no indication of toe reflection. When confronted and asked why the cursors were placed where they are, the operator can always put the blame on the computer.

2. The amplification ratios used (exp) are 2x (top) and 1x (bottom), for 15 m. long piles in dense calcareous sandstone. Since 1x is no amplification at all, it is evidently far from enough for such conditions.

3. The wave velocities (vel) assumed are 3700 m/s and 5250 m/s, respectively. This is somewhat inconsistent, since both piles are of the same concrete type and of the same age. Incidentally, the value of 5250 m/s is the longitudinal wave velocity in steel!

4. The filter used (fil) is 3.0 m long, which is the maximum allowed by the particular instrument. This assures that any feature shorter than 3.0 m will be invisible.

5. The assumed length of both piles was 15 m. The cursors were arbitrarily placed so that the difference between the assumed and the “measured” lengths is 10 cm. Such a degree of accuracy is simply too good to be true.

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Figure 3: Two very smooth reflectograms
CAN ONE DRAW THE SHAPE OF THE PILE?

Consider the following problem: It is required to plot the shape of an unknown structure on unknown supports (model), given the force applied to it at a certain point (input) and the resulting deflection (output). This problem is usually unsolvable, unless one makes certain assumptions regarding the model. The better the assumptions, the better the results but clearly the problem cannot be uniquely solved.

Certain operators claim that with their sonic instrument they are able to do just this, and describe the shape of the tested piles. To achieve this end, there are two available techniques: The artistic and the sophisticated.

THE ARTISTIC APPROACH

The practitioners of this method belong to the same group as card, coffee and palm readers. This means that they derive their inspiration just by looking at a reflectogram. For this purpose, the more ambiguous the reflectogram, the better. One sample of this approach, obtained from a certain developing country, is presented in Figure 4. The original interpretation provided with this result reads as follows: “The records indicate slight out-growth from -2 to -3 mtrs followed by return to normal cross-section. Slight necking is observed between -4.5 to -5 mtrs with subsequent return to normal cross-section. The upper 1/3 portion of the pile shows variation in impedance along the length of the shaft. The rest of the pile shaft appears to be uniform and there is a significant increase in soil resistance from -10 mtrs up (sic!) to the tip of the pile. Clear toe signal is observed at the right location corresponding to wave speed of 4500 m/s, which indicates concrete of excellent quality. The pile is free from major potential defects and it is therefore acceptable”.

![Figure 4: A reflectogram with artistic appeal](image-url)
This very detailed and impressive interpretation merits its own interpretation, as follows:

1. While the meaning of "slight" is somewhat subjective, it is a fact that the sonic method, using a wavelength of three metres, will rarely pinpoint slight changes in cross section.

2. Finding an isolated "slight necking" along 0.5 m of pile length is a rather difficult task. Doing it when it lies closely under an out-growth is plainly beyond the present capability of the sonic method.

3. The observation about "variation in impedance along the length of the shaft" is in fact a truism, always correct for any pile.

4. The diagnosis regarding the "significant increase in soil resistance from -10 mtrs up to the tip of the pile", while true, has no clue in the sonic test results. It is rather based on borehole logs and SPT results that were available to the writer.

5. A clear toe signal, or even an unclear one, is non-existent.

6. Cast in situ concrete with a wave speed of 4500 m/s is unattainable in the specific developing country. It is extremely rare, at best, in the developed ones.

THE SOPHISTICATED METHOD
To reach this level one needs some additional analytical software and, as an option, an instrumented hammer. In such a case, the test results are presented not only in the time domain, as before, but also in the frequency domain. In this case the graphic representation of the results is called a mobility plot. In the sophisticated method, the pile form is then determined not by pure observation, but by a signal-matching technique: Assuming a pile shape and a skin friction distribution, the program constructs a synthetic reflectogram that, by varying the parameters, can be made similar to the real one. Once this is done, the assumed pile shape and friction profile form one possible solution. This process can be done interactively or automatically, using an algorithm with a suitable convergence criterion.

The results of such a system are presented in Figure 5, which includes a mobility plot as well as a reflectogram and the pile shape "visualization". Since the tested pile was long, the soil very dense and the pile head poorly prepared, the test produced much noise and very little relevant information. The mobility plot does not show the regular peaks it theoretically should, and the "reflectogram" includes no visible toe reflection. Nevertheless, the instrument plotted a pile shape that has no similarity to the real thing. When confronted with tough questions, the operator can always use rule No. 1 and blame the computer. Figure 5 is, no doubt, an excellent illustration of the GIGO ("Garbage in, garbage out") principle.

219
ULTRASONIC TESTING

Unlike sonic testing, that uses long waves and a transducer pressed against to pile top, ultrasonic testing utilizes relatively short waves and is penetrative in character. Thus, it is widely accepted as the most powerful non-destructive method for pile testing. Ultrasonic testing comprises two distinct techniques: Cross-hole and single hole. Being simpler in theory than sonic testing, both methods are supposedly is less prone to fiddling with the results. However, a little ingenuity will always lead the way to abuse them.
MANIPULATING CROSS HOLE TESTING

Cross-hole testing consists of lowering a pair of ultrasonic transducers inside two parallel tubes, cast with the piles and filled with water. While the transducers are pulled back to the surface, the transmitter sends ultrasonic pulses to the receiver and the instrument displays the intercepted signals. Relatively uniform first arrival times (FAT) and energy indicate good concrete. A delay in the FAT and/or a decrease in the energy show the presence of a defect. The method has been standardized in Europe (Afnor 1993), and an ASTM standard is presently in the initial draft stages.

Although the cross hole test is fairly straightforward, some tricks can still be performed. The main one is manipulating the manual gain control. By increasing the gain, certain instruments do two things: First they increase the energy supplied to the transmitter and second, they lower the threshold value for identifying the FAT. Thus, by using a high gain setting the operator can hide certain defects (Figure 6). This simple trick is especially useful when the operator is hired by the piling contractor.

![Cross hole test results](image)

**Figure 6:** Cross hole test results for the same profile –
Gains decrease from high (left) to low (right)

SINGLE HOLE TESTING AND WATER QUALITY

With this technique, both transmitter and receiver are lowered in the same water-filled tube, one above the other (Brettmann et al. 1996). When the separation between the probes is small, the FAT will be registered by the waves travelling straight through the water at a velocity of 1500 m/sec. When the separation is increased, waves exiting the tube and travelling through the concrete will arrive earlier, in spite of covering a longer path. If this is the case, the FAT
vs. depth trace can provide information about the integrity of the concrete surrounding the tube.

The problem is, however, not as simple as that: Waves traveling in the concrete are strongly attenuated when crossing the wall of the tube twice, and when propagating in the concrete itself. In comparison, the waves traveling in the pipe through incompressible water lose almost no energy. Instruments unable to distinguish between the two will pick up the stronger signal, and thus provide reliable information about the water filling the tube. Although of little use to the client, such results (Figure 7) will keep the piling contractor content.

Figure 7: Single-hole Sonic Logging (SSL) results

CONCLUSIONS

1. Integrity testing can be (and therefore will be) abused because of ignorance and/or greed.

2. Integrity testing services should always be ordered and paid for by the owner, never by the piling contractor.

3. Integrity testing services should be obtained only from reputable firms, headed by a geotechnical engineer with excellent reputation, for a negotiated fee.

4. Different testing firms use different hardware, but the difference in the quality of personnel far outweighs any difference in instrumentation.

222
5. There is no mystery in integrity testing, and it can be explained to any graduate civil engineer. As a rule, a good pile testing professional will readily lecture to site inspection personnel about integrity testing techniques or recommend accessible literature.

6. As a rule, honest firms welcome and encourage questions of technical nature. Impostors, on the other hand, will avoid them like the plague. In many cases, when confronted with questions regarding their reports, they will react emotionally.

7. Because integrity-testing techniques have many limitations, serious pile testing professionals will use a question mark whenever they deem a result uncertain. They also may sometimes miss the mark. Impostors, on the other hand, radiate self-assurance, have never any doubts and provide results that are suspiciously close.

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Beware of pile-testing cowboys!