CAPABILITIES OF PILE INTEGRITY TESTING

PDA USERS DAY 1989
CLEVELAND, OHIO

by

C. Michael Morgano

CAPABILITIES OF PILE INTEGRITY TESTING

INTRODUCTION

In deep foundations, loads are supported by either a driven pile or one which is cast in place such as a drilled shaft or augered cast pile.

During installation, driven piles may be damaged or broken as a result of high driving stresses (tension or compression). Cast in place piles may have non uniformities such as necking, voids, inclusions etc. After installation, both driven or cast in place piles may also be damaged by large horizontal movements due to impacts, construction equipment, retaining wall failures, etc.

Since it is not practical and more important not economical in most projects to test every pile for its capacity (statically and/or dynamically), a nondestructive method, referred to as Pile Integrity Testing (P.I.T.), was developed to check the "integrity" of a shaft. Although integrity testing has been very successful in a great number of projects, it may have some limitations when testing piles with greatly varying cross section.

Piles with greatly varying cross section may make it difficult to distinguish between reflections from significant discontinuities and those from construction methods. And since internal pile damping and high skin friction tend to "dampen" out the impact. The pile length and more important pile embedment may limit the ability to obtain significant refections.

Piles with potentially variable cross section include drilled shafts and augered cast piles. However, integrity testing on these type piles have been performed often and in most cases, good results have been obtained. The intent of this paper is to present some results obtained from tests on these type of piles.

INSTRUMENTATION

In recent years, advancements in hardware and software have made the testing procedure faster and easier. Integrity testing is performed by affixing a sensitive accelerometer to the pile top and then striking the pile with a hand held hammer. Since the hammer impact causes a low strain wave to travel down the pile, the term "low" strain integrity testing was adopted.

The testing can be performed either by using a portable personal computer or with the Pile Driving Analyzer, "PDA". Other hardware include a accelerometer power supply and amplifier (signal conditioning). The records may be viewed on the computer monitor or an oscilloscope if using the PDA. A permanent copy of the results may be output to either a plotter or a line printer with graphics capabilities.

PROGRAM DETAILS

The acceleration record created from each hammer impact is interated to velocity and displayed on the PC monitor or oscilloscope. The velocity records (or acceleration records) may then be investigated for any refections from increases or decreases of impedance from points below the pile top. Impedance is defined as EA/C where E and A are the material elastic modulus and cross sectional area, respectively, and C is the stress wave speed. Thus, changes in impedance may indicate either proportional changes of cross sectional area or concrete quality.

An analysis option which is incorporated in the P.I.T. program is an exponential amplification routine. This option is used to amplify wave reflections which are weak due to pile and/or soil damping. In certain cases the reflections from the pile toe or discontinuities become evident only after such an amplification is applied.

Another analysis option allows the user to average any number of records. This technique is useful in separating effects of random mechanical and electronic noise pulses from relevant reflections such as pile discontinuities or the pile toe.

DISCUSSION

The following figures show some data obtained from four different projects which utilized cast-in-place piles. These data sets will be referred to as cases 1 through 4. For each case, a brief description of pile and the soil will be given, if available, followed by some notes on the piles "integrity" evaluation.

The averaged (amplified) velocity and acceleration records are shown in each figure. Note that the number of averaged blows is written in the header. They were plotted over a length scale although they are really functions of time. The time to length conversion was achieved by multiplication with the pile's wave speed.

Case 1

The piles tested were 16 inch diameter auger cast piles with a design length of 30 ft. However, due to construction methods, the actual lengths were most likely somewhat longer. The soil conditions could be generally described as variable which included fill, silts, loose to firm sands and soft to stiff clays. Traces of organics were also encountered.

Figures 1, 2 and 3 contain a total of ten records (averaged, amplified velocity and acceleration) for ten different piles. The four records in Figure 1 all show a reflection from the pile toe at a depth of 30 to 34 ft. below the pile top. Note that non of the records contain a strong positive (decrease in impedance) reflection prior to the pile toe meaning that all four piles are structurally sound. Other aspects of the piles integrity include the following:

Figure 1a: Uniform pile

1b: Slight necking and then crossectional increase at 7 ft; larger cross section likely beginning at 10 ft.

1c: Soft soil at 10 ft or possibly a slight gradual decrease in impedance from 10 to 22 ft.

1d: Small outgrowth at 18 ft.

All the records in Figure 2, except 2d, contain a reflection from the pile toe. Figure 2d does not contain a toe reflection. These four piles contain some degree of non uniformity in terms of an impedance decrease. Notes concerning the integrity of these piles are as follows:

Figure 2a: Slight impedance decrease at 7 ft; however pile is continues.

2b: A more significant impedance decrease is evident at 10 ft. Pile is also continues.

2c: Slight impedance decrease at approximately 6 ft. This observation is made since a change of slope is indicated following the peak input. However, the pile is also continues since the toe reflection is present.

2d: A large decrease in impedance at 4 ft. Pile is severely damaged and most likely broken since the toe reflection is not present.

The two records in Figure 3 show a pile with no major discontinuities (3a) and one pile broken at approximately 5 ft below the pile top (3b). Note once again the toe reflection is present for the sound pile and not for the broken pile. Also note that the output of these two records was from a graphics printer rather than a pen plotter.

Case 2

The records in this case are from so-called bored piles. These piles were 3 and 4 ft in diameter with reported lengths of 55 ft. Borings made in the vicinity of the test site showed primarily sand both above and below a layer of organic silt which was encountered 15 to 20 ft. below grade.

It is noted that these particular piles were also dynamically tested for capacity evaluation. These "high" strain tests were accomplished with the use of a PDA. A drop hammer, constructed of 4 steel prisms and weighing 32 kips, was used to deliver the impact.

Unfortunately, a nylon-tipped hammer was not available for the integrity tests and probably for that reason the records contained some high frequency vibrations. Another potential reason for the high frequency record components may be from a thin layer of mortar which was placed on top of the piles and which may have been slightly separated from sound concrete.

The records shown in Figures 4 and 5 represent those piles which were tested after the high strain tests. The records in Figure 6 are from a pile which was tested both before and after the high strain test. The records indicate the following:

Figure 4a: This pile survived the high strain test with, at most, some slight cracking. A clear toe signal indicates that the pile is basically sound.

4b: This pile apparently has several cracks which did not allow the wave to penetrate to the pile toe. The pile top mortar also may have caused difficulties.

Figure 5: This pile was of particular interest since during testing site personnel had given this pile a length of 55 ft. Based on the low strain records, the on-site diagnosis stated that a major crack was found at 42 ft. Later it was determined that the pile had been manufactured with a length of only 45 ft. Record inspection now showed that a decrease in impedance is likely at 42 ft with the toe producing a second strong velocity increase at 45 ft. The pile is practically sound since it did produce a toe signal.

Figure 6a: Before the high strain test, this pile showed a clear reflection from the pile toe at 60 ft. High frequency vibrations or some minor variations in cross section also possible.

6b: After the high strain test, the records did not show a clear toe reflection and instead showed several reflections from cracks. High strain testing also indicated that the pile cracked very early, *i.e.*, already after the first high strain blow.

Case 3

The records shown in this case are of a 16 inch diameter auger cast concrete pile with a reported length of 46 ft. The subsurface conditions may be generally described as sandy soils with cobbles.

As a rule of thumb, a toe reflection is usually seen for piles with lengths up to 30 pile diameters. For a 16 inch pile, this length would correspond to 40 ft. Therefore, one would expect difficulties in obtaining a toe reflection of a 46 ft. pile. Indeed, as can be seen in Figure 7a, a toe reflection is not evident.

However, further inspection, while making use of the exponential magnification routine, revealed that a reflection from the pile toe is indeed present. Figures 7b, 8a and 8b show a series of the identical record as shown in Figure 7a, except with different magnifications.

Note that magnifications values greater than 10 are necessary to see the toe reflection. At a magnification of 70, the reflection is very clear.

Case 4

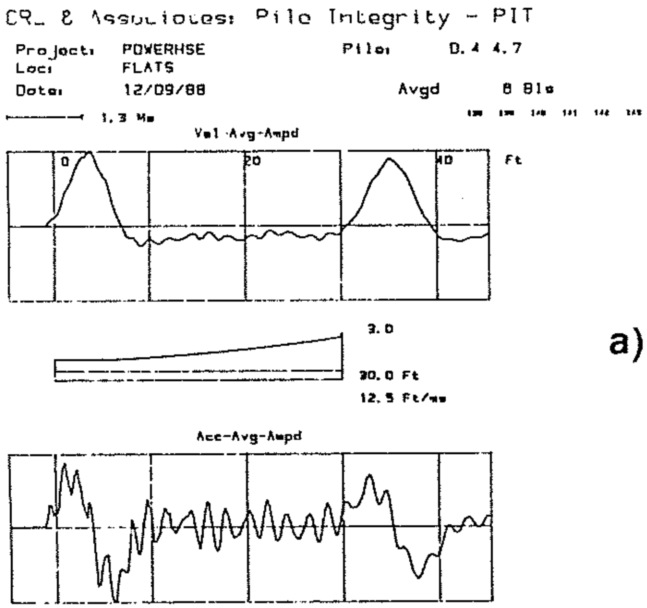
The velocity record shown in Figure 9 is for a 42 inch diameter drilled shaft with a reported length of 18 ft. As can be seen from the picture, four relatively large dowel rods were cast into the pile top. It was also reported that the pile contained some horizontal bars near the top of the pile. During the integrity testing the pile had been embedded almost completely. No information is available about the soils at this site.

The velocity record showed a strong toe reflection which means that it is, at least, continuous. A slight impedance decrease was noted at approximately 8 ft. The high frequency input (impact) was attributed to the high steel content near the pile top.

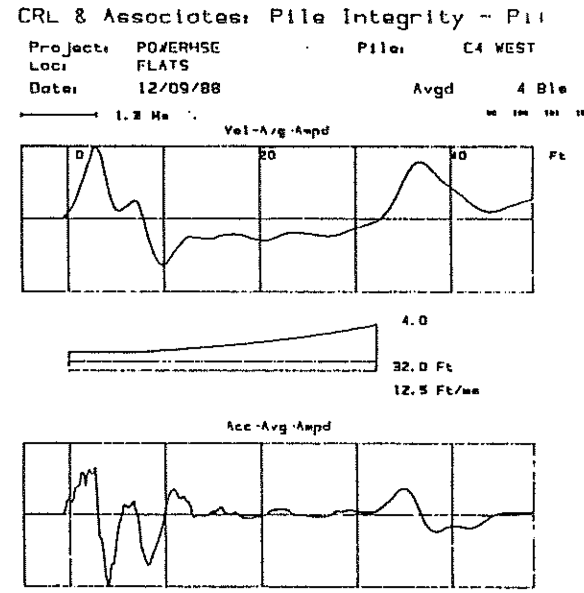
Later, the upper portion of the shaft was exposed. Inspection showed that indeed, there was a significant decrease in cross sectional area at approximately 9 ft. (reinforcement was exposed). More interesting, however, was the profile near the pile top. As shown in the picture, there are many significant cross sectional area changes within the top 5 ft. The high frequency impact, which was initially attributed to reflections from the high steel content, was after all, showing reflections from these cross sectional area changes.

CONCLUSION

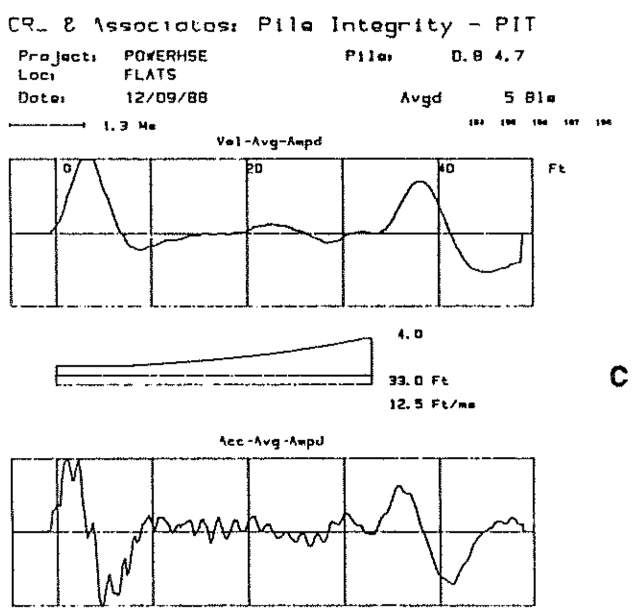
It has been shown that integrity testing can be a powerful tool in the deep foundation industry. Four cases were presented and discussed. Though the method has some limitations, the results have, in the past, been very good.



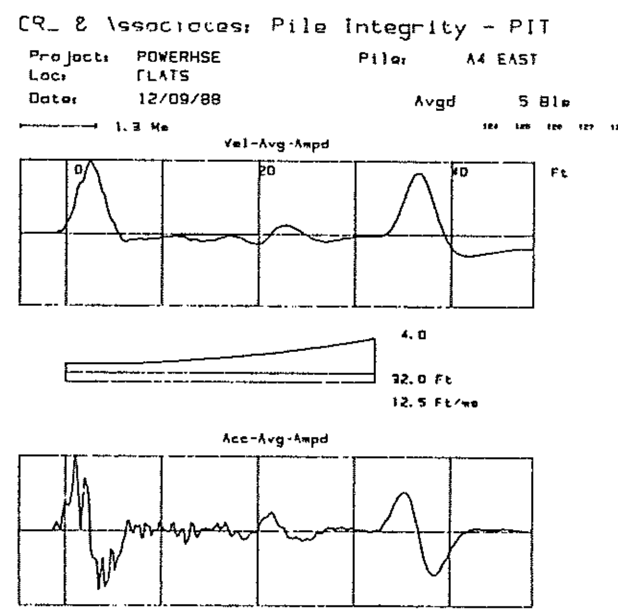
a)



b)



c)



d)

Figure 1

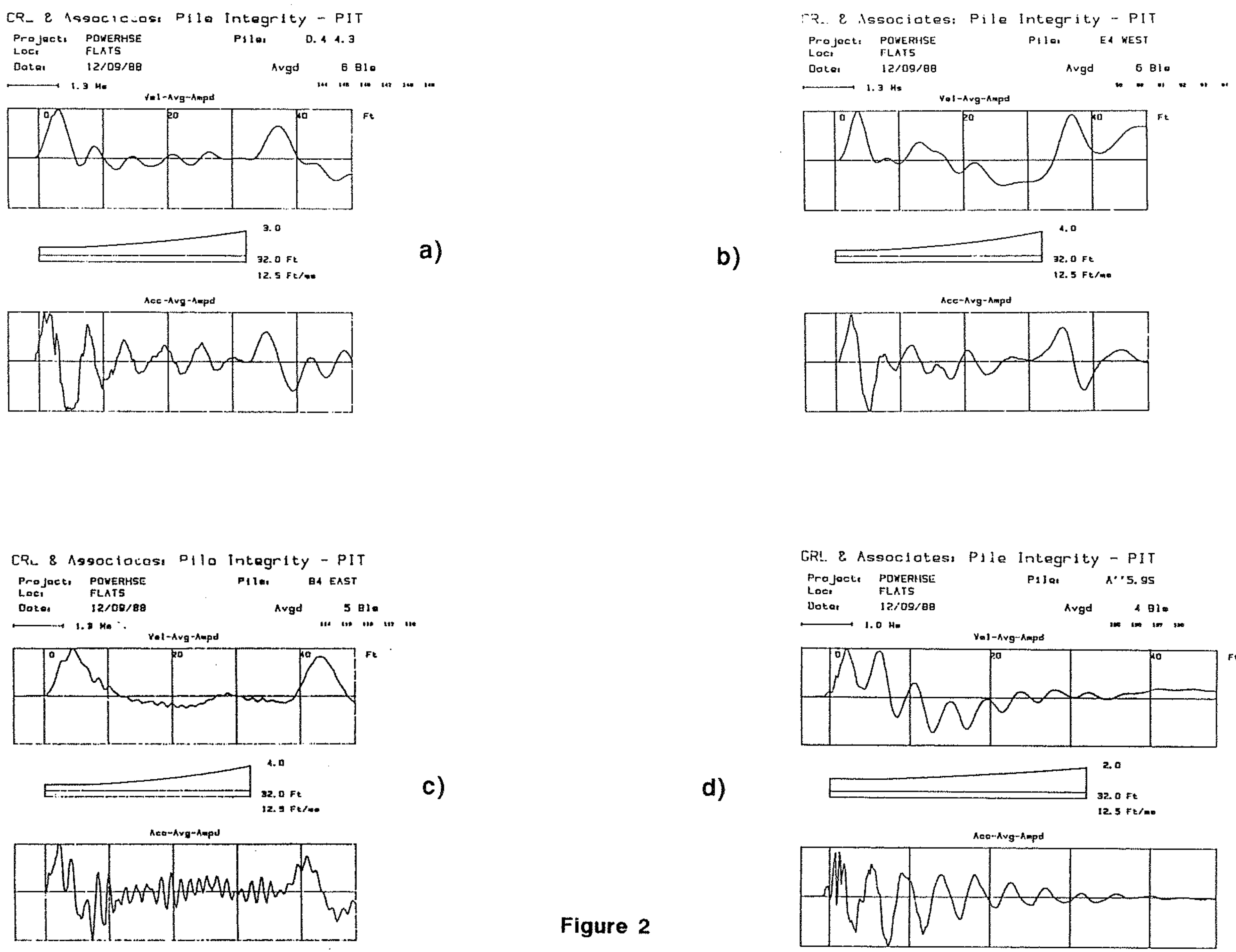
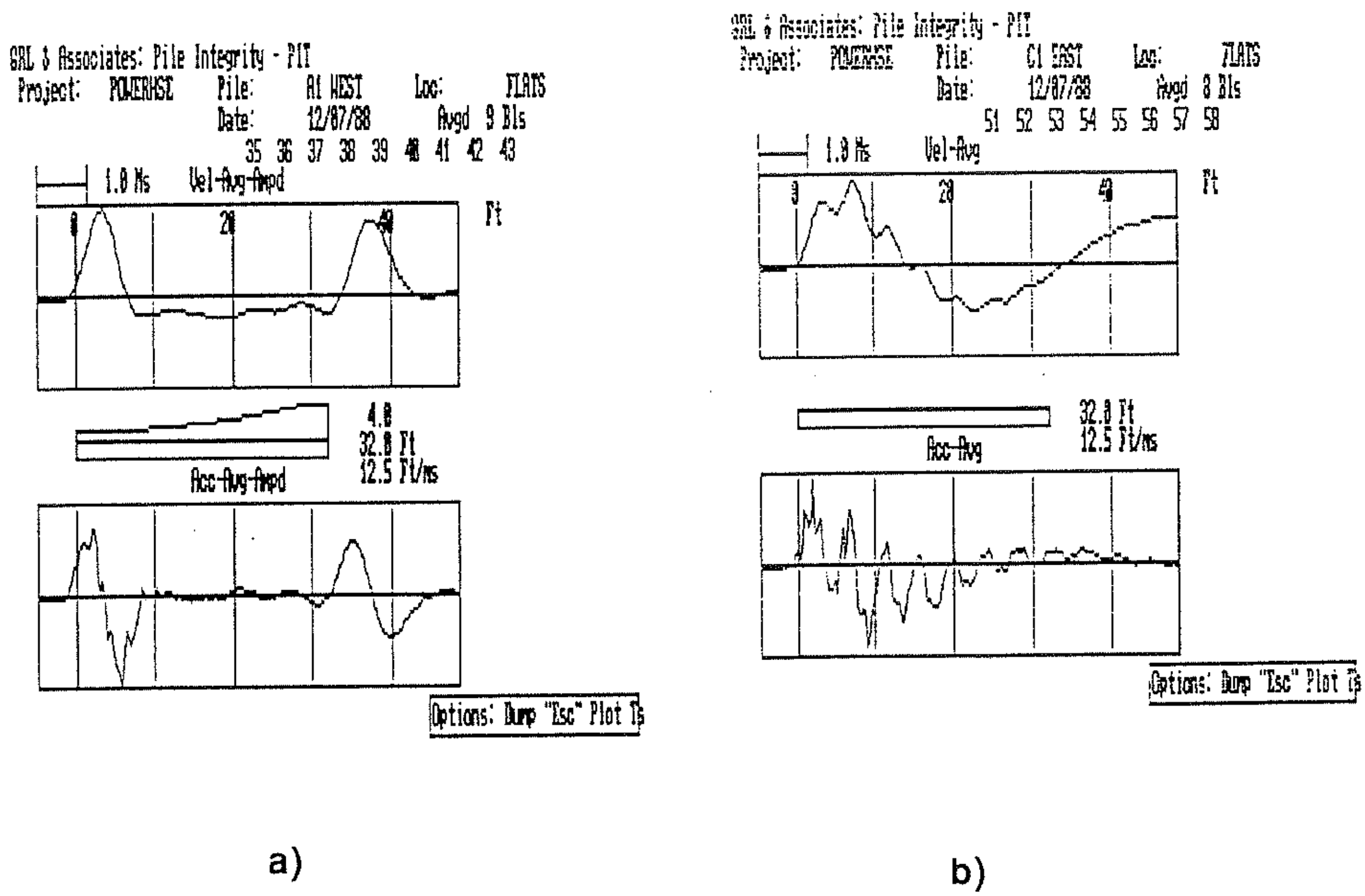
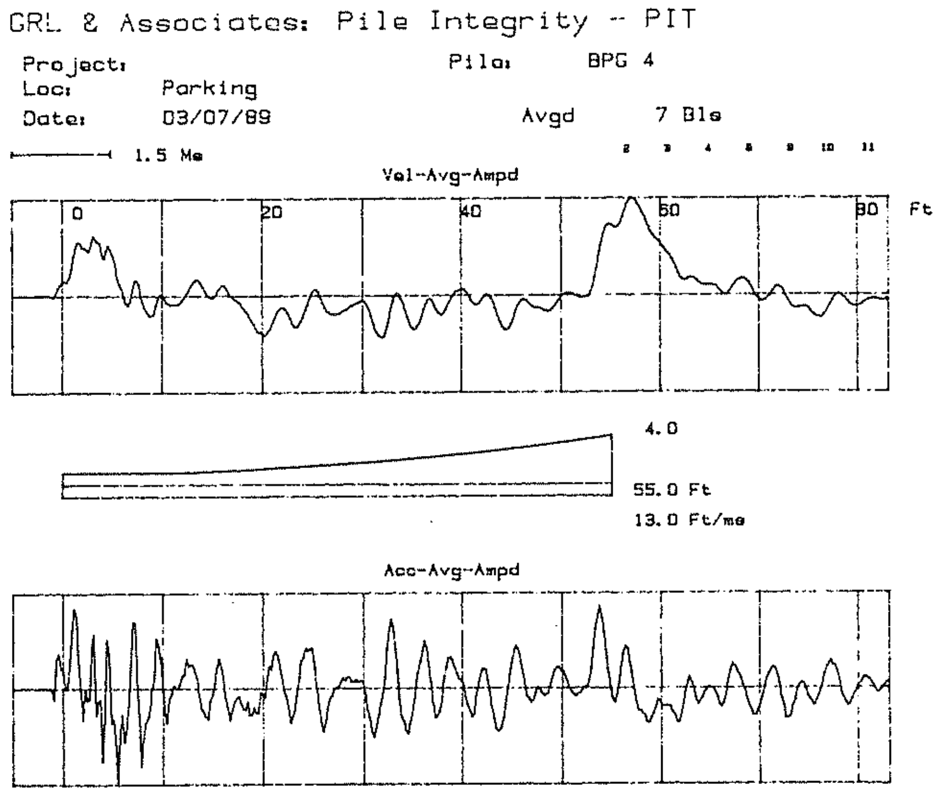

CR_ & Associcoos: Pile Integrity - PIT
Project: POWERHSE
Loc: FLATS
Date: 12/09/88
Pile: D.4 4.3
Avgd 6 Blo
1.3 Ms
Vel-Avg-Ampd
0
20
40
Ft
3.0
32.0 Ft
12.5 Ft/ms
Acc-Avg-Ampd
a)
CR. & Associates: Pile Integrity - PIT
Project: POWERHSE
Loc: FLATS
Date: 12/09/88
Pile: E4 WEST
Avgd 6 Blo
1.3 Ms
Vel-Avg-Ampd
0
20
40
Ft
4.0
32.0 Ft
12.5 Ft/ms
Acc-Avg-Ampd
b)
CR_ & Associocos: Pilo Integrity - PIT
Project: POWERHSE
Loc: FLATS
Date: 12/09/88
Pile: B4 EAST
Avgd 5 Blo
1.3 Ms
Vel-Avg-Ampd
0
20
40
Ft
4.0
32.0 Ft
12.5 Ft/ms
Acc-Avg-Ampd
c)
GRL & Associates: Pile Integrity - PIT
Project: POWERHSE
Loc: FLATS
Date: 12/09/88
Pile: A''5.9S
Avgd 4 Blo
1.0 Ms
Vel-Avg-Ampd
0
20
40
Ft
2.0
32.0 Ft
12.5 Ft/ms
Acc-Avg-Ampd
d)

Figure 2

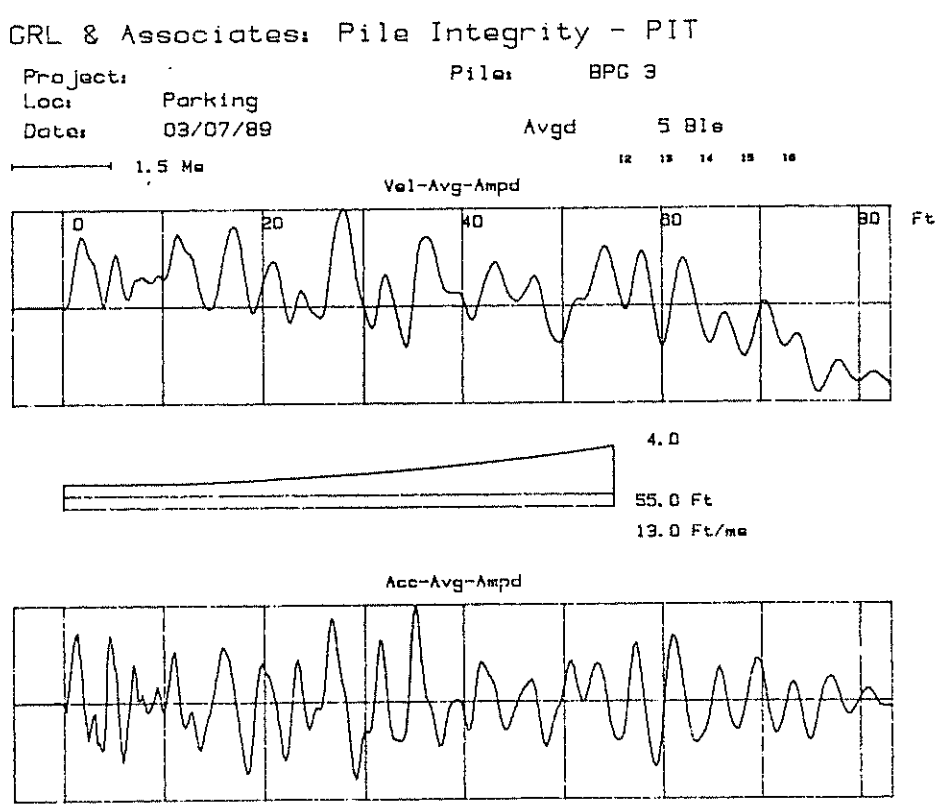


SRL & Associates: Pile Integrity - PIT
Project: POWERHSE Pile: A1 WEST Loc: FLATS
Date: 12/07/88 Avgd 9 Bls
35 36 37 38 39 40 41 42 43
1.0 Ms Vel-Avg-Ampd
0 20 40 Ft
4.0
32.8 Ft
12.5 Ft/ms
Acc-Avg-Ampd
Options: Dump "Esc" Plot Ts
a)
SRL & Associates: Pile Integrity - PIT
Project: POWERHSE Pile: C1 EAST Loc: FLATS
Date: 12/07/88 Avgd 8 Bls
51 52 53 54 55 56 57 58
1.0 Ms Vel-Avg
0 20 40 Ft
32.8 Ft
12.5 Ft/ms
Acc-Avg
Options: Dump "Esc" Plot Ts
b)

Figure 3


GRL & Associates: Pile Integrity - PIT
Project:
Loc: Parking
Date: 03/07/89
Pile: BPG 4
Avgd 7 Bls
1.5 Ms
Vel-Avg-Ampd
0
20
40
60
80
Ft
4.0
55.0 Ft
13.0 Ft/ms
Acc-Avg-Ampd

a)


GRL & Associates: Pile Integrity - PIT
Project:
Loc: Parking
Date: 03/07/89
Pile: BPG 3
Avgd 5 Bls
1.5 Ms
Vel-Avg-Ampd
0
20
40
60
80
Ft
4.0
55.0 Ft
13.0 Ft/ms
Acc-Avg-Ampd

b)

Figure 4

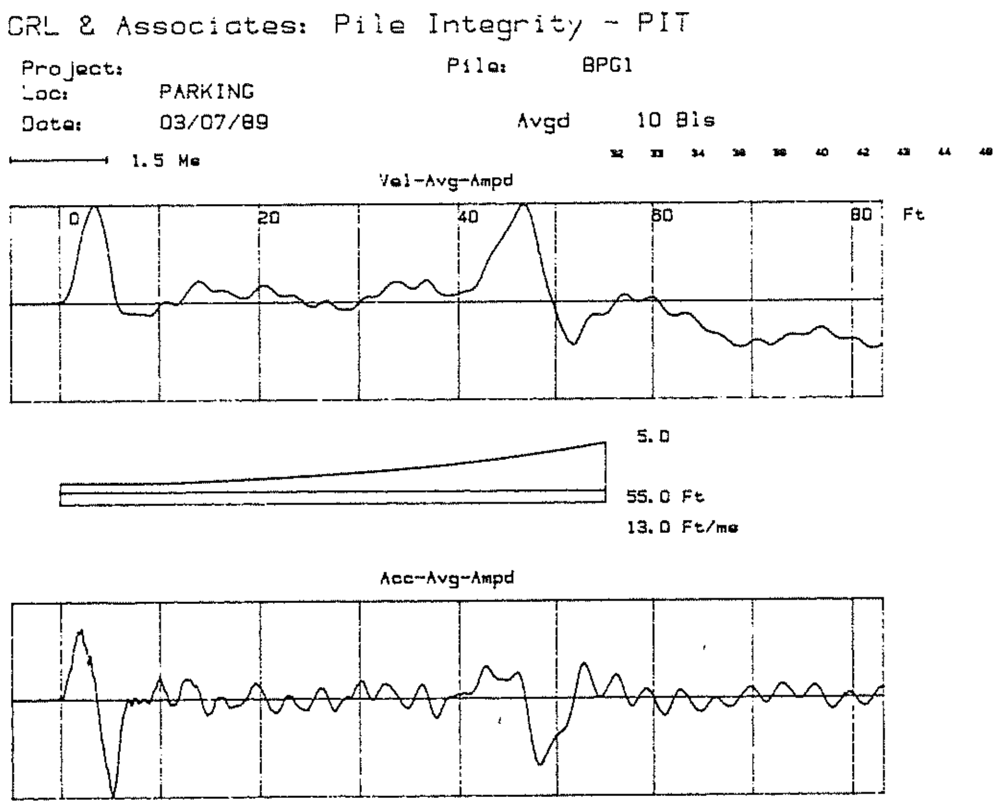
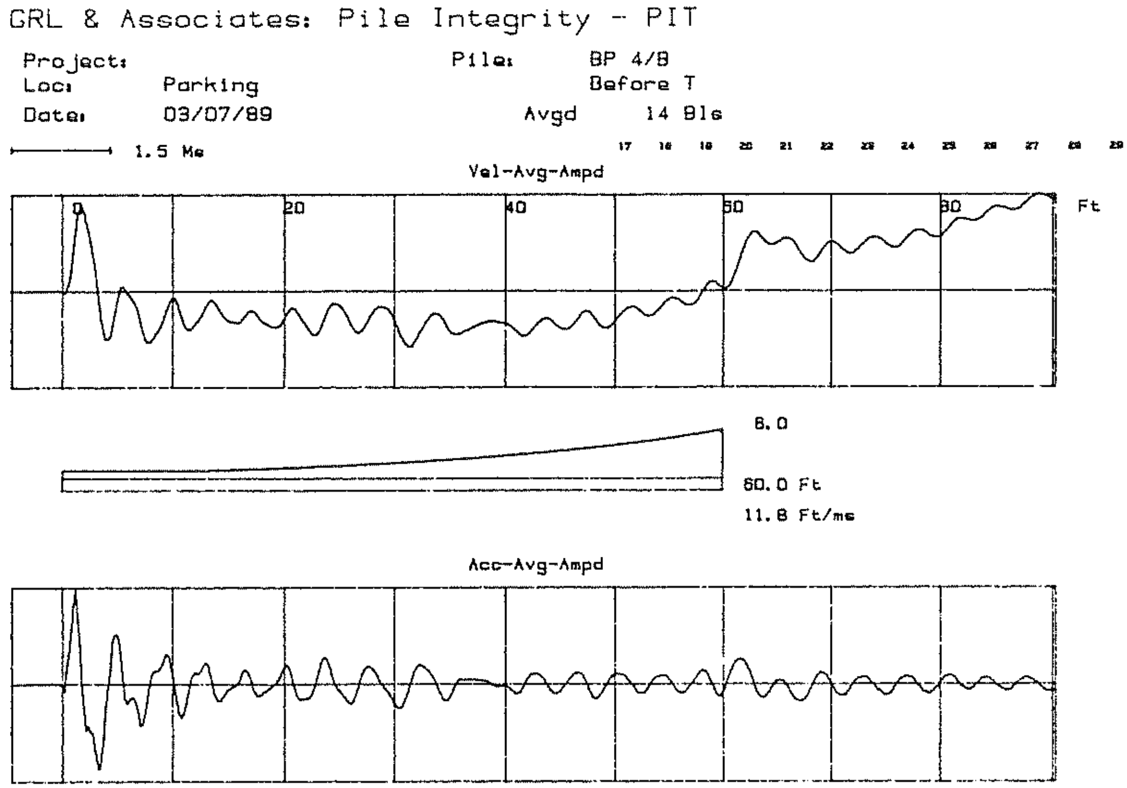
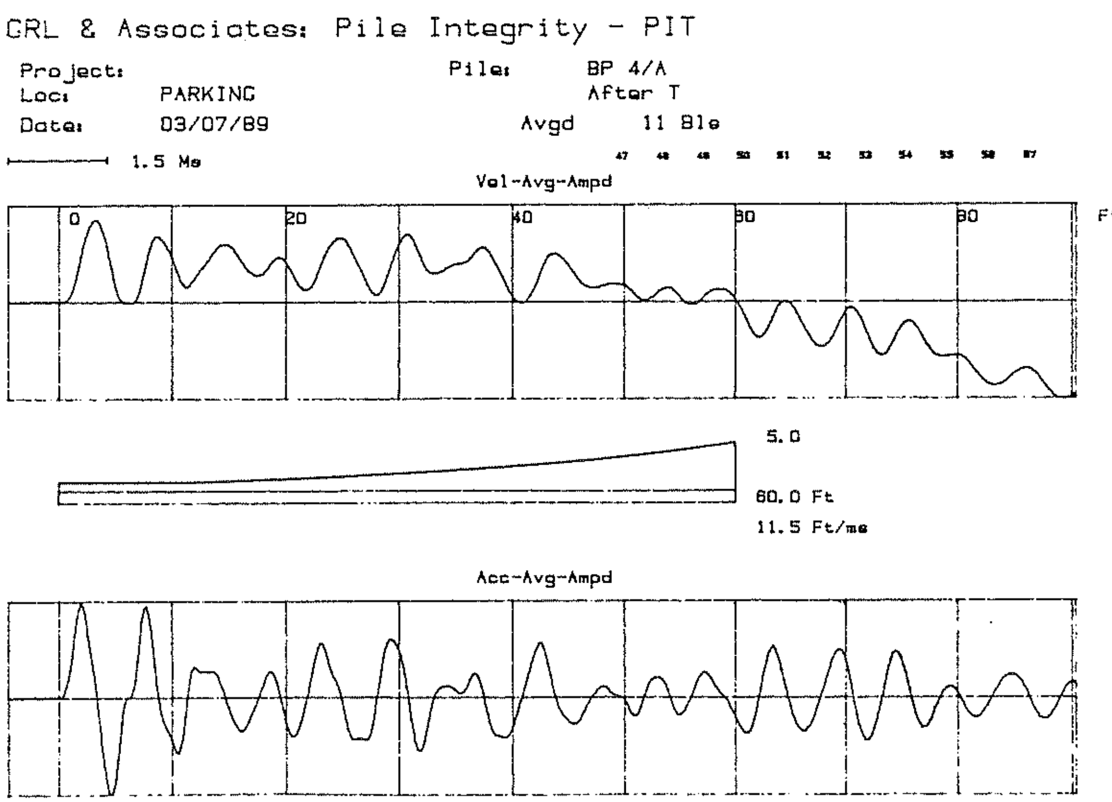

GRL & Associates: Pile Integrity - PIT
Project:
Pile: BPG1
Loc: PARKING
Date: 03/07/89
Avgd 10 Bls
1.5 Ms
Vel-Avg-Ampd
0
20
40
60
80
Ft
5.0
55.0 Ft
13.0 Ft/ms
Acc-Avg-Ampd

Figure 5

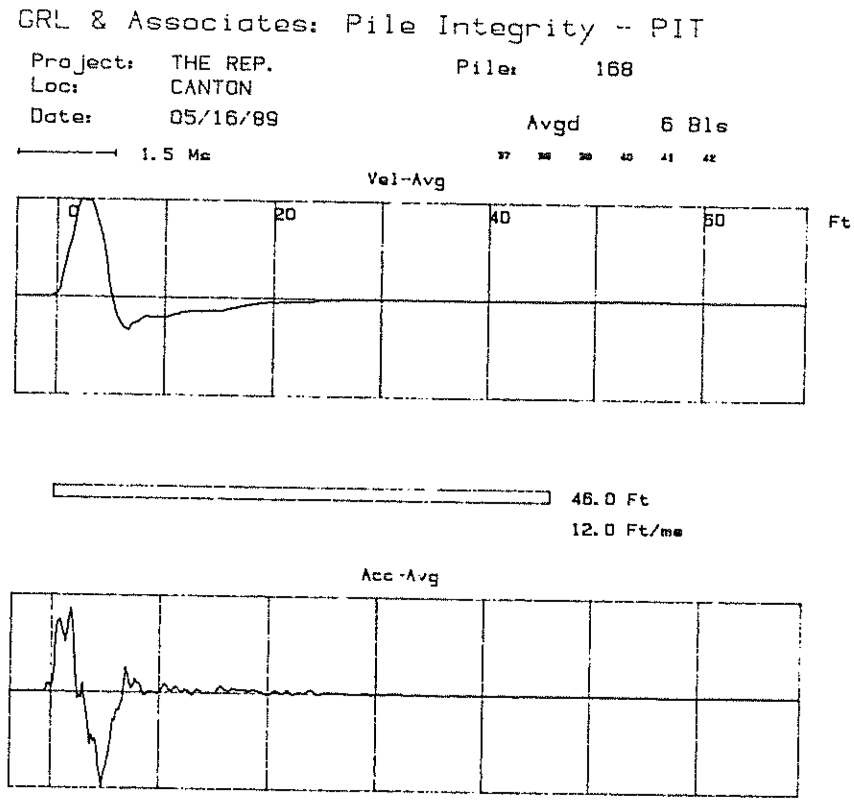

GRL & Associates: Pile Integrity - PIT
Project:
Loc: Parking
Date: 03/07/89
Pile: BP 4/B
Before T
Avgd 14 Bls
1.5 Ms
Vel-Avg-Ampd
0
20
40
60
80
Ft
6.0
60.0 Ft
11.8 Ft/ms
Acc-Avg-Ampd

a)

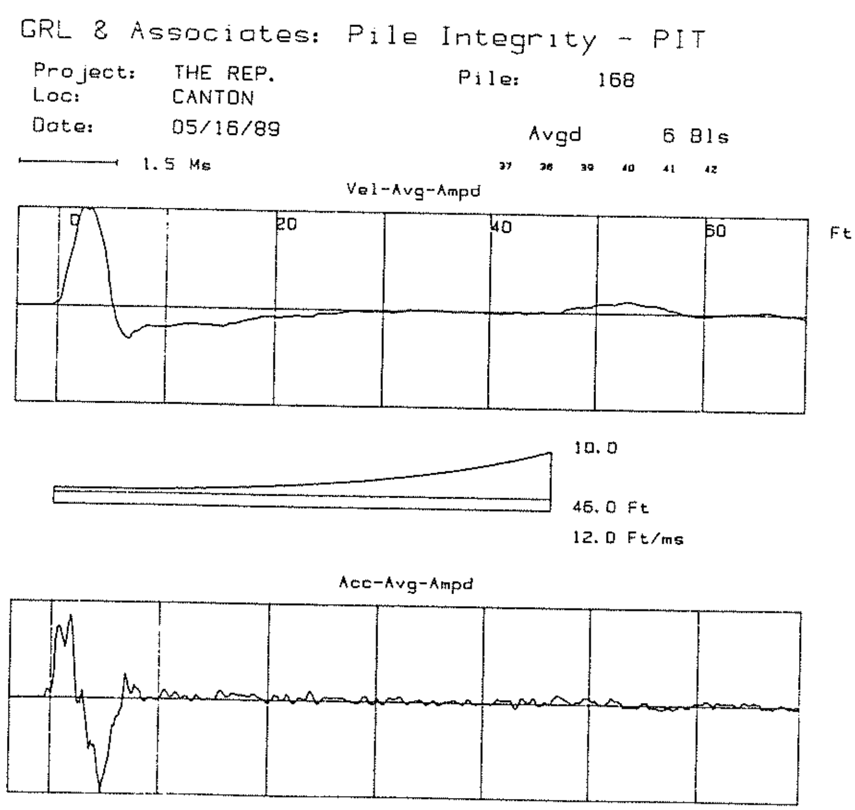

GRL & Associates: Pile Integrity - PIT
Project:
Loc: PARKING
Date: 03/07/89
Pile: BP 4/A
After T
Avgd 11 Bls
1.5 Ms
Vel-Avg-Ampd
0
20
40
60
80
Ft
5.0
60.0 Ft
11.5 Ft/ms
Acc-Avg-Ampd

b)

Figure 6

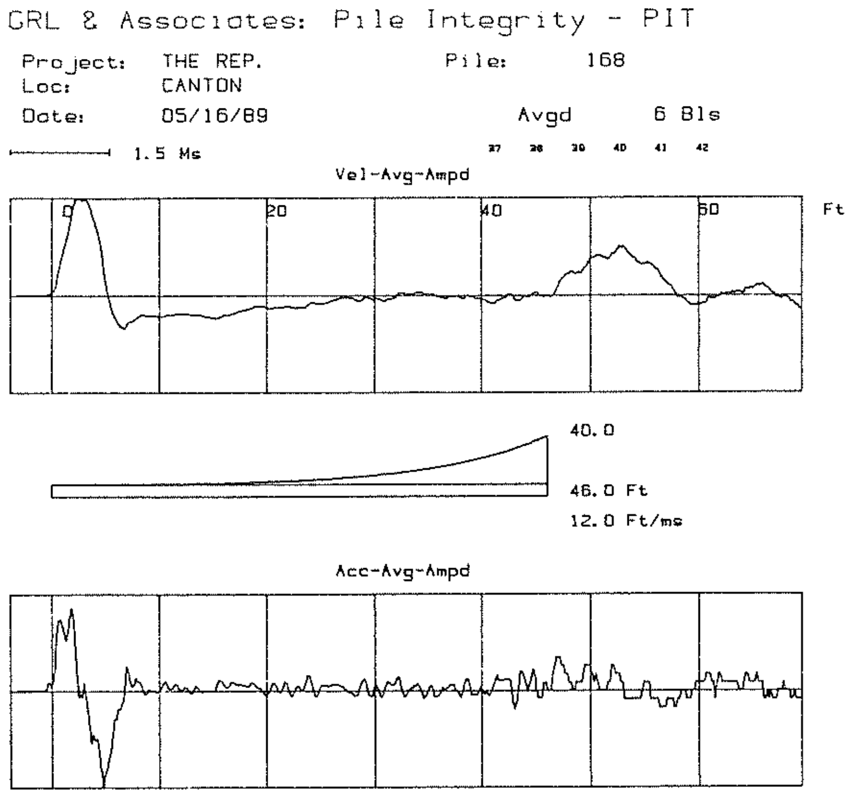

GRL & Associates: Pile Integrity - PIT
Project: THE REP.
Loc: CANTON
Date: 05/16/89
Pile: 168
Avgd 6 Bls
1.5 Ms
Vel-Avg
0
20
40
60
Ft
46.0 Ft
12.0 Ft/ms
Acc-Avg

a)

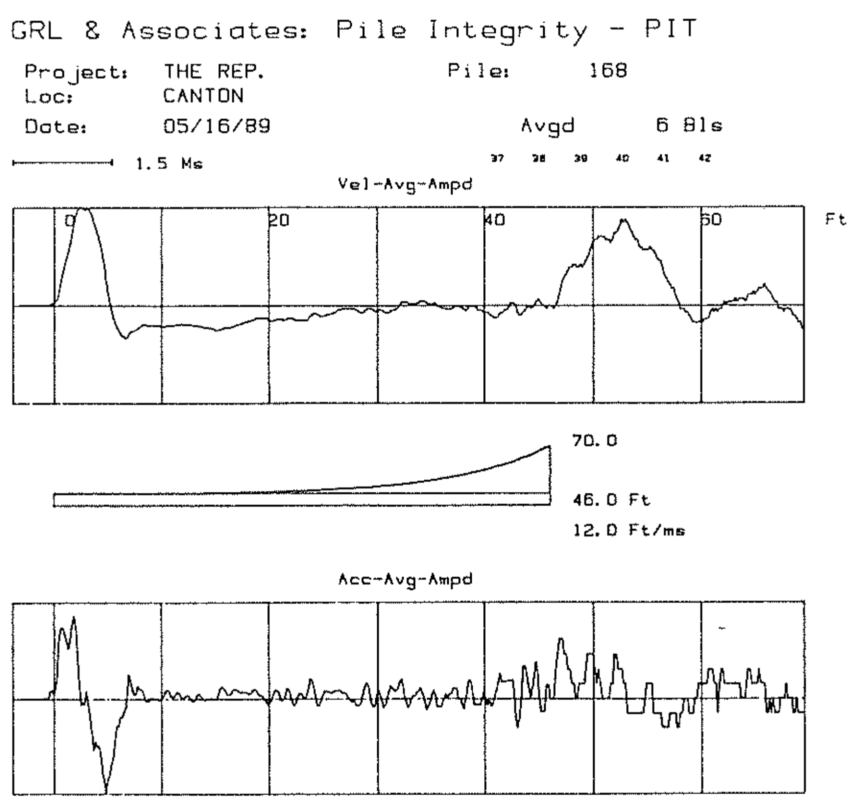

GRL & Associates: Pile Integrity - PIT
Project: THE REP.
Loc: CANTON
Date: 05/16/89
Pile: 168
Avgd 6 Bls
1.5 Ms
37 38 39 40 41 42
Vel-Avg-Ampd
0
20
40
60
Ft
10.0
46.0 Ft
12.0 Ft/ms
Acc-Avg-Ampd

b)

Figure 7


GRL & Associates: Pile Integrity - PIT
Project: THE REP.
Pile: 168
Loc: CANTON
Date: 05/16/89
Avgd 6 Bls
1.5 Ms
37 38 39 40 41 42
Vel-Avg-Ampd
0
20
40
60
Ft
40.0
46.0 Ft
12.0 Ft/ms
Acc-Avg-Ampd

a)


GRL & Associates: Pile Integrity - PIT
Project: THE REP.
Pile: 168
Loc: CANTON
Date: 05/16/89
Avgd 6 Bls
1.5 Ms
37 38 39 40 41 42
Vel-Avg-Ampd
0
20
40
60
Ft
70.0
46.0 Ft
12.0 Ft/ms
Acc-Avg-Ampd

b)

Figure 8

DAMES PT Pile: 22 JAX FL. 09/21/88

Avgd 7 Bls

172 173 174 176 179 180 181

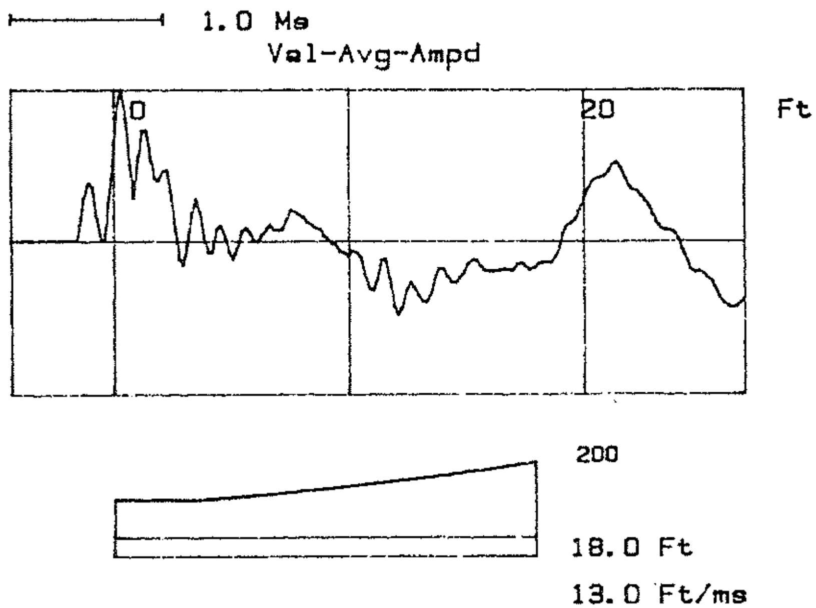
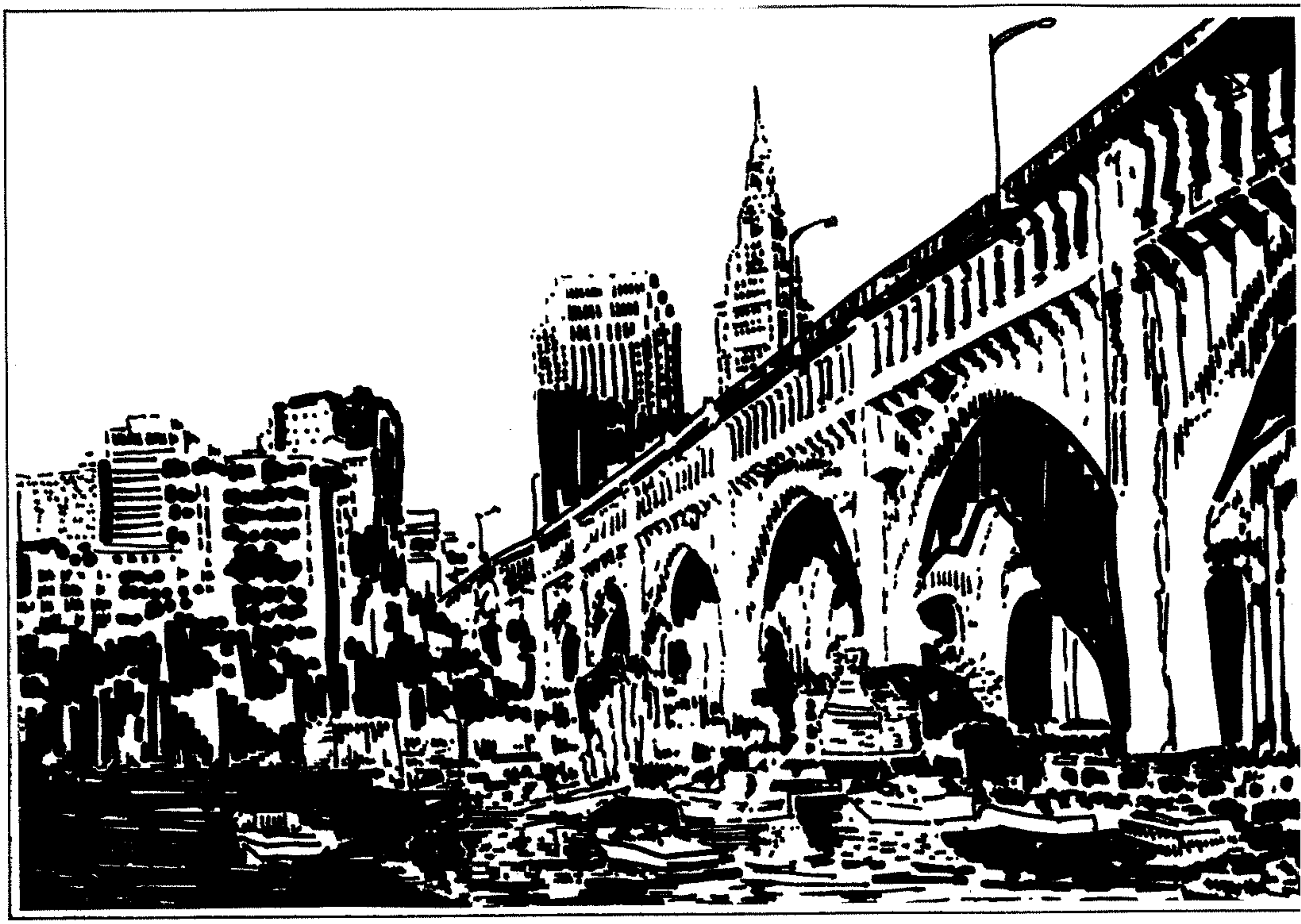


Figure 9

Cleveland
1989



PDA USERS DAY • CLEVELAN

JUNE 16 - 17, 1989

PILE DYNAMICS, INC.

4535 Emery Industrial Parkway ● Cleveland, Ohio 44128 ● U.S.A.
Phone 216-831-6131

Likins

PDA USERS DAY
1989
CLEVELAND

GOBLE RAUSCHE LIKINS AND ASSOCIATES, INC.
PILE DYNAMICS, INC.

4535 Emery Industrial Parkway
Cleveland, OH 44128
Phone (216) 831-6131
Fax (216) 831-0916
Telex 985-662