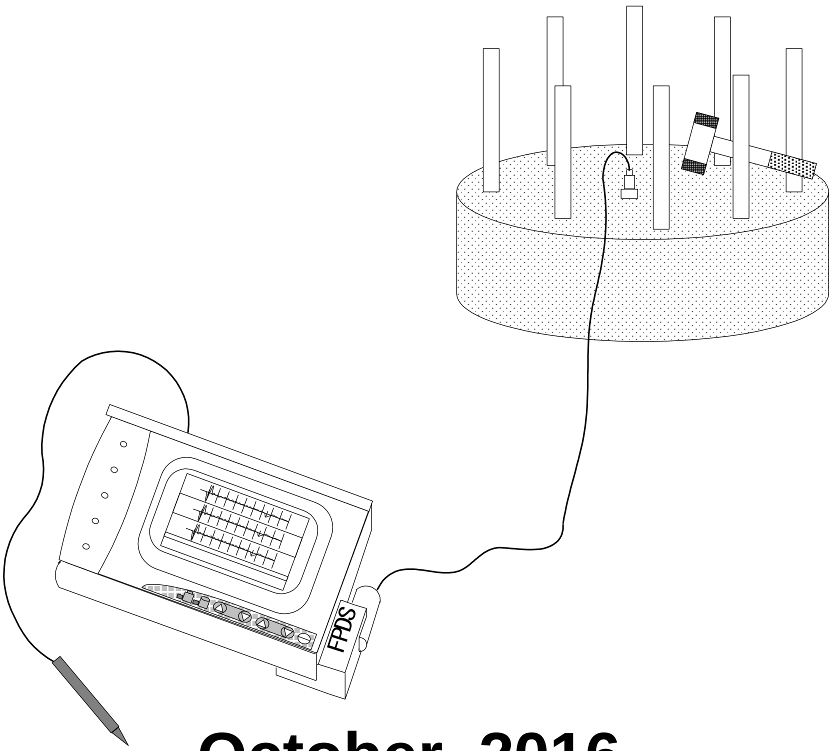
Pile Integrity Test



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Advance Geotechnical Research Institute Inc.

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1. Pile Integrity Testing

1.1. Overview of Integrity Test (PIT)

1.1.1. History of the Development of Integrity Test (PIT)

In Japan, pile quality control has often been overlooked due to the inherent difficulty of inspecting piles once they are embedded deep underground. In contrast, Europe and the United States began adopting wave theory-based methods for pile construction management and bearing capacity estimation in the 1960s, leading to the establishment of dynamic pile testing techniques.

The surge in demand for driven piles in Europe during the late 1970s coincided with an increase in quality-related issues associated with post-installation piles. This growing concern for pile integrity prompted the development of Integrity Testing (PIT), which utilizes the expertise gained from dynamic pile testing.

Pioneered by institutions such as the Netherlands Organization for Applied Scientific Research (TNO), the French Building Research Institute (CETBC), and Pile Dynamics Inc. (PDI) in the United States, PIT has evolved into a widely adopted practice worldwide.

1.1.2. Purpose of Integrity Test

The Integrity Test is a method of verifying the integrity of piles using low strain signals, and it can be used for early quality management of piles after construction, confirming the length of piles when reusing existing piles during structure replacement, or quickly and economically verifying the integrity of piles that have been damaged by earthquakes or other disasters.

There are various Integrity Testing for Piles methods that use low strain, such as Sonic Integrity Testing, Echo Testing, Vibration Testing, and Reflectometry Testing. Each of these methods involves applying external forces using hand hammers, shakers, or other devices, and measuring, analyzing, and evaluating the low-level strain changes in the pile body from the response signals.

Image 1-1 Testing Situation

1.2. Overview of PIT

1.2.1. (1) Purpose of PIT

PIT (Pile Integrity Test) was developed in Europe and the United States around 1965. Since 1975, it has been used to test millions of piles around the world and has found defects in many piles. PIT is a quick and economical method for verifying the integrity of installed foundation piles. It can detect defects such as changes in soil or pile cross-section, soil intrusion into the pile body, loss of cross-section (cracks) or increase, etc.

PIT measurement is performed by installing a transducer (accelerometer) on the pile head and striking the pile head with a light hand hammer. The input wave generated by this impact is reflected as a reflection wave by discontinuities such as cracks or the pile tip as it travels back and forth along the pile body. The stress wave generated by the impact is measured by an accelerometer, and the integrity of the pile is judged based on the information contained in the measured waveform.

1.2.2. Characteristics of PIT

PIT has the following characteristics:

- It can be used for cast-in-place concrete piles, precast concrete piles, steel pipe piles, and other types of piles.
- It can detect any defects in the pile at an early stage after construction.
- It is faster and more cost-effective than core drilling, excavation surveys, or load

testing.

- It can confirm the length of the constructed piles.
- If access to the pile is possible, the test can be conducted by one person, making it very convenient.
- It is rapid and economical enough to allow for testing of all piles, with the capability to conduct more than 10 tests per day.
- It has minimal impact on other site operations (such as construction schedules).

1.2.3. Limitations of PIT

PIT is a quick and economical test method using one-dimensional wave theory, but it has the following limitations:

- Small cross-sectional defects in piles, gradual increases or decreases in cross-section cannot be detected.
- It is a method for quickly and cheaply confirming the relative quality of constructed piles, but it cannot be used to determine the bearing capacity of piles.
- The stress wave may not be transmitted to the tip of the pile due to the damping of the stress wave by the surrounding friction, and the pile length may not be able to be determined. In very soft clay, a pile length of 50m has been confirmed.
- It is not suitable for jointed piles with loose joints or piles with extremely large discontinuities in cross-sectional change, such as footings or large pile caps.
- For steel pipe piles and steel piles, the circumference is large relative to the cross-sectional area, so the wave attenuation is large and shape noise is easily generated, and it may be difficult to analyze the waveform.
- Composite piles with different characteristics (such as changes in material) will have a reflection at the joint due to the change in pile cross-sectional area (impedance) at the joint. This reflection at the joint can be significant and make it difficult to determine the integrity of the pile below the joint.
- In the case of piles constructed using the pre-boring method, small cracks may not be detected because the adhesion of cement milk is not uniform (the cross-sectional area changes).

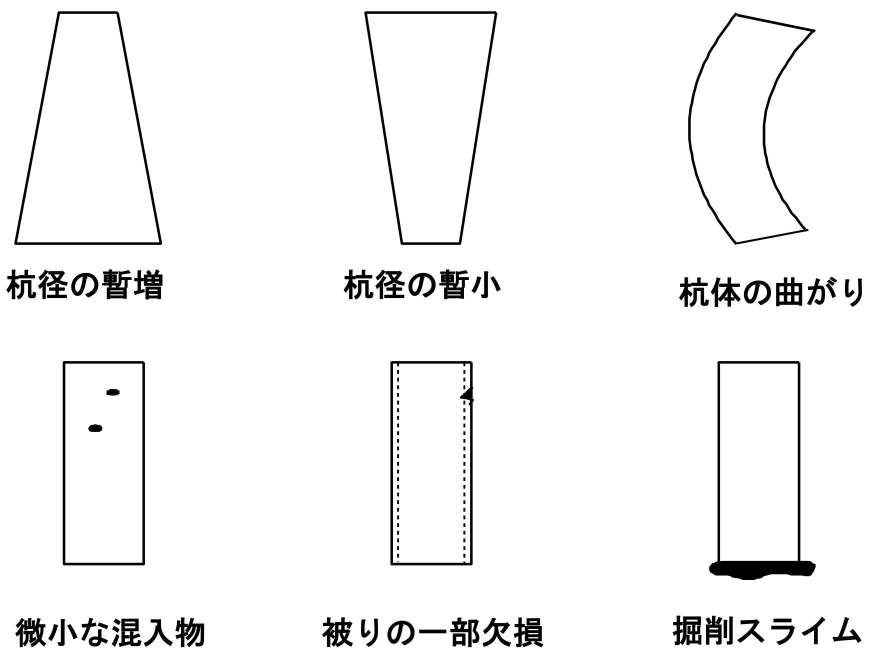


Figure 1-1 Limitations of PIT

2. Theory of PIT

When a pile head is struck with a hammer, the generated input wave spreads instantaneously across the entire pile diameter and propagates towards the pile tip as a plane wave. Reflection waves are generated by changes in pile cross-section and soil conditions. If discontinuities such as cracks occupy a significant portion of the pile cross-section, the input wave will not reach the tip without passing through the discontinuity. On the other hand, if the discontinuity is small, a reflection wave from the tip may be observed, but the waveform will include the effects of the first discontinuity. In addition, if there are multiple discontinuities, the reflections will overlap in a complex manner, making it difficult to determine the tip or discontinuities. Reflections can also occur from changes in pile material or the presence of foreign objects within the pile.

Reflection waves are caused by changes in impedance, i.e., the discontinuity. Large changes in impedance generate large reflection waves. Impedance is basically a function of pile cross-sectional area, wave propagation velocity as a function of pile material, and the state of constraint of the pile at that depth.

The impedance function and wave propagation velocity are expressed by the following equation:

$$Z = \frac{EA}{C} = A\sqrt{E\rho}$$

$$C = \sqrt{\frac{E}{\rho}}$$

Where, **Z**: Impedance, **A**: Pile cross-sectional area, **E**: Young's modulus of the pile material, **ρ**: Density of the pile material, **c**: Wave propagation velocity

In general, the wave propagation velocity is as follows for different materials:

- Cast-in-place concrete piles: 3800–4000 m/sec
- Precast concrete piles: 3500–4000 m/sec
- PHC piles: 4000–4500 m/sec
- Steel pipe piles and H-beam piles: 5120 m/sec

The reflection of waves at a discontinuity is illustrated in the figure on the right. The impedances of sections 1 and 2 are Z1 and Z2, respectively. The input waves to the discontinuity are V1↓ and V2↑, and the reflected waves are V1↑ and V2↓. The reflected waves V1↑ and V2↓ can be expressed by the following equation using the solution of one-dimensional wave theory:

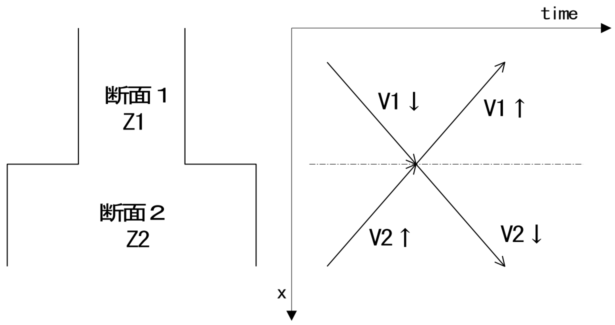


Figure 2-1:
Input and reflected waves at a section change

$$V1\uparrow = \frac{Z1 - Z2}{Z1 + Z2} V1\downarrow + \frac{2Z2}{Z1 + Z2} V2\uparrow$$

$$V2\downarrow = \frac{2Z1}{Z1 + Z2} V1\downarrow + \frac{Z1 - Z2}{Z1 + Z2} V2\uparrow$$

The following shows a simple derivation of the above equations.

From the one-dimensional wave equation D'Alembert's solution u, we obtain F↓ and F↑.

$$\mu = \mu\downarrow (x - c \cdot t) + \mu\uparrow (x + c \cdot t)$$

$$F\downarrow = ZV\downarrow$$

$$F\uparrow = -ZV\uparrow$$

The boundary conditions at the discontinuity are as follows:

$$V1\uparrow + V1\downarrow = V2\uparrow + V2\downarrow$$

$$F1\uparrow + F1\downarrow = F2\uparrow + F2\downarrow$$

Using the above equations, the equations for V1↑ and V2↓ can be derived.

Next, the reflection wave conditions in representative pile conditions are shown.

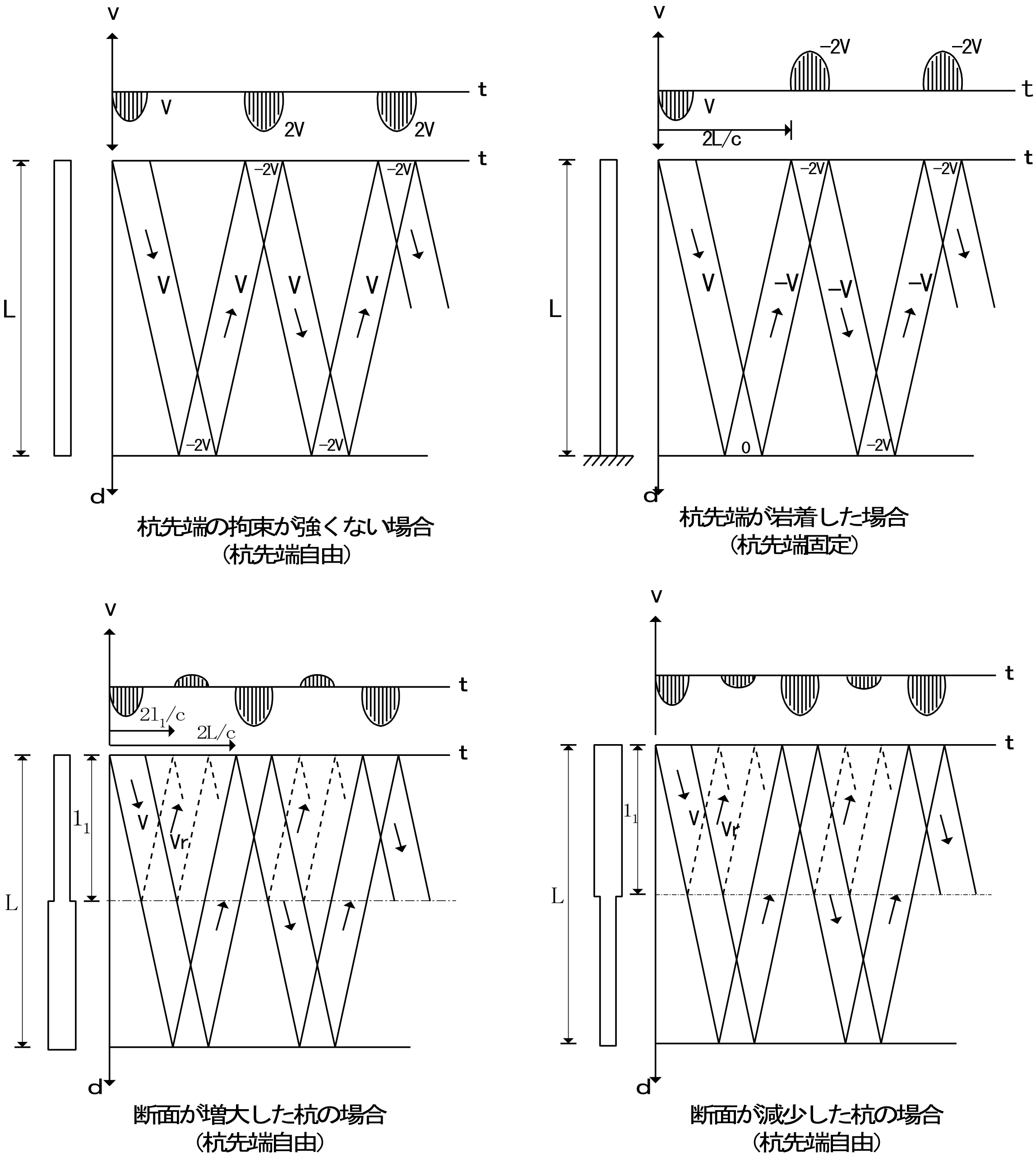


Figure 2-2: Reflection wave conditions in four general cases

Healthy piles typically exhibit the waveform of "loose pile tip constraint (free pile tip)".

If a discontinuity such as a crack exists in the pile, the second waveform will be measured, and the waveform can be used to determine whether the cross-sectional area has increased or decreased.

The following cases can be considered when the same waveform is measured as the waveform of increased cross-sectional area (positive reflection wave (PoPITive Reflection)):

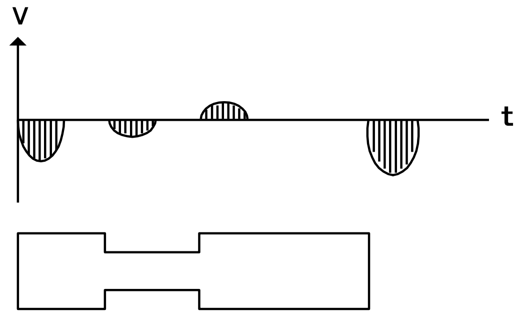
- High ground resistance
- High elastic modulus
- High pile material density

The following cases can be considered when the same waveform is measured as the waveform of decreased cross-sectional area (Negative Reflection Wave):

- Crack is present
- Joint is present
- Low ground resistance
- Low pile material density
- Low elastic modulus

Waveforms of cases where a portion of a pile has increased or decreased due to construction defects are shown below. The waveforms actually collected in the field are often a complex superposition of reflection waves at discontinuities.

○ Case of reduced cross-sectional area



○ Case of increased cross-sectional area

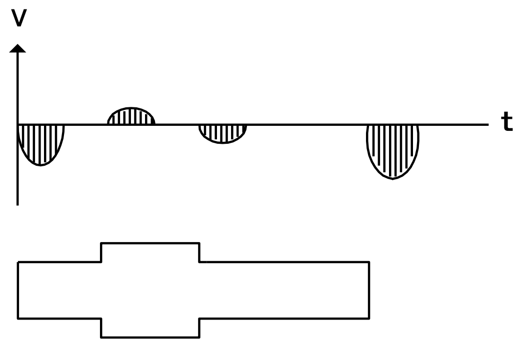


Figure 2-3: Waveforms of piles with reduced or increased cross-sectional area

Figure 2-4 shows an example waveform of a pile with footing. In this case, the reflection wave from the bottom of the footing returns early, making the reflection wave at the pile tip unclear. When the influence of the footing is minimal, the reflection wave at the tip can be confirmed. However, if the pile diameter is small and the thickness or planar extent of the footing is large, the influence of the footing becomes significant. In this case, the reflection wave from the bottom of the footing becomes larger, and the reflection wave at the pile tip becomes smaller, making it often impossible to confirm the reflection wave at the pile tip.

Additionally, in the case of piles with footing, there are also reflection waves from structures associated with the footing (such as piers, columns, underground beams, or walls), resulting in even more complex stress waves.

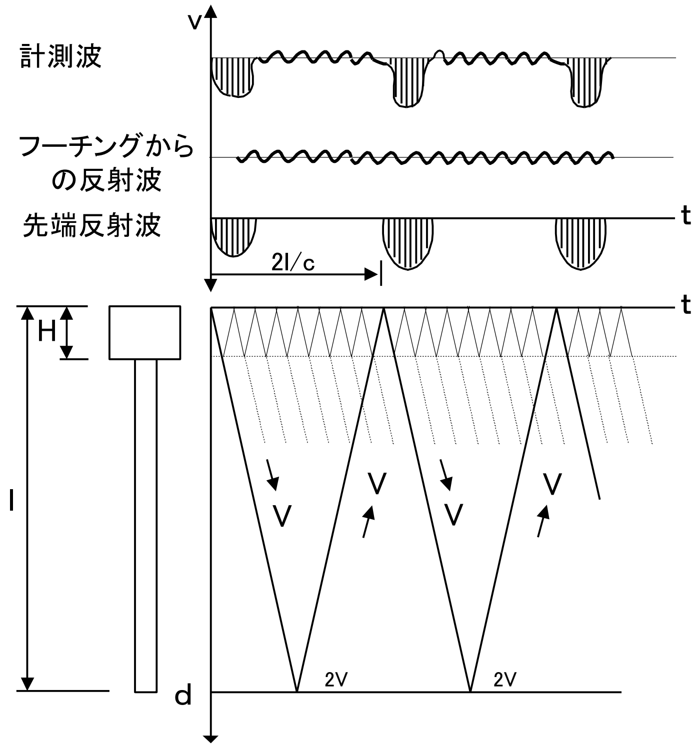


Figure 2-4: Model waveforms for piles with footings

3. PIT Test Method

3.1. Measuring System

PIT is an integrity test pile health investigation device. It consists of a data logger with A/D conversion and amplification function, and a receiver. It is powered by a battery, so it does not require a power supply during field measurement and is easy to carry. The measured data is stored on the internal hard disk of the main unit, so there is no upper limit on the number of measurements, and measurement is possible as long as the capacity of the hard disk is sufficient. The measurement program displays **three waveforms on one screen** to easily confirm the reproducibility of the measured waveform. It is also possible to judge the waveform and confirm the pile length on site by changing the settings such as amplification, filter, and propagation speed during measurement. The measured data is saved as raw data without mechanical processing such as a low-pass filter, so it can be easily set and analyzed later.
The outline of the test procedure is as follows.

3.1.1. PIT-X Device

The PIT-X device is a system equipped with A/D conversion and amplification functions. All operations can be performed with the included pen, allowing easy adjustment of amplification and other settings such as filters.
The program operates on MS-DOS/V, making it easy for anyone to use, and the output results are compatible with Japanese-made laser printers.

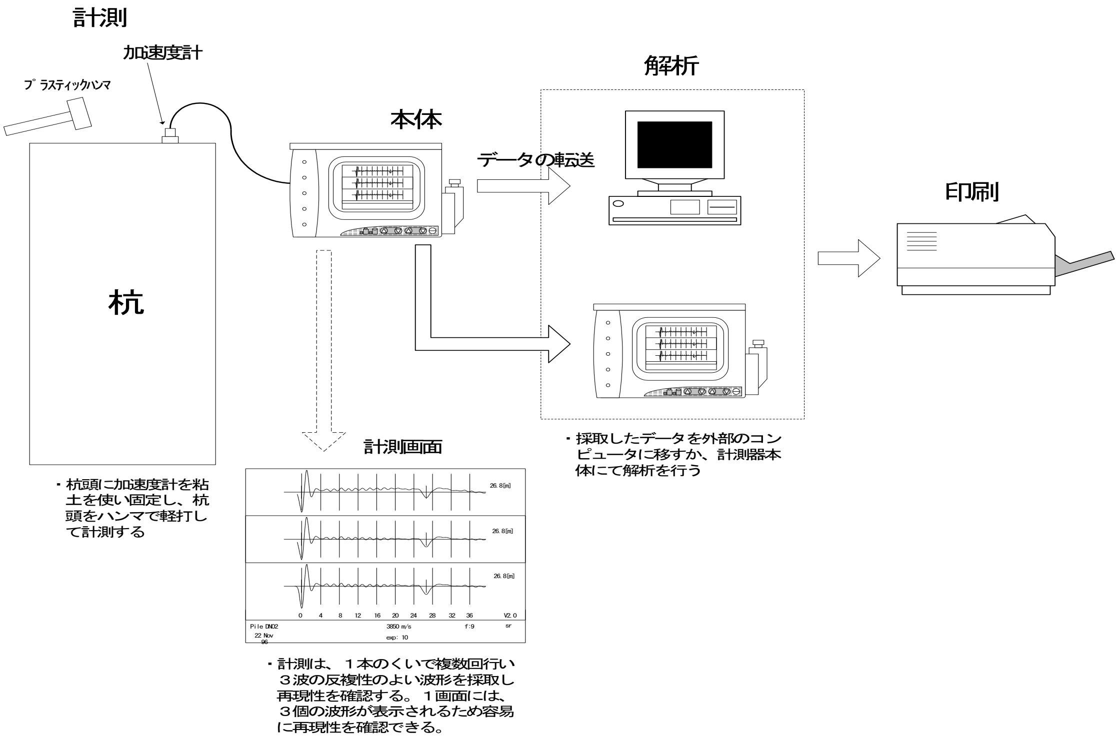


Figure 3-1: Overview of PIT

Table 3-1: PIT System Configuration

Name	Specifications	Manufacturer
PIT	Size: 135 x 104 x 52 mm Weight: 0.45 kg (including battery) Microprocessor: PXA270 @ 520 MHz Data Storage: Built-in 2 GB drive Data Output: USB port A/D Converter: 24-bit Analog Signal Response Frequency: 31 KHz (-3dB) Digital Sampling Frequency: > 1 MHz (net frequency after DSP > 32 KHz) Sampling Frequency Accuracy: Within 0.09% Wireless Range: Within 3m Sampling Speed: Normally 64 KHz (up to 128 KHz for short piles or foundation beams, etc.)	PDI
Accelerometer	Piezoelectric Accelerometer PE Type	PDI
Plastic Hammer or Instrumented Hammer	Weight: Approximately 1364g per unit, 3636g per unit	PDI

Photo 3-1: PIT System

3.2. Test Requirements

To conduct the PIT test, the following test conditions are necessary:

- The head or body of the pile must be exposed and accessible.
- There should be sufficient space near the pile head for measurement.
- For driven piles, pile head treatment should be completed.
  (Analysis of accurate pile length cannot be performed if there is slag present.)
- For driven piles, at least one week should have passed since installation.
  (Propagation velocity depends on concrete strength.)
- The pile head should not be wet, as it can adversely affect accelerometer placement.
- There should be no concrete spalling at the pile head.
  (For PHC piles, there should be no spalling of the end plate.)

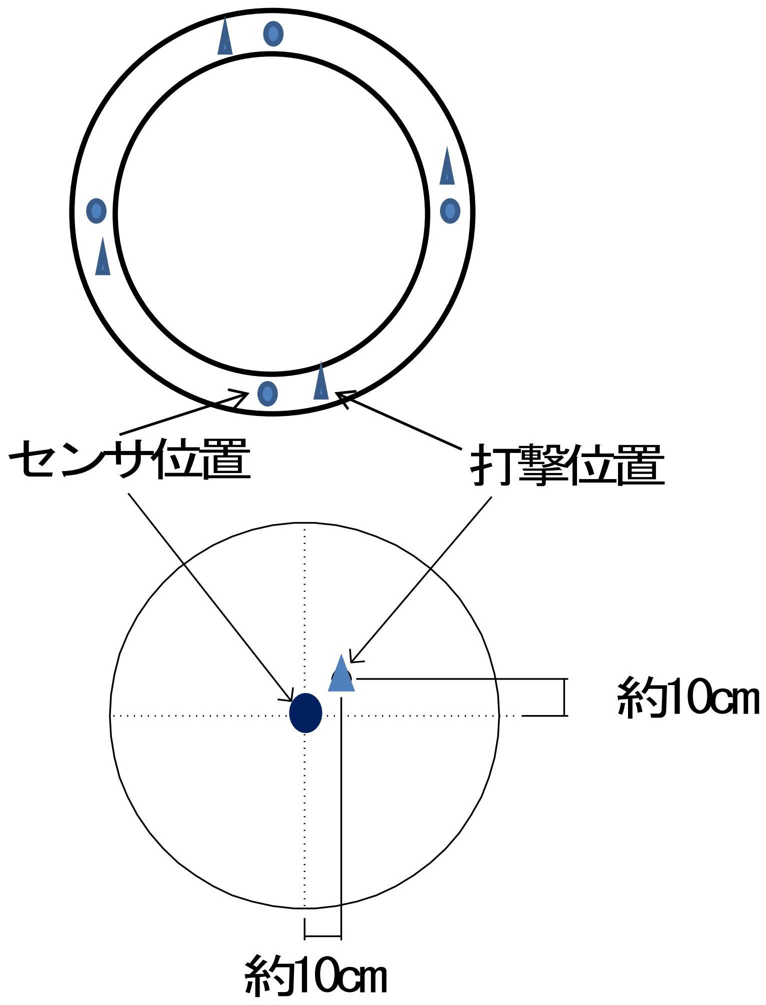
The following documents are required for the PIT test:

- Soil profile and soil test results
- Pile layout drawing
- Detailed pile drawing
- Construction date of driven piles, specifications, and concrete strength
- Other test results related to the pile (Measurement results, etc)

These pieces of information are used as references for analyzing collected waveforms, determining pile length, setting propagation velocities, and identifying reflections caused by soil conditions at the intermediate part of the pile.

3.3. Test Procedure

Measurement typically requires measurement equipment, a hammer, and a sensor (accelerometer), with no other specific requirements. For the measurement, attach the sensor (accelerometer) to the pile head in such a way that it adheres closely to the pile head, and conduct the measurement by lightly striking the pile head with a hand hammer or similar tool. In this process, for driven piles, place the sensor at the center of the pile head, while for precast piles, place it on the end plate, and strike from a position approximately 10 cm away. If the condition of the pile head is poor, for both types, it is necessary to select a location with better installation conditions for the pile head. The standard striking position for the pile and the mounting position for the sensor are shown in Figure 3-2, where the circle represents the sensor placement and the triangle represents the hammer striking position.



The measurement results can be confirmed on the spot. Typically, it is desirable to continue measurements until similar waveforms are observed and to collect at least three waveforms. If similar waveforms cannot be measured, there may be a problem with the measurement equipment or the condition of the pile. Additionally, the IT measurement length can be confirmed on the screen of the measurement equipment to verify input conditions, etc.

The IT measurement length is calculated by measuring the time from the peak of the input waveform to the peak of the reflected wave at the tip of the pile, and converting this into distance based on the propagation velocity (see Figure 3-3).

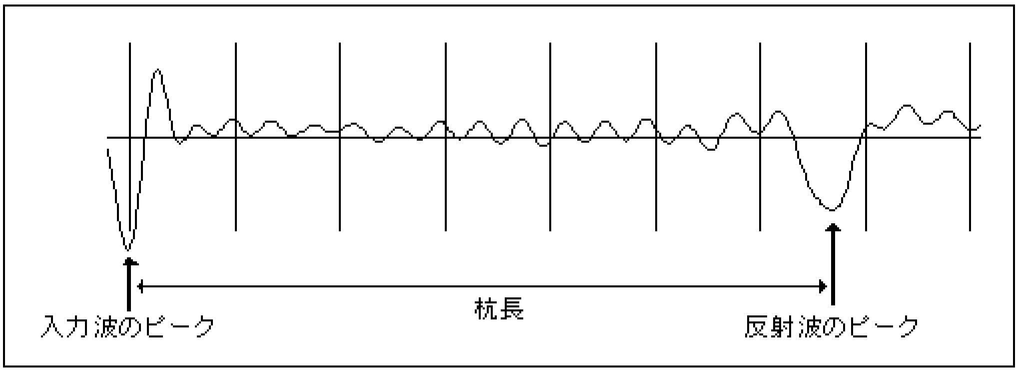


Figure 3-3: PIT Measurement Length

Figure 3-4 illustrates the flowchart of the test procedure, follow the steps accordingly.

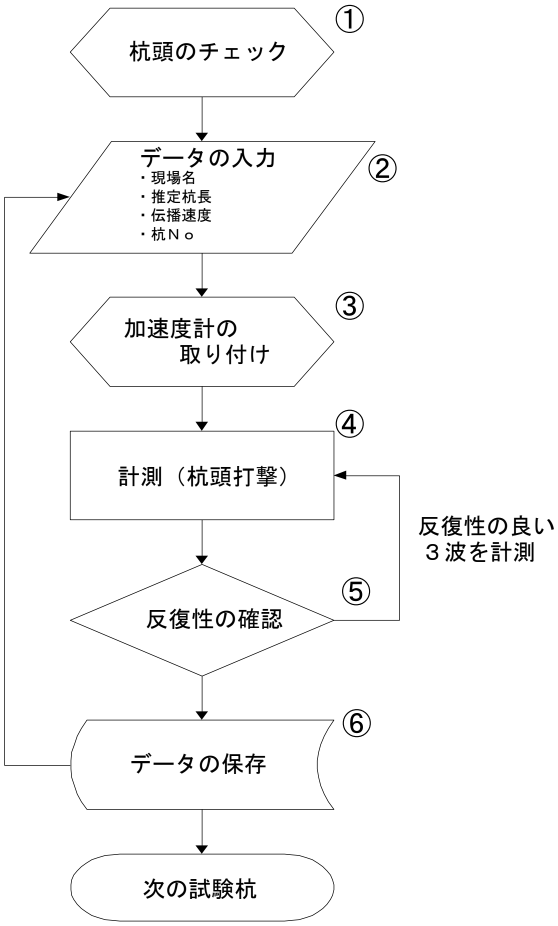


Figure 3-4: Test Flowchart

① Check the Pile head

Testing is typically conducted at the pile head, so it is necessary to check the condition of the pile head beforehand. If the pile head is wet, the adhesion between the accelerometer and the pile deteriorates, leading to increased noise in the collected waveforms. Additionally, mounting the accelerometer or striking the pile at parts of the pile head surface with floating concrete due to pile head treatment or other factors is not suitable for measurements, often resulting in abnormal waveforms being collected.

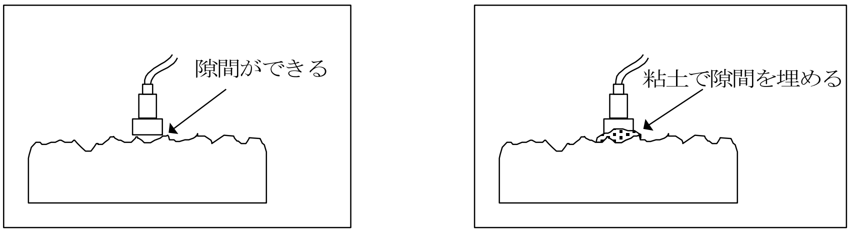
② Inputting Data

Just before the test, input the site name, estimated pile length, propagation velocity (wave velocity), hammer type, pile number, etc., into the measurement system.

③ Attaching the Accelerometer

During the test, the accelerometer is attached to the pile head using clay (petroplast) and lightly struck with a hammer.

When attaching the accelerometer, using clay enhances the adhesion between the pile and the accelerometer, improving the transmission of waves. Especially for driven piles, since the pile heads are uneven, it is necessary to fill in the irregularities with clay.



Clay unused   Clay used

Figure 3-5: Attachment of the Accelerometer

In addition, in the case of conducting tests on foundation piles of existing structures where the footing or underground beams are integrated, it is also possible to measure using the following methods. However, all of these methods generally result in lower accuracy compared to tests conducted at the pile head and may present difficulties in analysis.

Case 1: Attaching the sensor and striking the hammer both on the footing. (Figure 3-6 left)

- This method is simple to perform without requiring pre-test preparations. However, it often makes it impossible to assess the integrity of the pile due to the strong influence of the footing.
- Can be performed with regular testing equipment.

Case 2: Placing blocks beside the pile underneath the footing, then striking them to conduct measurements with an accelerometer attached to the side of the pile. (Figure 3-6 Center)

- Relatively less influenced by the footing, but reflections from the block may occur. Excavation or other preparations are necessary to work under the footing.
- Can be performed with regular testing equipment.

Case 3: Striking either above or below the footing and using two accelerometers to measure only the vertical waves. (Figure 3-6 right)

- Measurements can be taken without being affected by the footing, but space needs to be ensured for attaching the accelerometer below the footing.
- Requires primary processing of data to extract vertical waves.

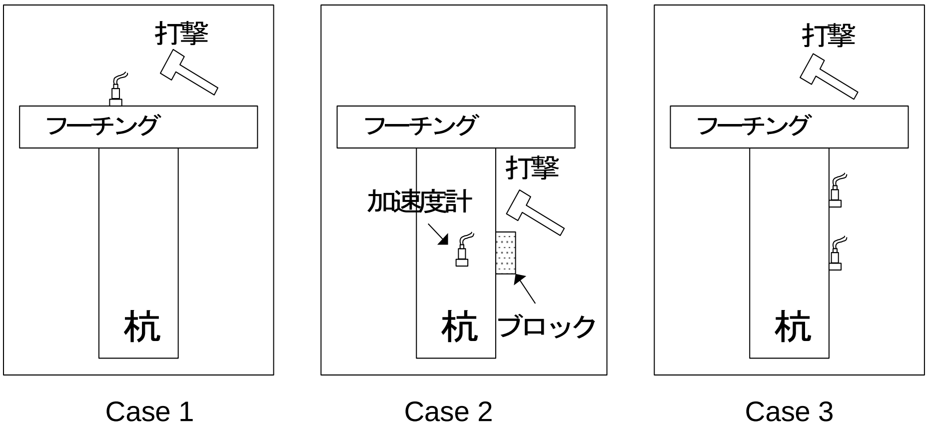


Figure 3-6: Measurement Methods in the Presence of Footing

④ & ⑤ **Measurement & Confirmation of Reproducibility:**

During each test, three waveforms are collected and displayed on the same screen to ensure quality control through reproducibility confirmation. At the site, the propagation velocity is initially set based on the ground conditions and pile length, and subsequent tests are conducted based on the judgment of the validity of the waveform. Additionally, a provisional pile length can be tentatively confirmed on-site based on the collected waveforms to check for significant damage or abnormalities in the pile body. When the condition of the pile head is poor or similar situations arise, causing significant waveform distortion and making it difficult to confirm the reflected waves, it is essential to confirm the reproducibility of three waveforms.

⑤ **Data Storage:**

Save the data. Saving is done on the built-in hard disk of the FPDS. The data is saved in a format that allows easy modification during analysis, including waveform data, amplification values, filter values, propagation velocity, estimated pile length, etc.

3.4. Processing of Collected Waveforms

The collected waveforms attenuate with depth and are further affected by noise from factors such as reinforcement bars and surrounding ground. Confirming reflections caused by tip reflections or abnormalities is difficult as it is, so it is necessary to perform amplification and noise processing along the time axis, as shown in Figure 3-7, to clarify tip reflections or abnormal reflections.

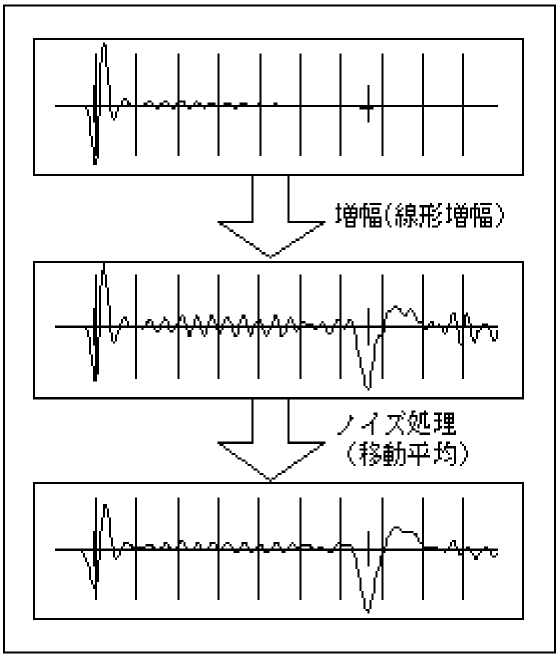


Figure 3-7: Waveform Processing

Two types of amplification methods are used here: linear amplification and exponential amplification. Linear amplification is suitable for signal analysis near the pile head, but since the amplification is constant, it is often difficult to analyze the tip portion. However, it is effective even for short piles. In the case of exponential amplification, the waveform attenuates with depth, but amplifying it with depth makes it possible to analyze near the tip. The concept of this amplification method is shown in Figure 3-8.

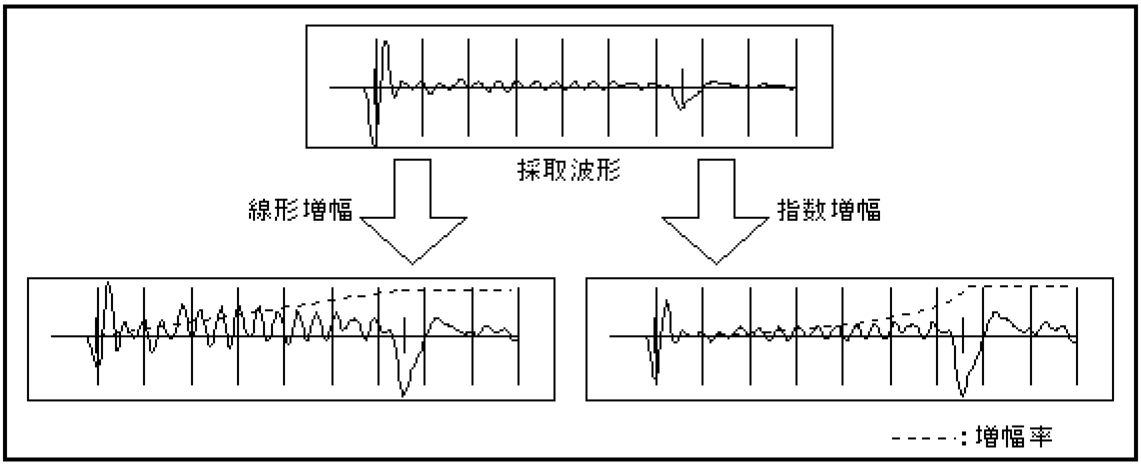


Figure 3-8: Conceptual Diagram of Amplification Methods

When using an instrumented hammer instead of a hand hammer during pile head striking, it is possible to obtain waveforms considering the influence of input wave reflections when striking the pile, by utilizing the accelerometer embedded in the hammer, as shown in (b) of Figure 3-9, from the waveforms measured with the conventional hammer shown in (a) of Figure 3-9. This allows obtaining waveforms considering the influence, as shown in (c) of Figure 3-9.
By using this instrumented hammer, it is possible to reduce the influence of input waves at the pile head appearing in the collected waveforms, making it easier to assess abnormalities in the pile near the pile head.

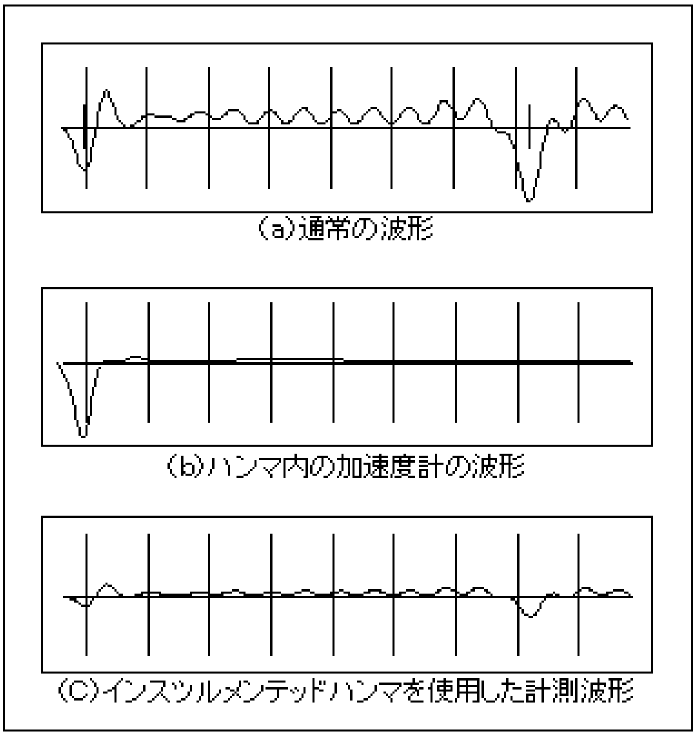


Figure 3-9: Waveform Processing with Instrumented Hammer

Instrumented Hammer

An accelerometer embedded in the hammer measures acceleration, and force is determined by multiplying the mass of the hammer by acceleration.

$F = m\alpha$

Using this force and the impedance Z of the pile head, it is converted into a velocity waveform.

$V = F / Z$

This velocity waveform corresponds to Figure 3-9 (b).

4. Measurement Results and Evaluation of PIT

4.1. Evaluation of Collected Waveforms

The evaluation of collected waveforms involves, as previously mentioned, identifying significant irregularities from waveforms with consistent features after amplification and noise processing. This is the primary step because reflections due to the pile tip, abnormalities in the pile body, and reflections due to ground effects often appear prominently in the collected waveforms. To determine whether reflections on the collected waveforms are due to abnormalities in the pile body or ground effects, comparing individual measurement waveforms is effective. Therefore, once irregularities are confirmed, it becomes necessary to further review various irregular factors.

The evaluation of waveforms is crucial and involves several key points:

- Confirmation of reflections that can be identified as originating from the pile tip near the design pile length.
- Confirmation of whether ground effects are observed in the reflection waveform.
- Whether the depth of the tip reflection is within an acceptable range due to construction or analytical reasons.
- Confirmation of reflection trends indicating discontinuities in the pile.
- Confirmation of reflections due to the presence of joints (for PHC Piles)
- Confirmation of reflections due to changes in the cross-sectional area of the pile.
- Confirmation of reflections due to changes in material properties.

4.2. Characteristics of Waveforms

The wave input at the pile head becomes a plane wave and travels the entire length of the pile back and forth. This wave typically propagates along the boundary between the pile material, such as concrete, and the surrounding ground, generating reflection signals due to changes in the impedance of the pile body. Therefore, it is not possible to obtain information from the measurement waveform about whether the pile is vertically installed in the soil or inclined, among other details. Additionally, because the change in impedance due to variations in concrete quality is small, it is impossible to estimate solely based on information obtained from reflection waves. Furthermore, if significant changes in impedance are observed, waves will not propagate beyond that point, resulting in repeated waveforms up to that point. Below are samples of typical waveforms.

4.3. Sample Waveforms

Figure 4-1 describes the basic interpretation of collected waveforms. Typically, collected waveforms are outputted with three waveforms per page, as shown in the figure. This allows for the confirmation of reproducibility and the determination of the depth of the pile length and any missing sections.

Sample waveforms collected from driven piles, PHC piles, steel piles (I-beams, steel sheet piles, steel pipe piles), and damaged piles are attached below. Additionally, waveforms comparing cases with and without footings are provided for driven piles and steel pipe piles.

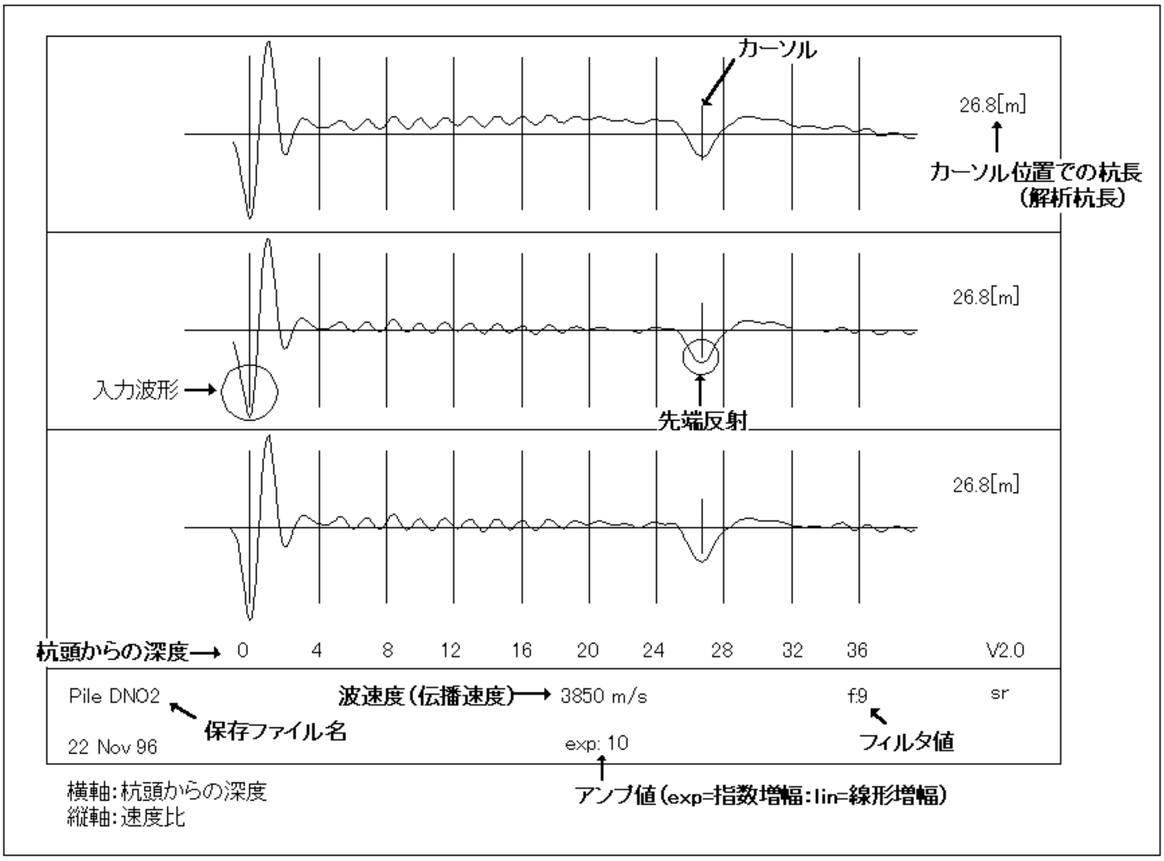


Figure 4-1: Interpretation of Collected Waveforms

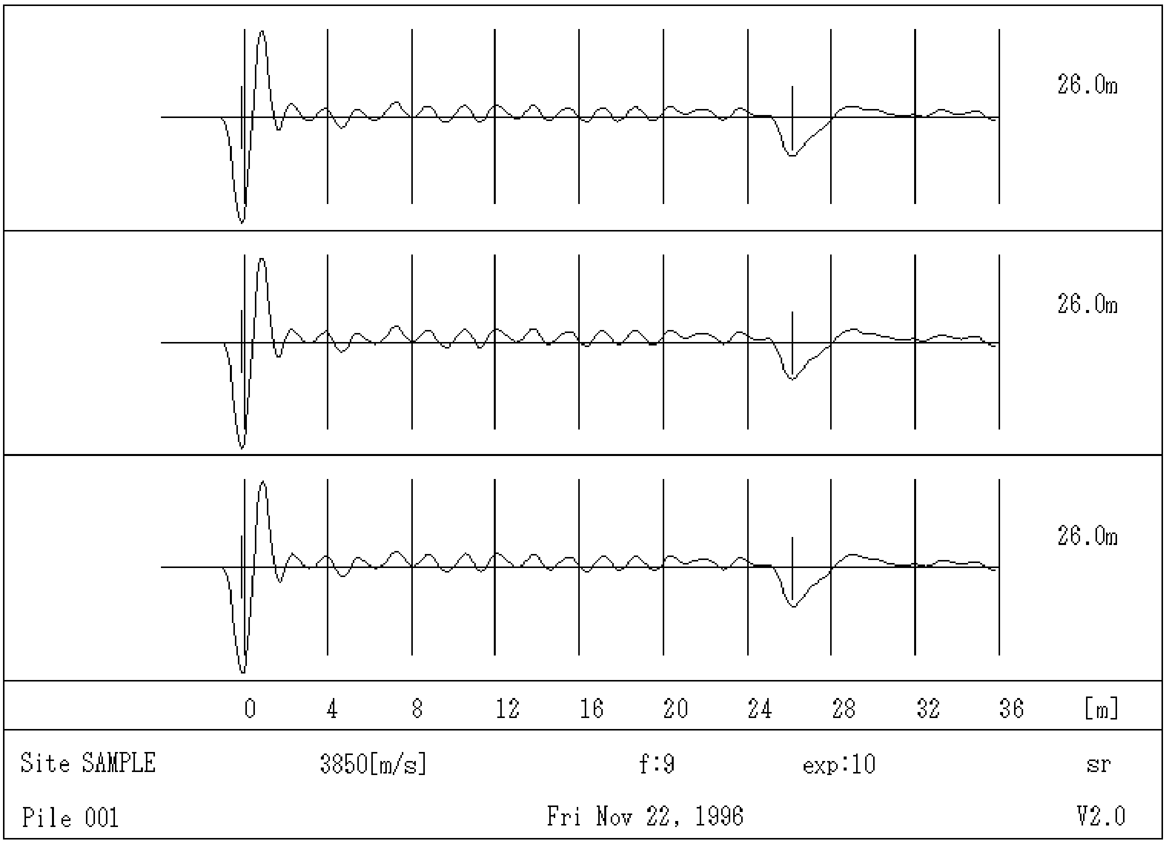
4.3.1. Sample 1

Pile Specifications:

- Pile Type: Driven Cast-in-Place Concrete Pile (Venot)
- Pile Length: 26.0 m
- Pile Diameter: 1000 mm

Details:

Initially, a large input wave from the hammer strike was observed, followed by small waves continuing up to approximately 25.0 meters, where a significant reflection from the pile tip was confirmed at 26.0 meters. The small waves observed here are not due to pile damage but can be attributed to reflections from the pile circumference or reinforcement bars, as the tip reflection is clearly obtained. These small waves are typical noise associated with driven piles.



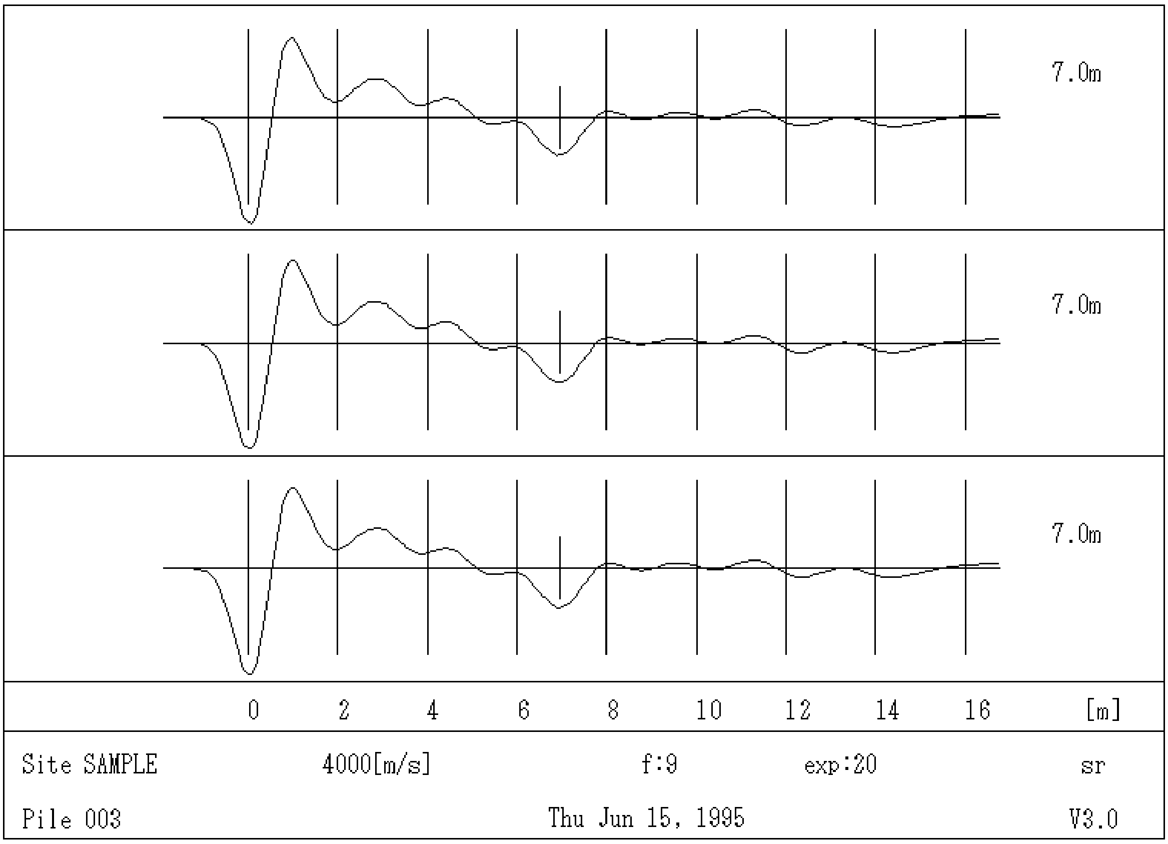
4.3.2. Sample 2

Pile Specifications:

- Pile Type: PHC Pile,Type A
- Pile Length: 7.0 m
- Pile Diameter: 450 mm

Details:

Compared to driven piles, PHC piles are more influenced by the ground, resulting in a waveform that shifts slightly upward between approximately 2.0 meters to 5.0 meters, forming a gentle wave. However, this is unlikely to be due to damage, as the tip reflection is clearly visible, indicating a sound pile.



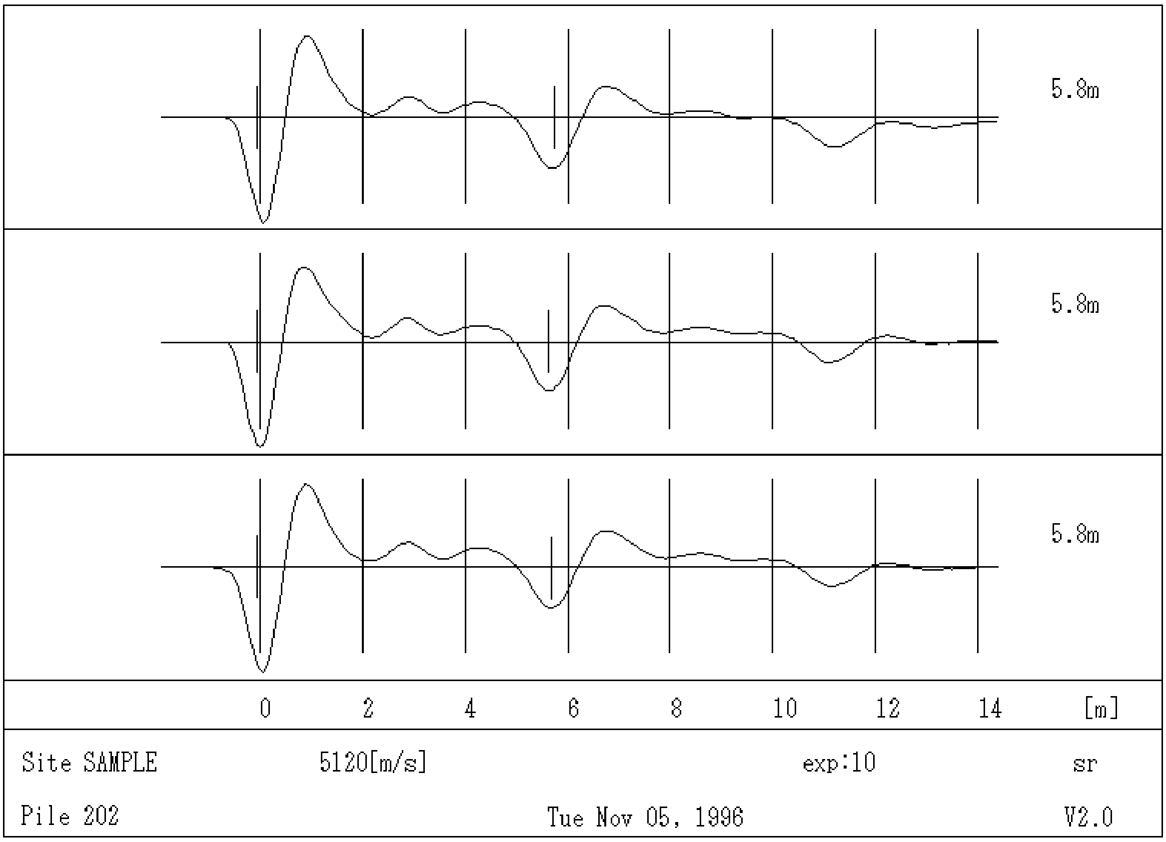
4.3.3. Sample 3

Pile Specifications:

- Pile Type: I-beam Steel Pile
- Pile Length: 6.0 m

Details:

This waveform was obtained for the purpose of confirming the length of an existing I-beam steel pile. Normally, I-beam steel piles and steel pipe piles, among others, are known to experience rapid waveform attenuation due to their large surface area compared to their cross-sectional area. However, in this test, due to the relatively short length of the pile, there was minimal influence from the ground, and a tip reflection was obtained at 5.8 meters. Additionally, a significant reflection was obtained at approximately 11.0 meters, which corresponds to two round trips of the reflection at 5.8 meters. Therefore, it is believed that even for piles exceeding 11.0 meters in length, it is possible to confirm the pile length.



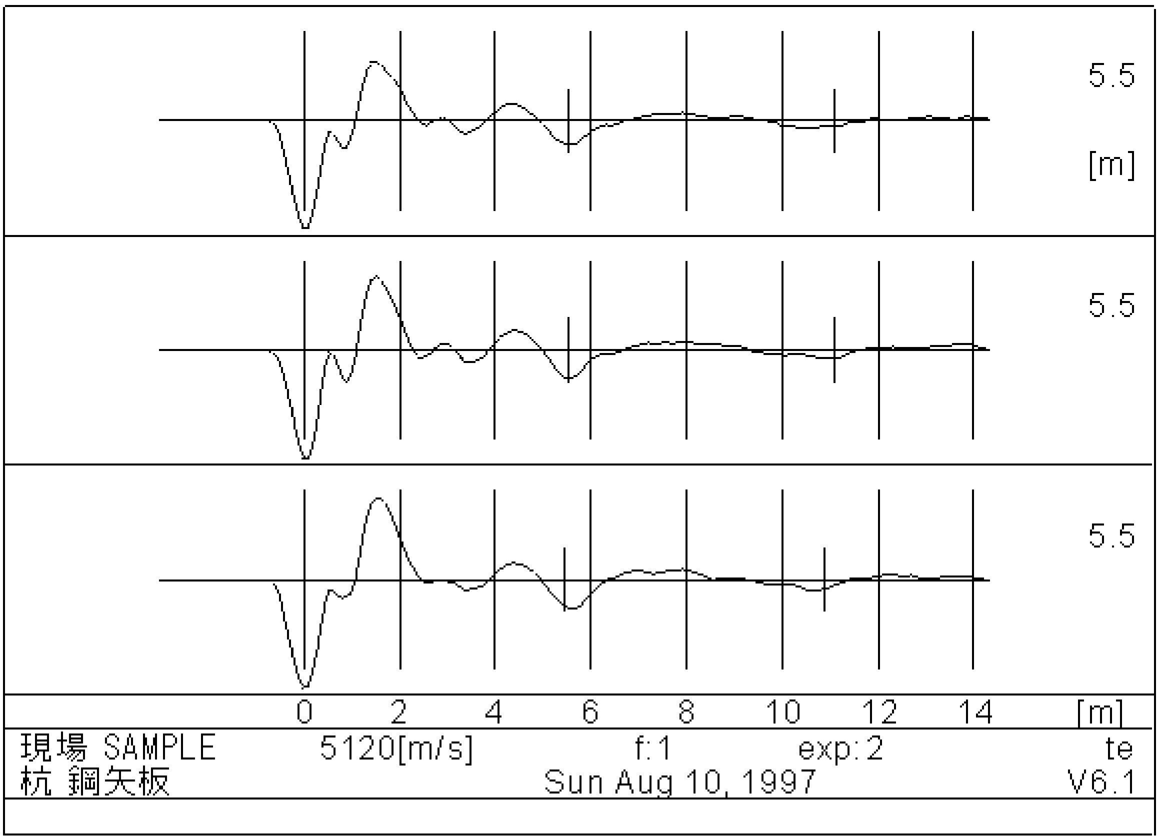
4.3.4. Sample 4

Pile Specifications:

- Pile Type: Steel Sheet Pile
- Pile Length: 6.0 meters

Details:

This figure shows a waveform obtained for the purpose of confirming the length of an existing steel sheet pile. Typically, steel sheet piles and steel pipe piles are known to experience rapid waveform attenuation due to their large surface area compared to their cross-sectional area. However, in this test, due to the relatively short length of the pile, there was minimal influence from the ground, and a tip reflection was obtained at 5.5 meters. Additionally, a significant reflection was obtained at approximately 11.0 meters, which corresponds to two round trips of the reflection at 5.5 meters. Therefore, it is believed that even for piles exceeding 11.0 meters in length, it is possible to confirm the pile length.



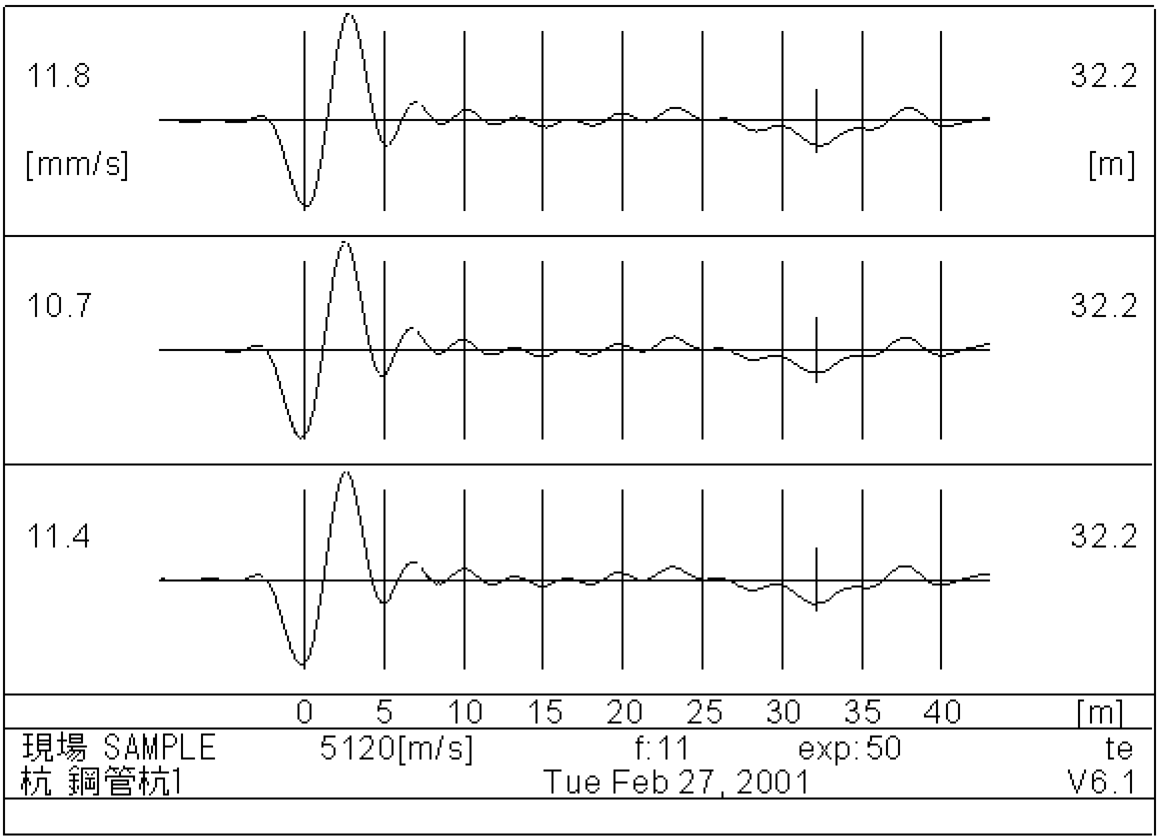
4.3.5. Sample 5

Pile Specifications:

- Pile Type: Steel Pipe Pile
- Pile Length: 32 meters
- Pile Diameter: 600 mm

Details:

This figure shows a waveform obtained for the purpose of confirming the length of an existing steel pipe pile. Typically, steel sheet piles and steel pipe piles are known to experience rapid waveform attenuation due to their large surface area compared to their cross-sectional area. However, in this test, a tip reflection was obtained at 32.2 meters.



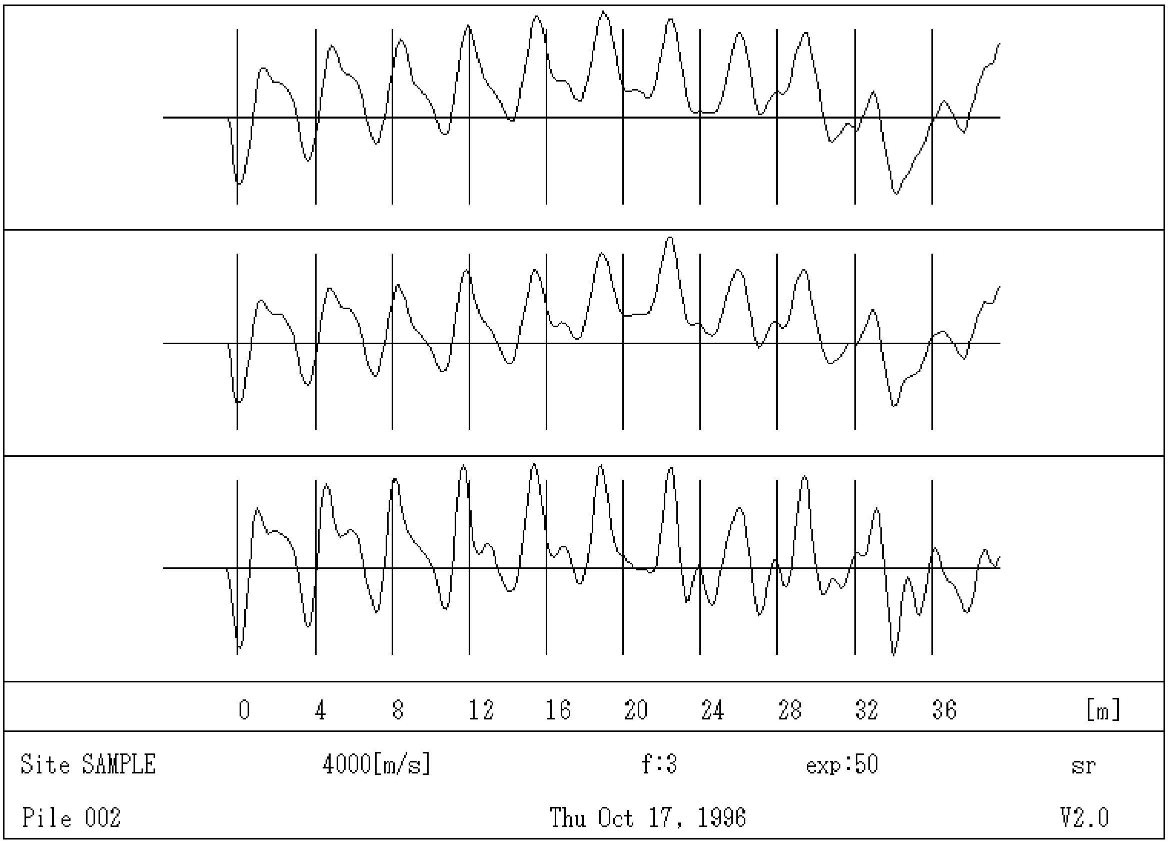
4.3.6. Sample 6 (Damaged Pile)

Pile Specifications:

- Pile Type: Driven Cast-in-Place Concrete Pile
- Pile Length: - meters
- Pile Diameter: 800 mm

Details:

This waveform is from a pile damaged in a disaster. There is missing data at 2.0 meters, and it appears to be completely broken around 3.8 meters. Therefore, no waves are transmitted beyond 3.8 meters, and waves are seen to travel back and forth within this range. As a result, similar waveforms can be observed at intervals of 3.8 meters (0-3.8m, 3.8-7.6m, 7.6-10.4m).



5. Akita PIT Test

5.1. Test Overview

5.1.1. Test Purpose

The purpose is to investigate the integrity of the existing foundation piles of the old bridge abutments in preparation for the replacement of the bridge.

5.1.2. Test Location

The testing location is in Noshiro District, Akita Prefecture.

5.1.3. Testing Company

The testing company is **AGRI Inc.**

5.1.4. Test Period

The testing date is November 21, 2011, and it took one day.

5.1.5. Location and Number of Test Piles

The positions of the test piles are as shown in Figure 5-1, and the total number of test piles is 8, all of which are φ300mm reinforced concrete piles.

Figure 5-1:

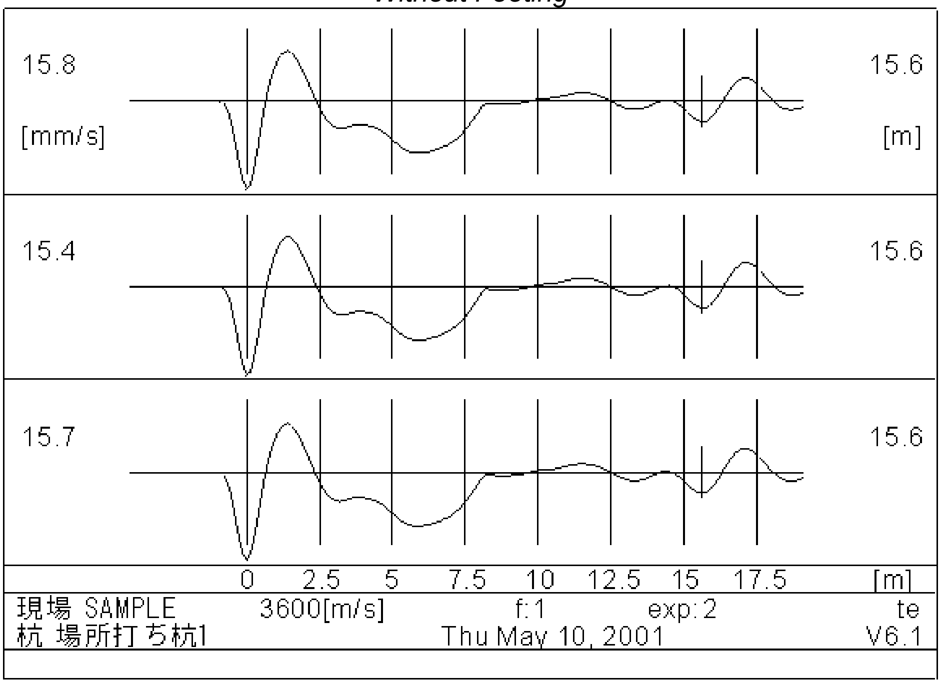
5.2. Test Results

5.2.1. Sample 7 (Waveform Comparison with and without Footings)

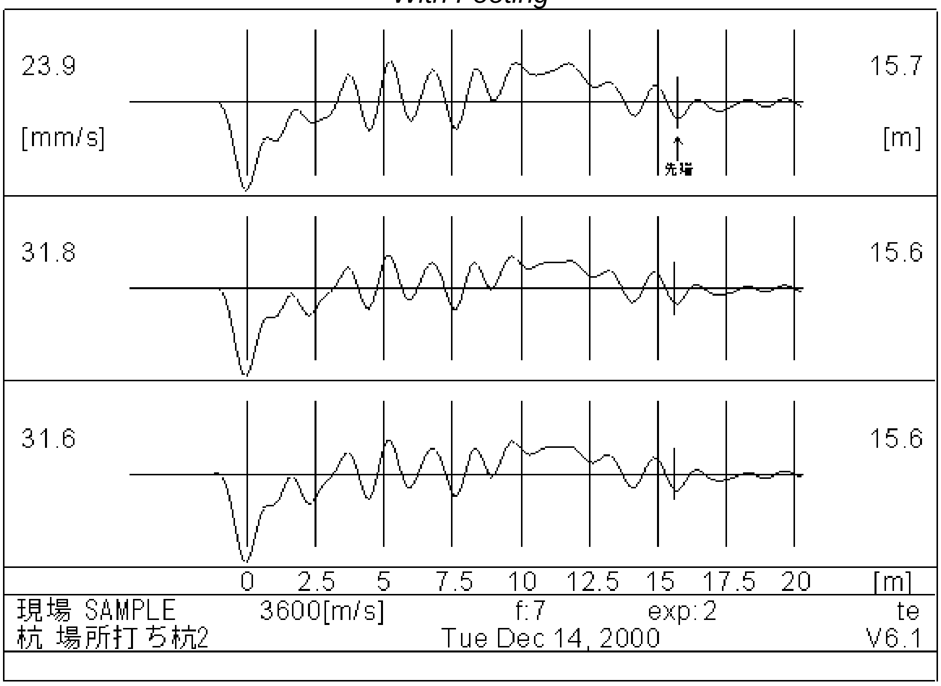
Pile Specifications:

- Pile Type: Driven Cast-in-Place Concrete Pile
- Pile Diameter: 900 mm

Without Footing



With Footing

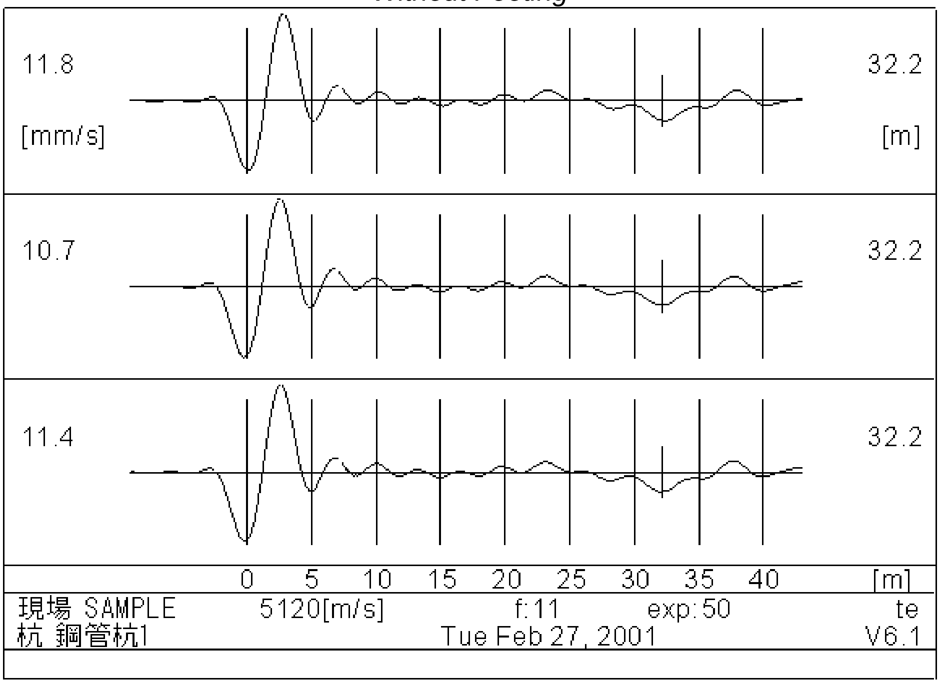


5.2.2 Sample 8 (Waveform Comparison with and without Footings)

Pile Specifications:

- Pile Type: Steel Pipe Pile
- Pile Diameter: 600 mm

Without Footing



With Footing