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DYNAMIC MEASUREMENT TECHNIQUES FOR PILE CAPACITY PREDICTION

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ABSTRACT

Pile Capacity prediction by the Stress-wave matching technique uses measured pile top velocity-or force-time signal as an input boundary condition. Reliable estimation of the pile capacity largely depends on availability of accurate and quality dynamic measurements of pile. This paper discusses some dynamic measurements obtained from two instrumented precast concrete piles. Various aspects of measurement techniques and their shortcomings are also highlighted.

Keywords: Pile Capacity, Dynamic measurement, Accelerometer, Strain gauge.

INTRODUCTION

Pile capacity prediction from dynamic measurements of pile during testing has been available for 20 years. Currently, almost all the available commercial software/instruments for estimating pile capacity use Stress-wave matching techniques, where either measured force or velocity-time trace at the pile top is used as a boundary condition, thereafter using wave equation model, a reasonable match is sought for computed and measured signal with due adjustment of soil parameters used in the model. Another widely used method called 'Case Method' [4] to estimate the mobilized static bearing capacity of pile, also uses the force and velocity measurements at the pile top. So it is obvious that quality measurements are the source of reliable estimation of pile capacity. Because of the dynamic nature of the quantities to be measured, a great deal of understanding and attention to be measured, a great deal of understanding and attention to be paid on selection of measurement units, frequency range of the measurements etc. Mainly two large classes of measurements are needed to interpret pile dynamics. Measurements involving (1) Strain, Stress, Pressure or Force and (2) Acceleration, Velocity or Displacement. Most of the cases interpretations are made on the basis of velocity and strain records at the pile top.

DYNAMIC MEASUREMENTS

Measurement system consists of two pairs of sensors attached to the opposite sides of the test pile, at the same distance from the pile top. Each pair is composed of strain transducers and accelerometers. For each hammer blow, measured strain is converted to force using cross sectional area and the dynamic modulus of elasticity, accelerometer signals are integrated with respect to time to get the velocity of pile at the measuring location.

Because of the transient nature and high frequency content of the pile impact, piezoelectric accelerometers are most often used. Piezoelectric accelerometers are extremely linear transducers and produce a wide range of transients without problem. For satisfactory results accelerometers should have resonant frequency above 7500 Hz and be linear to at least 1000g and 5000g for concrete and steel respectively [1].

Strain gauge is an extremely sensitive device with an electrical resistance that varies in direct proportion to changes in strain. Strain gauges bonded directly to the pile wall, compared to bolt-on and welded transducers, work well in dynamic measurements provided they are attached in ideal laboratory conditions and well protected. Strain gauges glued to the pile wall are virtually massless and therefore immune to inertia effects[3].

Signals from transducers need to be amplified to obtain a desired overall system sensitivity. Low and high frequency filtering is needed to eliminate unwanted signals, when recorded electronically in either analog or digital form, frequency components of signals should have a low pass cut-off frequency of 1500 Hz (-3 dB) [1]. When converting analog signal to a numerical value the sampling frequency should be 20 kHz for each channel of measurement [2].

Before converting, signal generated by transducers can be captured by digital storage transient recorders or can be displayed on an Oscilloscope. But it is convenient to use computer which drives A/D conversion boards. The continuous analogue input signals can be converted to a stream of discrete digital value to make them suitable for computer storage. Later, these data can be downloaded for displaying or further processing such as reducing, averaging etc.

TEST DETAILS

Each pile was 6m long and 100mm square section precast concrete pile and was instrumented with one pair of resistance wire strain gauges (TML, type PL-60-11) glued to the pile wall and one pair of piezoelectric accelerometers mounted on tufnol block also glued to the pile. Since piles were of precast concrete, gauge of sufficient length (60 mm) was used to span several pieces of aggregate in order to measure the representative strain in the pile.

Three types of piezoelectric accelerometer, each having different natural frequencies, were used. Details of the accelerometers used, is given in Table 1. Transducers were placed diametrically opposed and on equal radial distances, 0.3 meter from the top of the pile. Signals from strain gauges and accelerometers were amplified to equivalent volts, frequency component of the signals were filtered with low pass cut-off frequency set to 2.5 kHz and 3 kHz for strain gauge and accelerometer signal respectively, before acquisition accelerometer signals were integrated to velocity using integration network inside the charge amplifier.

Signals were captured through A/D converter in four channels, 1000 samples in each channel, with sampling frequency of 20 kHz. Acquisition module (for A/D conversion) has facility of analog conversion in 8-channel, 12-bit linear with maximum 89 kHz A/D conversion rate in each channel. Real time signal acquisition, frequency analysis of signals, digital triggering, monitor display, signal processing etc. were performed through a Digital Signal Processing software (DSP) Hypersignal-workstation.

Table 1 : Details of accelerometers

Accelerometer	**Type**	**Wt gm**	**Charge Sensitivity**	**Frequency Range kHz**
Bruel & Kjaer	4381	43	10±2%	4.8
Environmental Equipment	DQ 20	23	2.75	7.0
Bruel & Kjaer	4375	2.4	0.32±2%	16.5

RESULTS

Typical pile top force-time and velocity-time (multiplied by impedance) measurement is show in Figure 1.

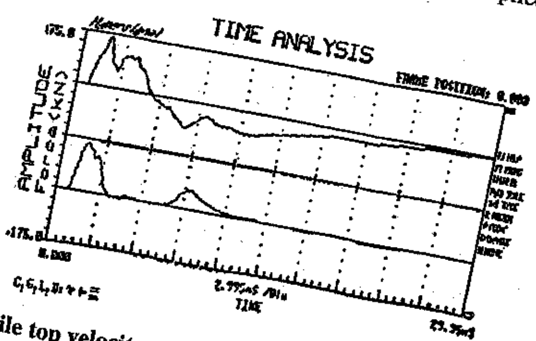

Figure 1 : Pile top velocity (multiplied by impedance, top) and Force (bottom) trace.

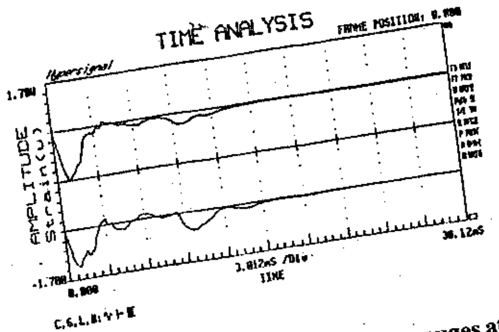

Figure 2 : Strain trace, in volts, for two strain gauges at the same section of pile, placed on oppsite sides.

Figure 2 presents the records obtained from the strain gauges bonded on opposite sides but at the same section of pile, difference in magnitude indicates the presence of bending effect due to eccentric hammer impact at pile top. Initial measurements of velocity were taken by using Bruel & Kjaer (B & K) accelerometer type 4381 having natural frequency of 4.8 kHz, produced distorted signal for drop heights higher than 0.5m. Figure 3 shows one of the such distorted signals. This could be because the accelerometer used was out of the pile's frequency range.

This accelerometer is then replaced by another accelerometer from Environmental Equipment Ltd. (EE) type DQ20 having a frequency of 7.0 kHz, which showed better performance. To check the quality performance of the latter, another Bruel & Kjaer (B&K) accelerometer type 4375 having a natural frequency of 16.5 kHz, which is well above the frequency that the pile usually produces during impact. The latter two accelerometers were used at the same time for the same blows, results produced identical velocity trace which is shown in Figure 4.

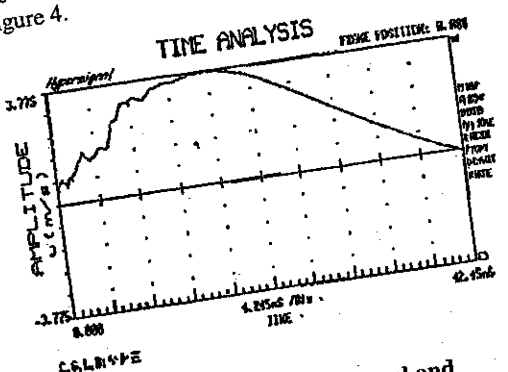

Figure 3 : Velocity signals generated by Bruel and Kjaer accelerometer type 4381.

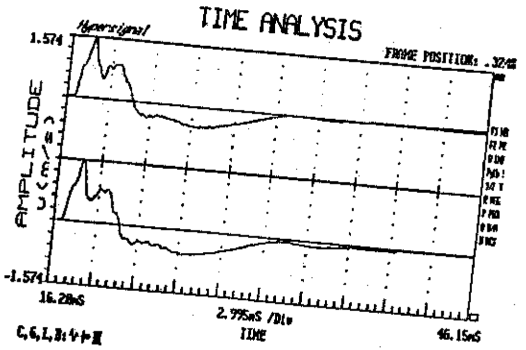

Figure 4 : Velocity trace for accelerometers B&K type 4375 (bottom) and EE type DQ20 (top).

Displacement trace obtained by double integration of the accelerometer signals produced unrealistic displacement for both peak and permanent set. One of the traces is shown in Figure 5. The low frequency content of the transient signal might have excited the peak of the filter and cause a the integration network to 'ring' and distort the measurement, which is common for using integration network for integrating transient signals. Peak dynamic displacement in Figure 5 shows value near 6.5 mm whereas actual peak displacement was 10mm.

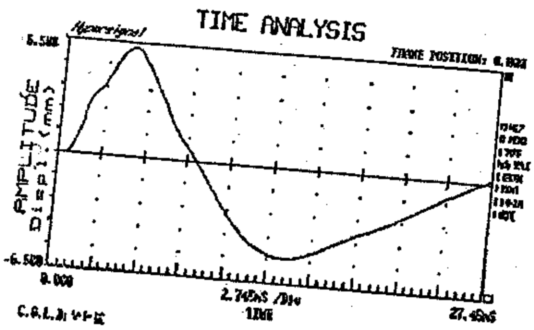

Figure 5 : Displacement trace obtained by double integration of acceleration signals.

A spectral analysis of Figure 1 is given in Figure 6 confirming the major frequency components are in the region of 1 kHz. It also indicates a band width of about 1 kHz for both strain gauge and accelerometer signals.

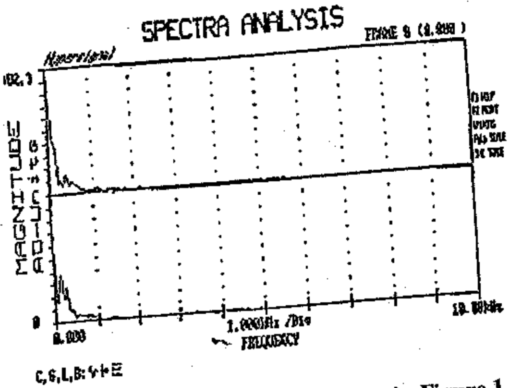

Figure 6 : Spectral analysis for signals shown in Figure 1.

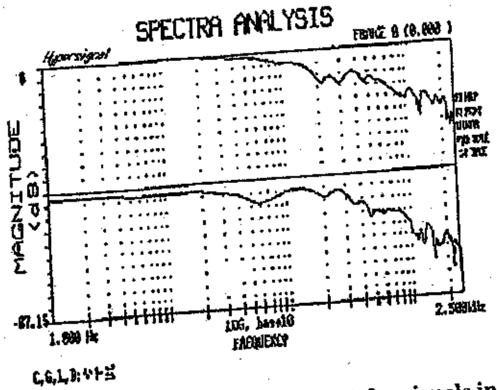

Figure 7 : Spectral analysis (Log-Log plot) for signals in Figure 1.

Spectral analysis for same signals plotted in Log-Log scale is given in Figure 7 shows force and velocity having equal frequency response curves.

DISCUSSIONS

Dynamic measurement techniques of piles are discussed here in the light of some dynamically tested instrumented precast piles. Proper selection of transducer is very important for reliable data. It is especially important that accelerometers, for measuring pile velocity should be of high natural frequency.

Analysis of raw data in frequency domain could reveal many important information of the nature of signals, e.g. bandwith of frequency components and, the region of dominance of frequency components. It is practically difficult to calculate displacement from double integration of acceleration signals. Electronic theodolite or optical displacement system can be used to adjust the measurement obtained from integration of signals.

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