Pile integrity testing and analysis

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ABSTRACT: The methods of installation of drilled shafts give rise to concerns among engineers regarding the structural integrity of the shafts. This has led to a reluctance to use these foundations by some engineers. Alternatively, many engineers are willing to accept these foundations provided that adequate inspection and integrity verification testing are performed.

Low strain integrity testing has seen substantial improvement in recent years. The testing cost has been substantially reduced, and, as a result, the methods are now widely employed. However, the results of these tests also can be accurately evaluated. The evaluation may be a simple visual inspection of the site by an experienced engineer. Recent improvements in analysis capabilities now offer less subjective interpretation at a reasonable cost. These new automated procedures are superior to the visual techniques of the past both from the standpoint of operator required know-how and user confidence in results.

1 INTRODUCTION

Pile Integrity Testing (P.I.T.), a low strain method for integrity testing of driven piles and drilled shafts, uses a variety of techniques for the interpretation of force and velocity records taken under the impact of a light hammer blow (Rauhche, Shen, Likins 1991). In its most basic form, the input pulse signals are inspected directly in the time domain or reflections of which and hence are referred to as the "Static Pulse Echo Method." The interpretation of the pile top velocity traces is further enhanced by a multiplication which occurs exponentially in time (Figure 1). This concept became practical with the development of digital data processing.

The amount of field data enables analyses made possible the development of the frequency domain Non Disturbance Testing (NDT) methods generally applicable to existing concrete. NDT was then applied to low strain pile testing resulting in the "Pile Dynamic Response Method" which displays the records in the frequency domain is a so-called moduli plot.

Interpretations in frequency and/or time domain are selected either according to individual preference or locally developed practices. Generally, the engineer feels more comfortable in the time domain, particularly if they have not working with high strain Pulse Method testing. However, the Pile Dynamic Response Method offers advantages of all interpretation tools. This paper discusses various analysis methods applicable to a low strain test. It also compares the results obtained with different hammer and sensors.

2 EQUIPMENT

Three devices are needed to perform a low strain integrity test: the hammer, with or without force sensor, the sensor, and the processor (Figure 1). The primary difference between various interpretation methods lies in the programming of the processor. The hammer and sensors are, with slight exceptions, very similar for transient dynamic response and pulse echo methods.

2.1 The Hammer

Depending on the pile site to be tested, the hammer mass should be between 3 and 5 kg. Smaller hammers should limit and high frequency content, while larger hammers apply greater energies to the pile top. To

![Fig. 1 Schematic of low strain pile integrity testing](image-url)
be used. The test must measure only deflections near the strip, placing the test as near the surface as possible. Sharp, narrow input pulses are better suited for thin strip tests. Wide strips and thick strips have smaller harriers and are preferable. However, as the frequency increased, a small increase in a thin strip, a large increase in a thick strip, and a small increase in a wide strip, and an increase in the large strip, was observed. Inability to vary the size of harriers is not a problem, but determining sizes of large, medium, and small is necessary. The size of harriers can vary, as they are not limited to a specific range of sizes. While the larger harriers may be able to generate a better reflection, they are more difficult to control.

Fig. 2 shows velocity traces obtained under these harriers' sizes on a 0.002 mm diameter steel shaft of 5.1 mm length and with a diameter of 4 mm. The test consisted of cutting a line of arbitrarily chosen points on the shaft, followed by a test of the same points on the other shaft. The largest harrier did not impose the resolution of the pulse-to-pulse separation at medium-sized harriers. On the other hand, the largest harrier did not improve the resolution of the pulse-to-pulse signal, compared with the medium-sized harrier, which would be the obvious choice for improving the test. If the slowest-moving damage is in the shaft, the signal is affected by noise and may not be observed in the test. Therefore, the harriers' input surface must be calibrated with a sacrifice which is not sufficient to control but sufficiently hard to generate a short pulse duration. A good conditioning method makes the task of determining the signal-to-noise ratio easier.

The harriers may be insufficient to measure the applied force. The inclination of the harriers' slope, the pressure sensor, and the accelerometer. The pressure sensor will be measured between the harrier's mean and the impact surface, while the accelerometer is attached rigidly behind the mean. Typically, the mean stress is one thousand times greater than the harrier weight (for the light harriers the figures vary from such a modest peak value of 50 lb). Ideally, the frequency spectrum of the harmer force as a function of the accelerometer's signal and its harmonics is relatively flat and noisy (Figure 2). Such wide-scope spectrum generally results in better accuracy in the frequency range. The power spectrum in Figure 2 was improved by using a fast Fourier transform.

2.2 The motion mirror

A motion mirror is a device that accelerates or decelerates the input signal as the input frequency is increased. Although acceleration curves of the input signal, velocity, and acceleration are easier to interpret, this frequency response is generally integrated. Geophones directly produce a satisfactory signal. Accelerometers and geophones have different properties in their high and low frequency ranges. Accelerometers, for example, yield more accurate results at high frequencies. Geophones have a lower frequency range but do not require the calculation of an integral equation. Geophones are generally handled better than accelerometers and therefore present more difficulty in the measurement process.

2.3 Processes

The development of the processes has evolved as the analysis techniques have matured. The scale pulse was originally viewed only in the time domain on an analog oscilloscope. Most results were obtained using a personal computer (Bodine, McGleen, and Murphy 1980), and today all data collection is done on a computer system. Figure 2 shows the "P.T.L. Cutter" which indicates cutter and automated systems, noting the data for time necessary to correlate, perform calculations for data interpretation, and plot the processed data.

Fig. 4 shows the FFP (Feather Fletcher Frequent) analyzer and the filter frequency-domain analysis. For in-line mobility analysis, initially a spectral analyzer was used. However, modern approaches, such as the Fourier transforms (FFT) analyzer and the frequency-domain analysis, have been widely adopted.

|| Force | Amplitude |
|-------|----------|
|      |          |

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3 DATA MANIPULATIONS AND ANALYSIS

As discussed in the literature (Rees, O. L. 1995), the interpretation of the pit-yaw velocity or mobility can be considerably enhanced with the introduction of new transformation techniques. These transformations will be demonstrated using an example (Fig. 4) shaft recently prepared for the United States Federal Highway Administration at Texas A&M University.

3.1 Filtering

Probably all electronic measurements are filtered to remove unwanted frequency components. In fact, most electronic amplifiers have an inherent built-in frequency response filter. The most common filtering network is usually a network that allows low frequency components through while filtering the high-frequency components. The most common way in which this filtering is done is by a low-pass filter. Additional, more complex digital low-pass filtering is sometimes necessary when unwanted high-frequency components may make the interpretation of low-frequency signal impossible.

High-pass filtering removes low frequency components or, as a constant shift or a slow drift. Velocity signals derived from accelerometers records have been critically filtered (on an erratic low-frequency behavior which they yield through dynamic stiffness (see velocity calculations below)). While accelerometers are dynamic instruments whose signals easily drift towards zero, the average velocity (actually the average frequency component) is a system set to zero. This means that the displacement calculated from the velocity signal appears at the end of the record, nearly a reasonable assumption considering the low signal energy. However, removing of extraneous low-frequency components, as suggested by Pascual (1968) and de Jager (1985), may distort random signals as that seen in Fig. 6. This means that the displacement calculated from the velocity signal is always at the end of the record, unlike the measured displacement. Clearly, the calculated signals values that they have relative velocity. However, such a relative effect may be easily avoided by merely comparing force and velocity at the same time of impact.

3.2 Amplification

Below, the signals are in digital form, they are usually amplified by the circuitry and digitizing the same manner as that used in the digital recorder. However, a high-resolution analog-to-digital converter, such as the 16-bit A/D of the P.I.T. Collector, makes this task critical. The high-resolution analog-to-digital converter within the data logger has traveled the longest distance. As much as 1th part of the signal strength is reduced by transverse components or external (spatial) damping. Feedbacks or deviations are also recorded by those damping effects which are at deeper depths are therefore more difficult to detect. A gain of 1000 is sufficient to ensure all effects in the net can be recorded by the amplifier. Any frequencies above this gain are usually filtered. However, in general, all harmonics are not uniformly damped and therefore the beginning of the amplification should be delayed until the base wave from which it begins to increase exponentially. The technique is given in Figure 5a and 5b. It also calculates a constant signal level (that is an even and high signal damping of 5 decibels per unit) amplification of 100 psi load response was achieved (possible at time 2.6% but was steady increase after 26% amplification. The results showed a 3-4 m with with much strength and then increased exponentially and as indicated below Figure 5b.

3.3 Force, time and mobility

former transformation of pit-yaw velocity and force versus time signals leads to the corresponding velocity force spectra. Dividing the velocity spectrum by the frequency space power (Fig. 7).

Fig. 4 P.I.T. Collector

Fig. 5 (A) Amplifier and (B) amplified velocity time record evaluated for 8 psi pulse. Velocity spectra are frequency shown in (C) and (D).
3.4 Velocity reflections

The recorded velocity reflections are obtained when the velocity transducers are subjected to an FFT. Of course, their "reflectors" have the dimension of velocity and are thus again a function of length (or time) like the original signal. Choosing only the positive value of the FFT, the location of the pulse in time (hence beams time gain) also shaft deflections can then frequently be located.

3.5 The Beta method

To assess the relative change of a cross section from an observed ground wave arrived in the pile top velocity record, the Beta value can be calculated based on simple wave mechanics. This measure is the ratio between upper pile importance or cross section (Rausch, Cable 1979) and is easily calculated from the relative magnitude of the reflection to the incident wave.  

\[
\beta = \frac{S_{\text{reflect}}}{S_{\text{incident}}} 
\]  

(1)

Soil resistance effects have not been included in this equation since it is assumed that they have been accounted for by exponential simplifications. Since it also assumes that the length of cross sectional change is greater than the pile length, the method may undervalue the severity of a short cross section change.

3.6 Impedance profile

This method is based on a simple algorithm which yields a pile shape as a function of depth (Davis, Horton 1981). Rather than relying on the relative peak value of a reflector wave as in the Beta method, the impedance profile is directly calculated as the integral of the enhanced reflected pulse-calculation in the impact pulse. Soil resistance effects must be properly considered before the impedance profile can be calculated. In complete cases, misinterpretation may occur if the necessary results adjustments and integration are performed completely automatically.

3.7 FTWAP

This wave equation analysis program uses either the measured force or an assumed force (approximated to the velocity during the early impact event) as an input at the pile head. The program will be considers this and a model is usually assumed based on results obtained on other "reference" piles. FTWAP then calculates the entire pile top velocity which is then compared with the measured one. If these two values do not agree, the pile model is adjusted and the analysis repeated until a good match is achieved.

This program is similar to CAPWAP where the pile geometry is assumed to be known and the soil parameters are calculated. Actually, the soil resistance effects are never definitely known and for that reason engineering judgments may very effectively affect the results. On the other hand, FTWAP computes a pile shape relatively quickly (and accurately enough for any chosen set model). Therefore the effect of soil model variation on calculated pile shape can be very easily investigated that observing the engineer to assess the (structural) condition of a shaft.

EXAMPLE

The methods described above have been used to evaluate the records obtained on a (special) test shaft of tapered shape containing a cross section. Figure 7 shows the velocity and force diagrams with the length, the FTWAP and the CAPWAP impedance profiles which closely match the design shape (these results are in terms of cross sectional area).
Figure 2 shows the results used in the frequency domain. The length and the polar moment are clearly outlined in the mobility graph. The high-pass filtering and smoothing of the data, the low-frequency dynamic stiffness, are calculated to be 800 kN/m (the minimum of the scale, considering a broad area, was 986 kN/m).

Summary and Conclusions

This paper presents a summary of required equipment and available instrumentation methods for low-strain testing. The following conclusions are appropriate:

1. Some pulse echo and transient dynamic methods are closely related. The pulse-echo method does not require a transceiver hammer, however, it is easy to make this additional measurement. The signal is too short used to calculate results in either the base or frequency domain.

2. Potential data collection techniques are available for time-domain analysis to aid locating and correlate the type of disturbance that affected the pile length.

3. For mobility calculations, a "fixed" hammer must be used.

4. The value of the dynamic method calculated from the relationship between velocity and force proves to be frequency in the base-impedance and highly dependent on the filtering technique used.

5. Various methods are available for the calculation of the pile impedance profile. Exact cases, theoretical and reasonably accurate results can be obtained. For complex cases with more than one major impedance variation (increase or decrease), these methods become less reliable.

References


