3.3. Evaluation of Building Foundation Damage

Basic Terminology:

Damage: Destruction, deformation, inclination and settlement of a building foundation caused by an earthquake.

Damage grade: Degree of danger of destruction, deformation, inclination and settlement of a building foundation caused due to earthquake.

Retrofit: Secure a necessary aseismic capability reinforcing the aseismic capability of existing building foundations which decreases due to an earthquake, and assume an existing building to be reusable.

Safety: Building foundation conditions which ensure the safety of human life even at a possible severe earthquake.

Purpose: Methodology for evaluating safety of building foundations after earthquake or tsunami

Important Points:

Timing:

Timing	Evaluation Methodology	Example
Immediate	· First announcement of building damage	· Reports of eye witness & Feelings by local habitants · Broadcast
Within few days	· Quick inspection of building	· Evaluation into 3 ranks, inspected, limited entry and no entry
Within few weeks	· Damage survey in a typical area · Confirmation of building foundation	· Judge the cause of settlement and inclination on building
After several months	· Damage Classification	· Seismic capacity assessment · Judge the retrofit method and design

Grade:

Grade	Methodology	Measures
Minimum Necessary	Reports of eye witness & Feelings by local habitants	Information to habitants
Better	Instant evaluation	Advice to habitants about Restoration
Best	Evaluation of safety of building foundation	Advice to habitants about Retrofitting

3.3.1. Damage investigation flow chart

The flow of building-foundation damage investigation is presented in Figure 3.3.1-1. Within two or three days after an earthquake, a quick inspection of the buildings is done to decide on the degree of danger from aftershocks and on whether it is necessary to restrict the use of the buildings (Step 1). An inspection sheet used at the time is presented in Example 1.

To judge whether the inclination or settlement of buildings is due to their foundations (Step 2), inspectors enter buildings that had been judged to need detailed investigation. This is done several weeks after the earthquake. This inspection refers to records in the quick inspection sheet for the ground in a broad area (Example 1 in Section 3.1) and to records in the sheet for the ground in each building site (Example 2 in Section 3.1).

Several weeks after the earthquake, experts start the detailed investigation on the damage to the foundations and the ground for the buildings that have suffered the damage judged attributable to the former (Steps 3 and 4 in Section 3.1). The investigation refers to damage grade classification sheet for the ground in a broad area (Example 3 in Section 3.1) and such a sheet for the ground in each building site (Example 4 in Section 3.1). From the result of this investigation, the damage grade classification of each foundation is determined, and judgment is made on whether it is in need of repair and reinforcement. When the repair and reinforcement of the foundation are required, their methods are studied to select the most appropriate ones.

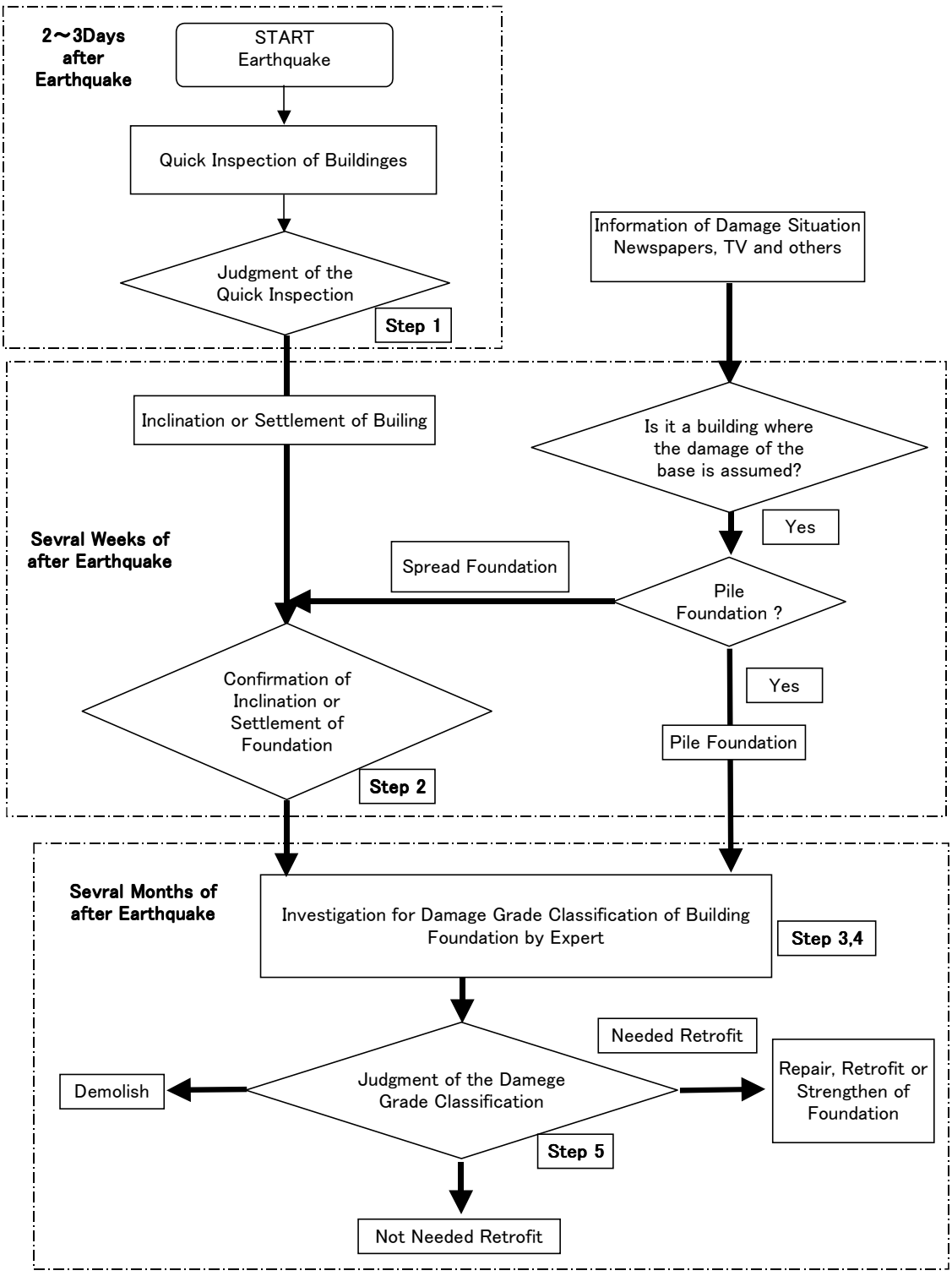


Fig. 3.3.1-1 Damage Investigation Flow of Building Foundation

Damage Investigation Flow of Building Foundation Step

Step 1

Accompanies the quick inspection in the building, and the outline of damages (subsidence, inclination, and situation of limb ground etc.) of the building foundation is investigated.

Step 2

It is investigated to judge the cause of subsidence and inclination in the building.

Step 3

Investigation for the damage grade classification of building foundation by the expert

In Case, there are a settlement and an inclination in the building foundation.

Or the damage of the building foundation is assumed from a surrounding damage situation.

Refer to the example of investigation seat and investigation method for the investigation item.

Step 4

The damage grade classification of the building foundation is executed based on the investigation result of the building foundation.

Step 5

Removal of building or a repair and a retrofit in the building foundation are judged based on the damage grade classification of the building foundation.

When the building foundation is repaired, the repair method is selected.

Table 3.3.1 Site Investigation Sheet for Building Foundation[1]

Sheet No.
Time&Date
Recoder

Outline of Building	
Building Name	
Architectural year	
Adress	
Type	☐SRC, ☐RC, ☐S, ☐Others
Stracture Form	☐Wall type, ☐Rigid Frame
Building Use	☐House, ☐Shoop, ☐Office ☐School, ☐Warehouse, ☐Others
Building Size	
Number of Stories	Upper Stories ___F, Ground Stories ___F
Plane	__(m) x __(m), ☐Square, ☐Rectangle, ☐Others
Foundation Type	☐Pile Foundation, ☐Spread Foundation
Outline of Building Damage	
Settlement	max. ___(mm), Situation of Settlement :
Inclination	max. ___(mm), Situation of Inclination :
Horizontal Movement	max. ___(mm), Situation of Movement :
Column	☐No Damage, ☐Damage, Damage Level
Inside Wall	☐No Damage, ☐Damage, Damage Level
Outside Wall	☐No Damage, ☐Damage, Damage Level
Other Structures	☐No Damage, ☐Damage, Damage Parts

Presence of Materials	
	☐Boling Log or Soil Profile ☐Foundation Plan or Piling Plan ☐Topographic Map ☐Design Documents ☐Quick Inspection Sheet

Example 1 (Cont.) **Sheet 2/3**

Outline of Buildind Foundation	
Pile Foundation	
PileType	☐RC, ☐PC, ☐AC, ☐PHC ☐Steel, ☐Cast in place, ☐Others( )
Pile Diameter	(mm)
Pile Length	(m)
Total Pile Number	
Spread Foundation	
Foundation Type	☐Raft(Mat) Foundation, ☐Continuous Footing ☐Independent Footing
Depth of Footing	(m)
Outline of Buildind Foundation Damage	
Pile Foundation	
Damage Part	☐Pile Head, ☐Other Part of Pile
Damage Patern	☐Bending Failure, ☐Shear Failure, ☐Axial Failure
Damage Level	☐Ⅴ, ☐Ⅳ, ☐Ⅲ, ☐Ⅱ, ☐Ⅰ
Total Number of Damage Pile	
Total Number of Investigation Pile	
Damage situation of Deep Position	Result of Pile Integrity Test, Borehole Camera or Others
Damage situation	Attached Photo
Footing Foundation	
Damage Level	☐Ⅴ, ☐Ⅳ, ☐Ⅲ, ☐Ⅱ, ☐Ⅰ
Damage situation	Attached Photo
Foooting Beam	
Damage Level	☐Ⅴ, ☐Ⅳ, ☐Ⅲ, ☐Ⅱ, ☐Ⅰ
Damage situation	Attached Photo

Example 1 (Cont.) **Sheet 3/3**

Outline of Ground Condition	
Topography	☐Plain, ☐Slope, ☐Plateau ☐Lowland, ☐Reclaimed Ground, ☐Others
Thickness of Alluvial deposit	☐Sandy Soil Layer __(m) ☐Cohesive Soil Layer __(m)
Load Bearing Layer	Depth __(m), Soil Type
Attached	Boling Log or Soil Profile
Outline of Site Damage	
Ground	☐Settlement, ☐Crack, ☐Sand boil or Sedimentation ☐Movement, ☐Slope failure, ☐Retaining Wall, ☐
Damage situation	Attached Photo

Outline of Eathquake Damage of Circumstances	
Seismic Intensity	
Damage of	
Building	☐Collapse, ☐Inclination, ☐Settlement ☐Movement, ☐Others
	Distance and Other information
Ground	☐Settlement, ☐Crack, ☐Sand boil or Sedimentation ☐Movement, ☐Slope failure, ☐Others
	Distance and Other information
Retaining Wall	☐Collapse, ☐Inclination, ☐Settlement ☐Movement, ☐Others
	Distance and Other information

3.3.2. Investigation method

Table 3.3.2-1 shows a list of detailed investigation methods used to judge the damage grade classifications of pile foundations. Cited as investigation methods are a) pile integrity test, b) borehole camera, c) inclinometer, d) acoustic emissions, and e) visual observation, each of which is outlined below.

Table 3.3.2-1 Outline of Damage Investigation Method of Foundation

Investigation method	Method	Outline	Confirmation Item
Integrity Test	The pile head is lightly stricken with the hammer. The acceleration response of pile head is measured.	The length of pile, the pile shape, and the crack point, etc. is presumed based on the elasticity wave motion	・Pile length ・Section shape ・Crack ・Damage part
Borehole Camera	The concrete of pile is observed with a small video camera of the waterproof type.	The crack of pile midair part and the pile borehole is specified.	・Crack ・Damage part
Inclinometer	The inclinometer of the insertion type is inserted in the paling. The inclination angle of pile is continuously measured from pile head.	The crack and the cutting part of pile are presumed from discontinuity in the inclination angle of pile.	・Situation to which pile is wind ・Cutting part ・Damage part
Acoustic Emission	The elasticity wave in the supersonic wave generated from the concrete of damaged pile is measured.	The damage part of pile is presumed from the histogram of Acoustic Emission source.	・Cutting part ・Damage part
Watching observation	The ground in surroundings of the building foundation is dug. The damage situation of the building foundation is observed directly.	The damage situation of the building foundation can be observed directly.	・Crack ・Damage part ・Settlement ・Inclination situation

1) Pile Integrity Test

Purpose:

Pile integrity test can be used by the following three purposes.

i) Quality management of new establishment piles

ii) Shape investigation of existing piles

iii) Damage investigation of existing piles

Here, pile integrity test is used to investigate damage of the existing piles after an earthquake.

Outline of Pile Integrity Test:

Pile integrity test investigates the health of regret by using a low warp.

A sonic test in pile integrity test is an examination method of measuring the response of the regret with the acceleration meter etc. by generating the low strain by hitting the paling head lightly with the hand hammer as shown in Figure 3.3.2-1.

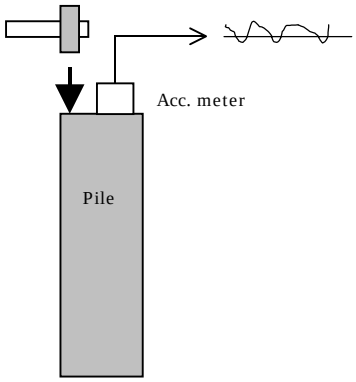


Fig.3.3.2-1 Outline of Pile Integrity Test

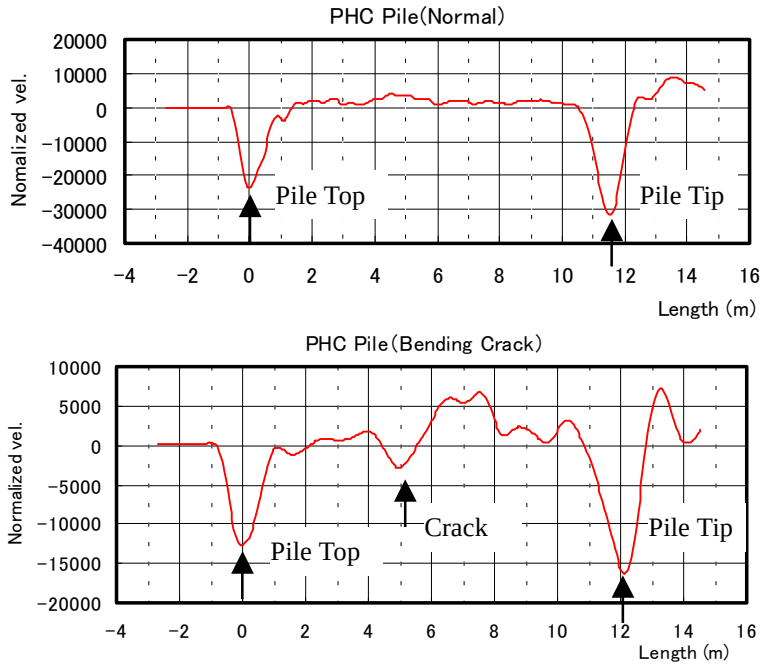


Fig.3.3.2-2 Output of Pile Integrity Test (PHC Pile in Japan)

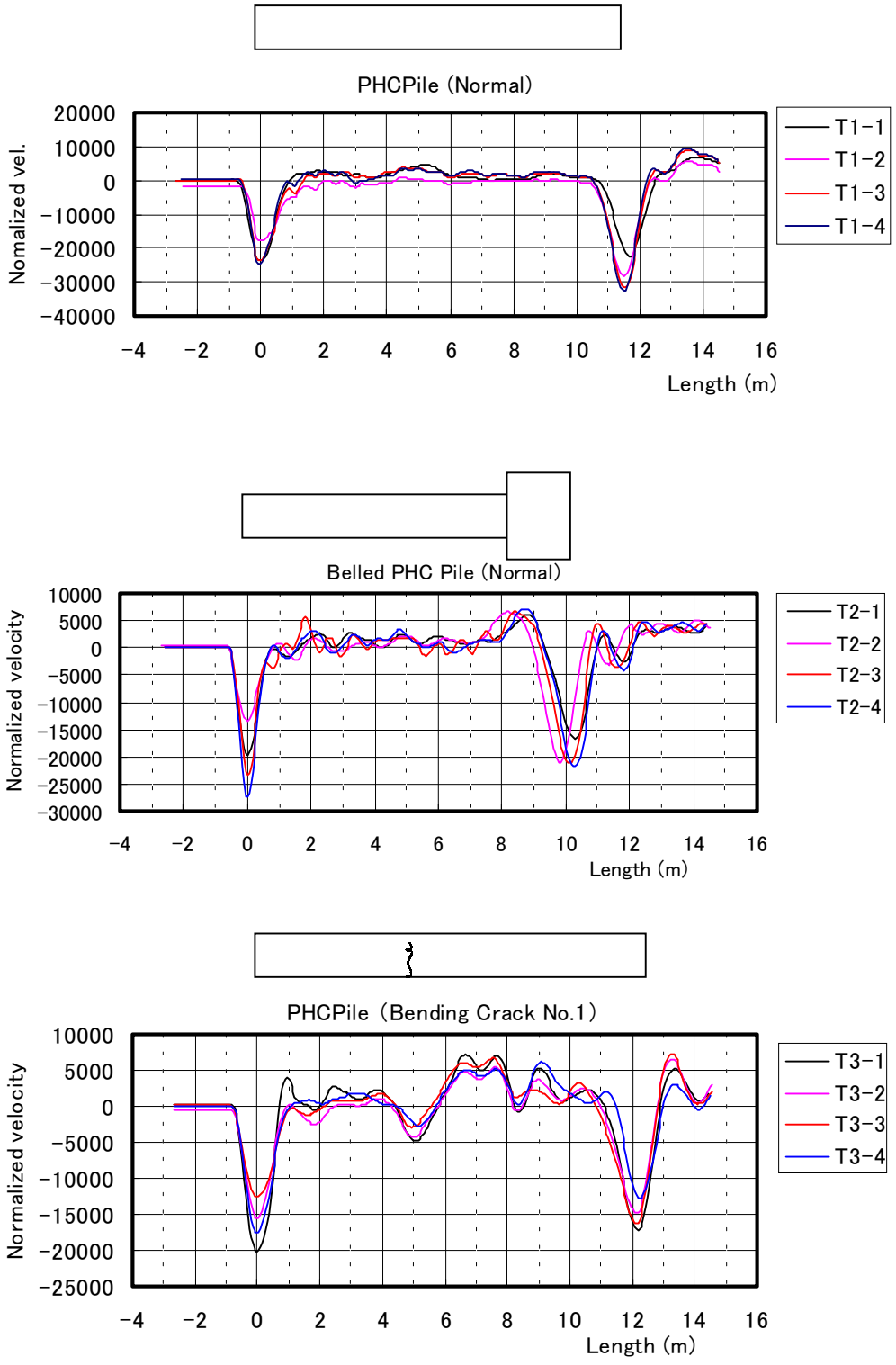


Fig.3.3.2-3 Example of PHC Pile Integrity Test Results

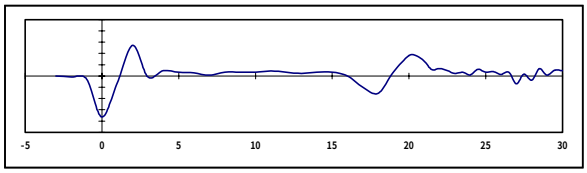
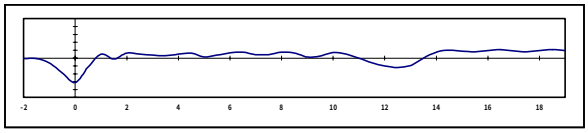
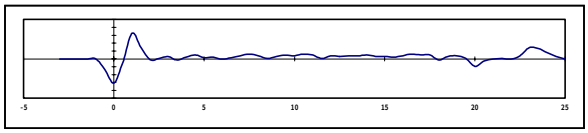
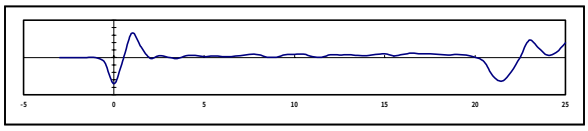
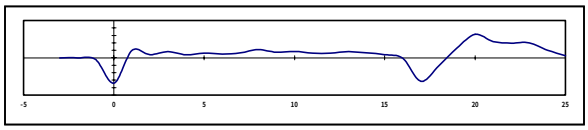
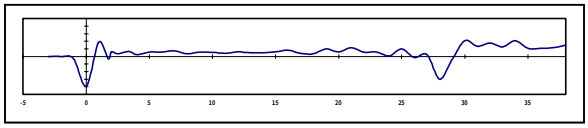
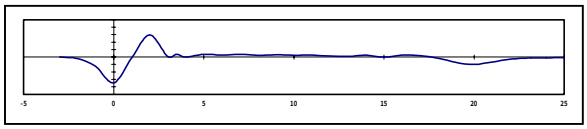
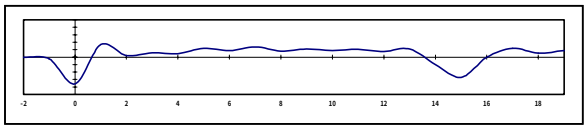
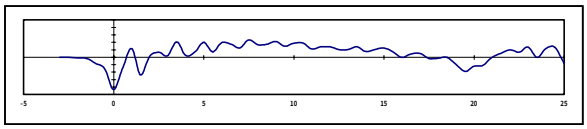
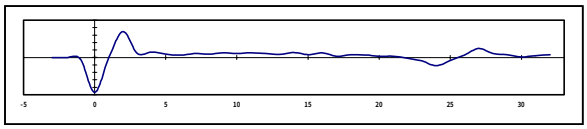
1	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 18m casing pipe 4m-2400mm gaide casing pipe 7m-2200mm It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown. The reflection with the casing can be confirmed to 3.5m and 6.5m.	
2	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 12m 1200mm It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
3	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 19.4m 2500m (belled diameter 2800mm) It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
4	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 20.9m 2100m (Belled diameter 3200mm) It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
5	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 17.5m 2000mm It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
6	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 27m 800mm It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
7	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 24m 1900m (Belled diameter 2600mm) The reflection of belled part is indistinct though the reflection of the paling point is plain. It is judged that this is thought the one by the ground condition.	
8	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 15.45m 1500m (Belled diameter 2600mm) It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	
9	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 19.33m 1100mm The measurement wave has received the influence by cut-off of pile head. It is preferable to the Integrity Tests again after re-cementation of pile head.	
10	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 24m 1500mm It is judged that there is no damage in the pile because there is no downward shape of waves by which damage is shown.	

Fig. 3.3.2-4 Example of Cast-in-place Pile Integrity Test Results (Not damaged) [4]

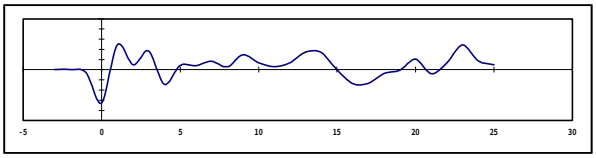
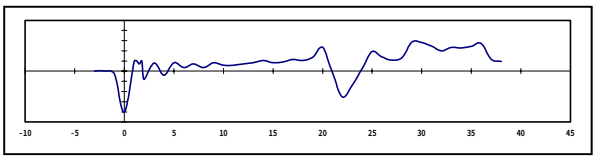
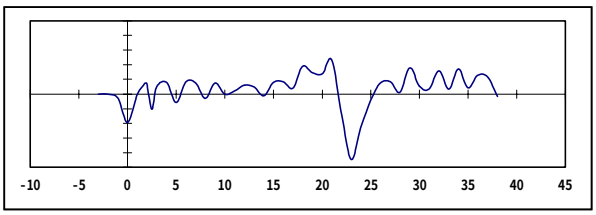
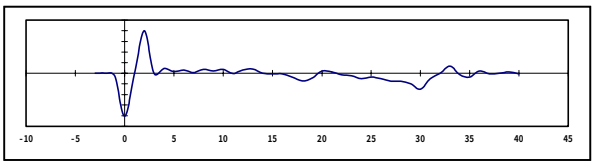
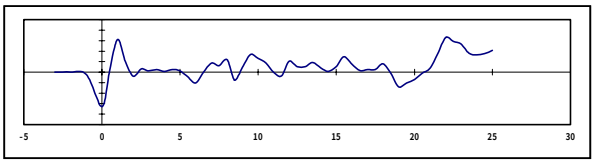
1	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 17.5m 2000mm A downward shape of waves of about 4m shows the reduction-of-area. Because the reflection of the pile point can be confirmed, it is judged that it is partial damage.	
2	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 24m 1700m (Belled diameter 2600mm) A downward shape of waves of about 2.5m shows the reduction-of-area. Because the reflection of the pile point can be confirmed, it is judged that it is partial damage.	
3	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile(Belled Type) 24m 2200m (Belled diameter 3600mm) The cross sectional area of pile of about 2.5m decreases. The repetition shape of waves at deeper position than 2.5m is a reflection of the damage part. The reflection of the point of pile can be confirmed. Because the reflection at 2.5m is large, it is thought that the level of damage of pile is large.	
4	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 29.95m 1500mm The shape of waves by which partial damage is shown can be confirmed to about 27m. The reflection of pile point is about 30m. It is thought that there is a decrease in a partial pile section in about 27m.	
5	Pile Type Design Length Pile Diameter Measurement Result	Cast-in-place pile 18.2m 2100mm A downward reflection by which the reduction-of-area is shown can be confirmed to 6m and about 9m. It is thought that it is a decrease in a partial pile section because it can confirm the reflection of pile point.	

Fig. 3.3.2-5 Example of Cast-in-place Pile Integrity Test Results (Damaged) [4]

2) Borehole camera

Purpose: to ascertain the conditions of damage to the pile

Outline of the borehole camera:

Places damaged by cracks in a pile are observed through images obtained by a video camera or CCD camera inserted into the hollow section of the pile or a borehole made in its concrete.

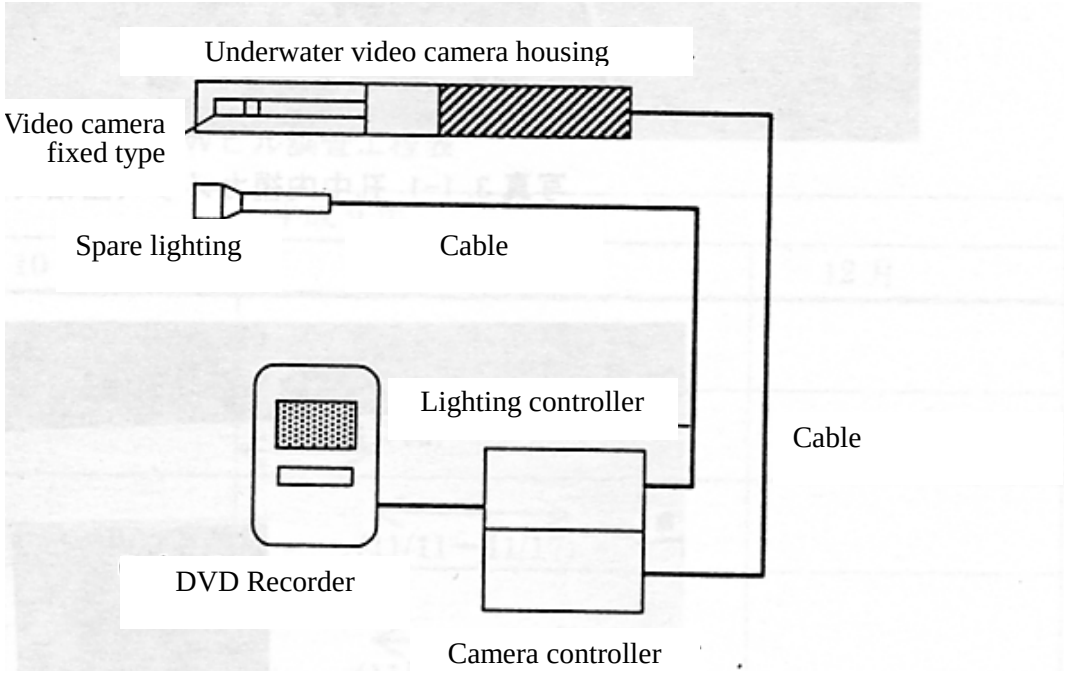


Fig.3.3.2-6 Fixed Type Borehole Camera[2]

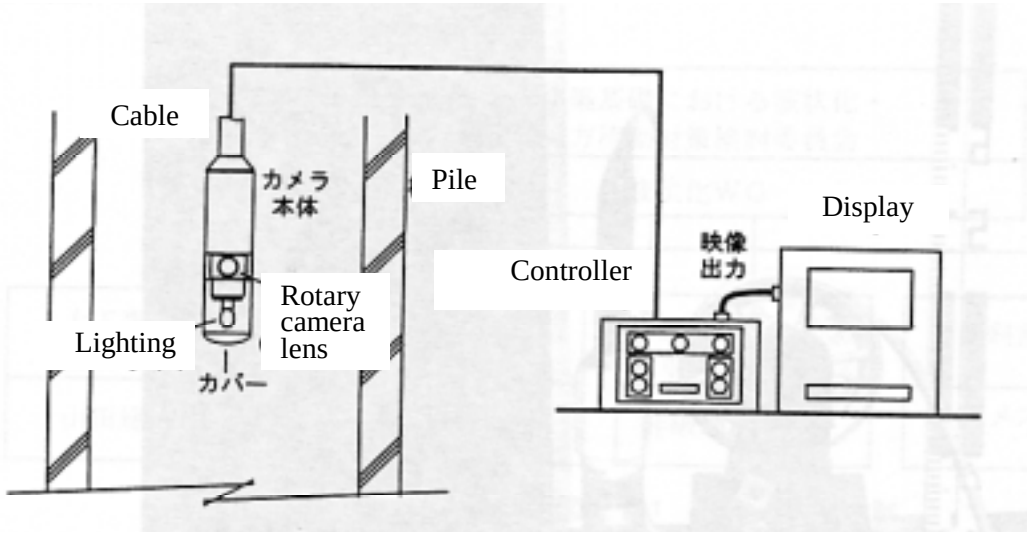


Fig.3.3.2-7 Rotary Type Borehole Camera[2]

3) Inclinometer

Purpose: to measure the horizontal displacement of the pile

Outline of the inclinometer:

The horizontal displacement of a pile is determined by successively measuring its inclination with an inclinometer inserted into its hollow section.

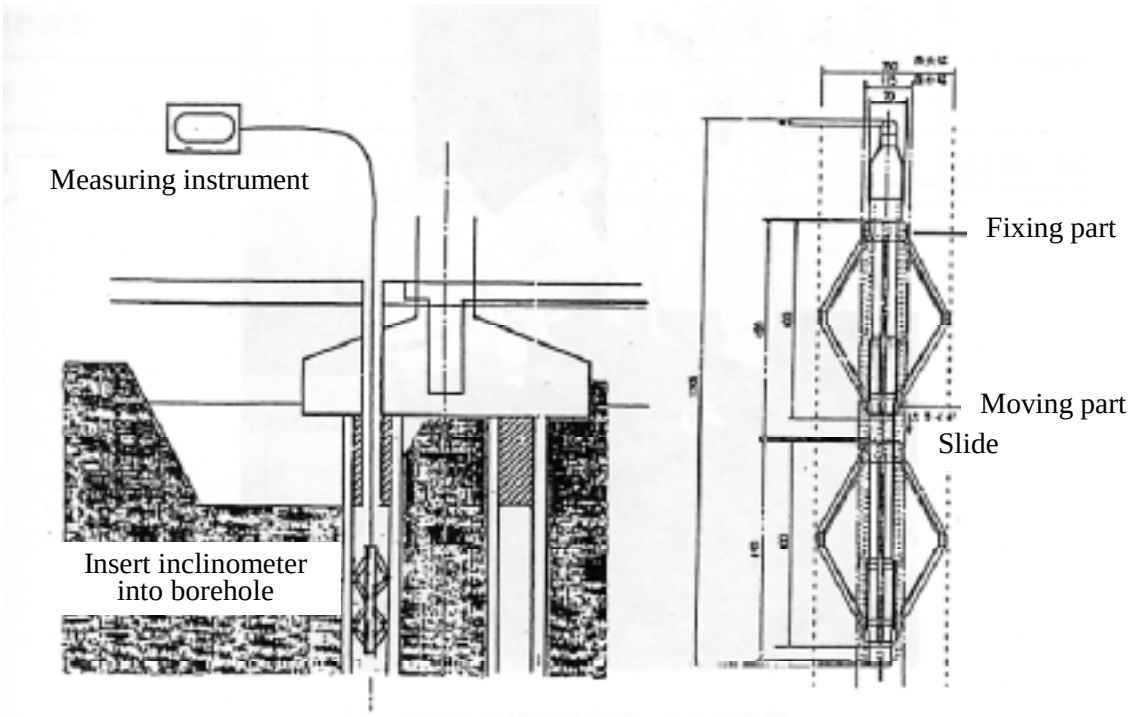


Fig. 3.3.2-8 Insert Type Inclinometer[2]

4) Acoustic emissions

Purpose: to ascertain the damage conditions at places that cannot be visually observed

Outline of acoustic emissions:

Defects such as cracking in the concrete are detected using elastic waves (ultrasonic waves, electromagnetic waves, etc.) that propagate through structures.

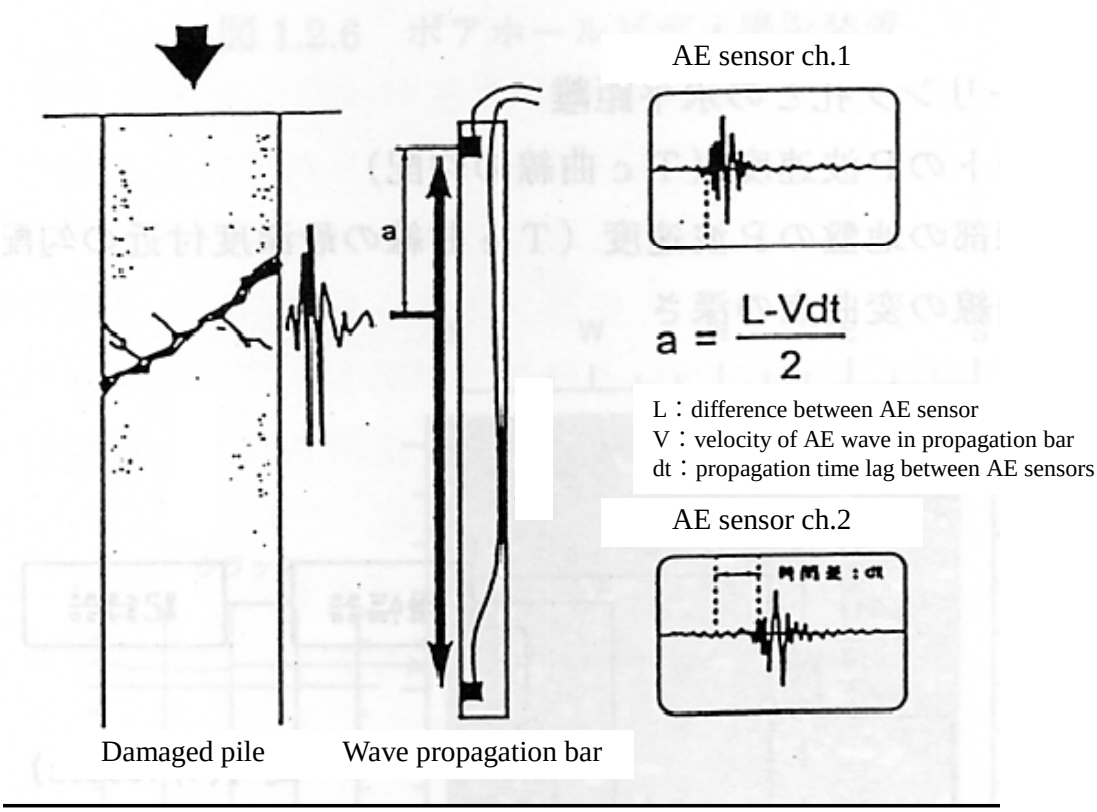


Fig. 3.3.2-9 Measuring Image of Acoustic Emission[3]

5) Visual observation

Purpose: to visually inspect the conditions of damage to foundation members such as pile-head sections, footing beams, footing slabs, and underground walls

Outline of visual observation:

Foundation members are directly observed when they are observable from the inside of a building. Piles and footing beams are observed by excavating the ground around them.

Reference

[1] Damage Grade Classification Manual of Building Foundation and Some Examples of Repair Techniques, Kenchiku Kenkyu Shiryo, BRI, August 1997. (in Japanese)

[2] Committee Report on Soundness Judgement Technology of Earth Structure and

Foundation, Japanese Geotechnical Society, March 1999. (in Japanese)

[3] Committee on Building Foundation Technology against Liquefaction and Lateral Spreading: Study on Liquefaction and Lateral Spreading in the 1995 Hyogoken-Nanbu Earthquake, Building Research Report No.138, BRI, November 2000. (in Japanese)

[4] Ministry of Land, Infrastructure and Transport, General Technology Development Project, “Technology Development on Quality Management System for Construction Works”, Volume of Building Construction, March 2001. (in Japanese)