Korean Design Standard

KCS 11 50 40 : 2019

# Pile Load Test

December 06, 2019
http://www.kcsc.re.kr



국토교통부

# Foreword

• In accordance with the change to the construction standards code system, the duplications and conflicts between existing construction standards (design standards, standard specifications) were compared and reviewed and then integrated into this standard as a standard code.

• This standard provides the standards for pile load tests. The history of this standard and its revisions is as follows.

| Construction Standard | Main Content | Enacted or Revised (Year. Month) |
|---|---|---|
| KDS 11 50 40 : 2016 | • Integrated and maintained as code according to the changes to the construction standards code system | Enacted (2016.6) |
| KDS 11 50 40 : 2016 | • Amended according to Korean Industry Standards and Construction Standards | Amended (2018.7) |

# Table of Contents

# 1. General

## 1.1 Scope of application

(1) This standard applies to the static load test, bidirectional load test, dynamic load test, vertical pullout load test, and horizontal load test (hereinafter referred to as test), in which axial compressive force or pulling force and horizontal force are applied to the pile head of a single pile installed in a vertical position.

(2) The purpose of the horizontal load test is to determine the load-displacement relationship through horizontal loading of single piles or pile groups. This test may be applied to all deep foundations, regardless of the construction method or specifications.

## 1.2 Reference

### 1.2.1 Related laws and regulations

No content

### 1.2.2 Related standards

- KS F 2206 Method of compression test for wood
- KS F 2438 Testing method for static modulus of elasticity and Poisson ′s ratio in compression of cylindrical concrete specimens

## 1.3 Materials to submit

### 1.3.1 Test plan

(1) The test plan shall include basic aspects of the implementation system, such as the layout of the piles, specifications, quantity and arrangement of piles, the level of pile heads, locations, quantity and specifications of test piles, design load, the planned maximum test load, and the loading and measuring methods.

(2) In the test plan, the adequacy of the planned maximum test load should be reviewed considering the purpose of the test, ground conditions, load conditions applied on the piles used, and the pile construction method.

(3) The test plan shall consider the construction period, construction cost, and testing cost, in addition to analyzing the adequacy of the testing equipment, loading and measuring methods, and analysis methods.

(4) Examine test piles to confirm if the planned maximum test load can be applied, and if necessary, plan separate test piles.

### 1.3.2 Test results and analysis report

(1) Perform the tests according to the test plan and report the results.

(2) In addition to the test results, the report shall include details of any particular events that occur during the testing process.

## 1.4 Definitions of terms

- Static load: A load for which resistance that depends on the velocity and acceleration of the pile and ground can be disregarded
- Bidirectional pile load test: A test in which a pressurizing load device is installed at the fore-end of the cast-in-place pile, or at an arbitrary location in order to apply a static downward and upward axial load
- One-way cyclic load test: A test method in which a load is repeatedly applied that increases or decreases at regular intervals in one direction of the pile
- Two-way cyclic load test: A test method for two-way loading by arranging loading positions at 180-degree intervals
- Incremental loading method: A loading method that increases the load while maintaining the load gradually for a certain period of time
- Continuous loading method: A loading method that increases the load continuously without maintaining the load
- Standard loading method: A loading method that gradually increases the load, while maintaining the load for a certain period of time at a random load stage
- Cyclic loading method: A loading method that loads and unloads the load by cycles
- Planned maximum test load: The maximum load applied to a test pile to achieve the purpose of the test
- Load capacity: Shall be defined as one-way load (i.e., the jack capacity), not as the total load in the upper and lower directions. The load capacity should be at least the planned maximum test load.
- Use pile (Main pile): Piles installed as the foundation of a structure
- Test pile: Piles used for load tests
- Pile diameter: Outer diameter of a pile
- Maximum diameter of a pile: The maximum diameter of the part that forms a boundary with the original ground, such as the diameter of a pile, the diameter of the fore-end cementation, and the diameter of the expanded fore-end
- Sensor for measuring the axial load transfer: In general, stress meters and strain meters are used as sensors for measuring the axial load transfer, which mainly uses vibration or electric resistance sensors. The sensors should be installed to indicate the friction bearing capacity of each ground layer.

- Capblock: Material inserted between the pile driver plate and the drive cap at the top of the pile (also referred to as a hammer cushion)
- Cushion: Material inserted between the drive cap on top of the pile and the pile (also referred to as a pile cushion)
- Impact event: The time in which the pile moves, including compression and/or tensile, in the direction of penetration by applying impact force
- Pile impedance: The resistance of a pile to velocity change while pile driving
- Integrity index: An index that indicates the extent of damage to a pile due to pile driving
- PDA (Pile Driving Analysis): An analysis to check the integrity of the pile during pile driving by continuously measuring the compressive/tensile stress, maximum energy transferred, and the penetration resistance that occurs on a pile while driving, to confirm the driveability of the pile by measuring the suitability of hammer selection and the penetration resistance of the pile, and to confirm/verify the pile driving management standards (hammer drop height-final penetration-bearing capacity relationship) by a wave equation, or to develop new pile driving management standards.
- EOID (End Of Initial Driving): A term defining when to perform the dynamic load test to evaluate the bearing capacity, which is generally immediately after pile driving
- Restriking: A dynamic load test performed once a certain period of time has elapsed after piling to check the increase and decrease of skin friction and to confirm the time effect of bearing capacity over time, and to calculate the allowable bearing capacity of the pile
- Failure of piles: Indicates that excessive displacement has occurred in the horizontal direction of a single pile or group pile under a constant or reduced load

## 2. Tests

### 2.1 Static load test

#### 2.1.1 Purpose

(1) The purpose of the test is to obtain data on the properties of the vertical bearing capacity of a pile due to static load, or to confirm the design vertical bearing capacity of a specified pile. In addition, sensors for measuring the load transfer can be installed on a test pile to measure the distribution of frictional force and end bearing capacity by ground layer.

#### 2.1.2 Basic plan

(1) The test plan considers the purpose of the test, ground conditions, load conditions applied on the piles used, pile construction method, the specifications, number and arrangement of the piles used, the level of pile heads, the construction period, and the construction cost, and determines the planned maximum test load, the specifications, number, and locations of piles used, testing

equipment, the loading and measuring methods, and the basic aspects of the implementation system.

### 2.1.3 Planned maximum test load

(1) Depending on the purpose of the test, the planned maximum test load shall be at least the expected ultimate bearing capacity of the pile or the allowable bearing capacity considering the safety factor.

(2) When the conditions of the test pile differ from the design conditions of the main pile, determine the planned maximum test load by considering the effect of the difference on the bearing capacity.

### 2.1.4 Specifications, quantity, and location of test piles

(1) In principle, the test piles shall have the same specifications as the typical main pile. The test piles shall be planned separately from the main piles, and the main piles shall be constructed by analyzing the results of the test piles.

(2) If the strength of the pile material is sufficient and the displacement of the piles after the test does not have an adverse effect on the structure, the test piles may be used as the main piles.

(3) Determine the quantity and location of the test piles according to the purpose of the test.

### 2.1.5 Test equipment

(1) Reaction resistors include the reaction piles, ground anchors, and actual loads, or a combination of these, so choose among them.

(2) When using multiple reaction resistors, the combination of reaction piles and ground anchors is not recommended.

### 2.1.6 Loading and measuring methods

(1) For the loading method, use the incremental loading method.

(2) In principle, use the standard loading method and the cyclic loading method for vertical compression load tests. If necessary, adjust the loading cycle.

(3) Determine the items to measure and the measuring equipment according to the purpose of the test.

### 2.1.7 Preparing the implementation plan

(1) Before performing the test, develop an implementation plan based on the contents of the basic plan and the results of the field survey.

(2) The implementation plan shall include the purpose of the test; ground conditions; the planned maximum test load; the specifications, location, and construction method of the test piles; the

assembly diagram of the testing equipment; the specifications of the hydraulic jack; design calculation of the reaction device; the specifications and construction method of the reaction resistor; measurement items; the configuration, specification, and position of the measuring equipment; the loading method; the measurement period; the composition of test elements; items to record in the field; how to organize the results; the progress schedule; and the precautions to observe during the test period.

### 2.1.8 Test pile design

(1) The materials of the test pile should be sufficiently strong against the load of the maximum load test.

(2) Determine the length of the test pile by considering the assembly of the load and reaction system, the installation of the control beam, and the length of the overhang to attach the measuring equipment.

(3) If necessary, reinforce the head of the test pile by considering the influence of the eccentricity of the load.

(4) If performing negative skin friction prevention work, examine the buckling of piles if necessary.

### 2.1.9 Constructing and curing test piles

(1) In principle, the test piles should be constructed in the same manner as main piles.

(2) Record the status of constructing test piles in detail.

(3) Cure for a sufficient period of time to restore the strength of the disturbed ground due to constructing test piles and to cure the concrete and cement paste properly.

(4) During the curing period, be careful not to apply loads, impact, and vibration that may have adverse effects on the test piles.

### 2.1.10 Installing test equipment and environmental maintenance of the test site

(1) Install the test equipment according to the implementation plan.

(2) Cover the test equipment with sheets and install drains around the test site to prevent adverse effects from direct sunlight, rain, and wind.

(3) Review the effects of vibration from construction, machines, and vehicles near the test site, and if necessary, develop measures to reduce the influence.

### 2.1.11 Test equipment configuration

(1) The test equipment consists of a loading device, a reaction device, and a measuring device.

(2) The loading device consists of a hydraulic jack, a pump, and a loading plate.

(3) The reaction device consists of a reaction resistor, a loading platform, and joint members.

(4) The measuring device consists of a measuring instrument, a control point, and a control beam,

and the measuring instrument is composed of sensors that measure load, displacement, and deformation, and an automatic measuring system that displays and records the measurements.

### 2.1.12 Loading device

(1) The loading device shall be sufficiently safe against the planned maximum test load.

(2) The hydraulic jack shall be equipped with a circular bottom plate by default, and shall only use hydraulic jacks that have been tested and calibrated.

(3) The hydraulic jack shall have a sufficient load capacity for the planned maximum test load and sufficient stroke to cope with the displacement of the test pile and reaction device.

(4) Install the hydraulic jack so that there is no eccentricity in relation to the test pile.

(5) If using multiple hydraulic jacks, apply the same specifications to enable associated control.

(6) The pump shall have sufficient capacity to cope with the load capacity of the hydraulic jack and the set loading rate, and also must be equipped with an automatic load compensation device.

(7) The loading plate shall have sufficient rigidity against the planned maximum test load, and shall be installed horizontally.

### 2.1.13 Reaction device

(1) The reaction device shall have sufficient resistance against the planned maximum test load.

(2) Install the reaction resistor symmetrically with respect to the test pile.

(3) The spacing between the test piles and reaction piles, or the spacing between the test piles and ground anchors, or the spacing between the test piles and pedestals, shall be at least 3 times the maximum diameter of the test pile, or at least 1.5 m.

(4) When using main piles as reaction piles, be careful not to damage the main piles.

(5) When using ground anchors, examine the elongation of the tensile material and develop measures to prevent interference with the test.

(6) Install the anchorage of the ground anchor at a depth that does not affect the bearing capacity characteristics of the test pile.

(7) Install a pedestal so that the actual load and the weight of the loading platform do not act directly on the test pile.

(8) The loading platform shall be safe against bending, shear, ground pressure, and buckling, and the structure shall not overturn.

### 2.1.14 Measuring instruments

(1) Use tested and calibrated measuring instruments according to the purpose of the test.

(2) Install sensors in the proper position and orientation.

(3) When installing sensors, ensure that the sensors are not disturbed by the displacement and deformation of the test pile, loading device, and reaction device according to the progress of the

test.

### 2.1.15 Control point and control beam

(1) Set the control point on a main pile or temporary pile.

(2) If using a main pile as the control point, use a pile located at least 2.5 times the diameter away from the test pile and reaction pile, respectively.

(3) If using a temporary pile as the control point, use a pile installed at a location at least 5 times the diameter of the test pile or more than 2 m away from the test pile, and at least 3 times the diameter away from the reaction pile.

(4) The control point shall be at least 2.5 m away from the ground anchor, the loading plate of the ground anchor, the actual load, and the pedestal of the loading platform.

(5) Install the control beam exactly at the control point so that any deformation caused by temperature changes does not have a significant effect on the measurements.

(6) The control point and beam shall be sufficiently rigid to not be affected by ground vibrations.

### 2.1.16 Loading method

(1) If the incremental loading method is used, the number of load stages, number of cycles, loading rate, and the load duration shall be as shown in Table 1.5-1.

**Table 1.5-1 Loading using the incremental loading method**

| Number of load stages | More than 8 stages | |
|---|---|---|
| Number of cycles | 1 cycle of more than 4 cycles | |
| Loading rate | When the load is increased: $\frac{\text{planned maximum load}}{\text{number of load stages}}$/min | |
| | When the load is reduced: Twice as much as when the load is increased | |
| Load duration of each load stage | New load stage | A fixed time more than 30 min |
| | hysteresis load stage | A fixed time more than 2 min |
| | 0 load stage | A fixed time more than 15 min |

(2) If using the continuous loading method, set an appropriate number of cycles according to the purpose of the test, and increase the load continuously at a constant loading speed.

### 2.1.17 Measurement items

(1) Select the items to measure from among the following according to the purpose of the test.

① Time

② Test load

③ Displacement of pile head

④ Displacement of the fore-end and mid-section
⑤ Deformation of the pile
⑥ Horizontal displacement of pile head
⑦ Displacement of the reaction device
⑧ Other

### 2.1.18 Testing personnel

(1) The testing personnel shall consist of a test manager and a person in charge of loading, measuring, and safety management.

### 2.1.19 Duties of the testing personnel

(1) The test manager shall assign the responsible personnel based on the implementation plan, and manage the overall process in order to safely achieve the purpose of the test.
(2) Before starting the test, each responsible person shall check the safety of the test equipment and confirm that each device operates normally.
(3) The person in charge of loading shall operate the loading device based on the specified loading method.
(4) In addition to organizing and illustrating main data to understand the test status, the person in charge of measurement shall measure the required measurement items at the set times.
(5) The person in charge of safety management shall focus on the safety and environmental maintenance of the test equipment during the test.

### 2.1.20 Starting, stopping, and ending the test

(1) Start the test after organizing conditions such as environmental maintenance of the test site, preparation of each device, and the climate condition.
(2) If any problems with the test equipment or pile occur, stop the test immediately and only resume the test after resolving the cause and when it is deemed that the test can be continued.
(3) End the test once the purpose of the test has been achieved, or when results cannot be obtained and it is deemed that the test cannot be continued.

### 2.1.21 Field records

(1) During the test, record the following items in the field.
① The year, month, day, and time of starting, stopping, and ending the test
② The names of the testing personnel
③ Climate condition
④ The arrangement and specifications of the test equipment and test pile
⑤ Photos of the test equipment and test conditions

⑥ Remarks (The context, cause, and how the situation was handled when there is a difference from the planned testing method)

### 2.1.22 Organizing the results

(1) Organize the measured data and plot relationship curves such as the load-time, displacement-time, load-displacement, load-elastic recovery, and load-residual displacement curves.

(2) Obtain the characteristics related to the vertical bearing capacity of the pile according to the purpose of the test. Characteristics include the yield bearing capacity, ultimate bearing capacity, and the vertical spring constant of the pile head, which are determined through the following methods.

① The yield bearing capacity refers to the load at the clear deflecting point indicated by log P-los S, which is comprehensively determined using the S-log t method, $\Delta S/\Delta \log t$ -P method, and the point at which the residual displacement rapidly increases.

② The ultimate bearing capacity is the load at which the penetration resistance reaches a maximum. However, the fore-end displacement shall be within 10% of the diameter of the fore-end.

③ Calculate the vertical spring constant of the pile head based on the secant gradient of the load-displacement curve.

(3) If you measured the strain of the pile, plot the distribution of axial strain and axial force. Based on the distribution of axial force, evaluate the characteristics of skin resistance and end resistance for each section.

### 2.1.23 Report

(1) State the purpose of the test, the overview of the ground and soil conditions, the test process, the specifications and construction records of the test piles, testing equipment, the loading and measuring methods, and the test results in the report.

(2) For the soil conditions, add detailed information such as ground survey and soil test data.

## 2.2 Bidirectional load test

### 2.2.1 Purpose

(1) This test may be divided into a bearing capacity characteristics test and a bearing capacity verification test depending on the purpose. The former is intended to obtain data on the characteristics of the end bearing capacity or skin bearing capacity of the pile, or both, while the latter is intended to verify whether a specified pile satisfies the design bearing capacity.

### 2.2.2 Basics

(1) In terms of the test plan, determine the basic requirements such as the planned maximum test load, the specification, number, and location of the test piles, testing equipment, and the loading and measuring methods, by considering the purpose of the test, ground conditions, the load conditions applied on the piles used, pile construction method, the specifications, number, and arrangement of the piles used, the level of the pile head, the construction period, and the construction cost.

### 2.2.3 Planned maximum test load

(1) Determine the planned maximum test load according to the purpose of the test after fully considering the expected end resistance, skin resistance, and design bearing capacity of the pile.

(2) If the main purpose of the test is to evaluate the end bearing capacity, the planned maximum test load shall be a value exceeding the expected ultimate end bearing capacity.

(3) If the main purpose of the test is to evaluate the skin resistance characteristics, the planned maximum test load shall be a value exceeding the expected ultimate skin friction.

(4) If the main purpose of the test is to confirm the design bearing capacity, the planned maximum test load shall be a value exceeding the design bearing capacity considering the safety factor.

(5) If the conditions of the test pile differ from the design conditions of the main pile, determine the planned maximum test load by considering the effect of the bearing capacity due to the difference.

### 2.2.4 Specifications, quantity, and location of test piles

(1) In principle, the test piles shall have the same specifications as the typical main pile, and it is recommended that they be planned separately from the main piles. However, the main piles may be used as test piles.

(2) If the strength of the pile material is sufficient and the displacement of the piles after the test does not have an adverse effect on the structure, the test piles may be used as the main piles.

(3) Determine the quantity and location of the test piles according to the purpose of the test.

(4) For load tests to confirm the design bearing capacity, select 1 test pile for each structure, and add the number of test piles by considering the ground conditions and the specifications of the piles.

(5) Plan a roughness test when it is necessary to verify the skin friction of the pile.

### 2.2.5 Test equipment

(1) Install the bidirectional loading device at a position where the lower and upper reaction forces are balanced.

(2) In terms of the integrity of the test pile after completing the load test, the bidirectional loading

device shall not degrade the original integrity of the pile body and bidirectional loading device prior to the load test.

(3) Since pile head and end displacement after the bidirectional load test correspond to the displacement of the exposed jack rod, which may lead to pile settlement in the future, the test pile can only be used as a main pile by using a loading device capable of making the displacement of the exposed rod 0.

(4) Verify the jack and loading system using appropriate methods and calibrate the jack properly.

(5) Determine the capacity, stroke, and installation position of the bidirectional loading device according to the planned maximum test load.

### 2.2.6 Loading and measuring methods

(1) In principle, use the standard loading method and the repeated loading method for the bidirectional pile load test. If necessary, adjust the loading cycle.

(2) Determine the measurement items and measuring instruments according to the purpose of the test. For measuring displacement, measure the upward displacement at 2 or more points, the downward displacement at 2 or more points, and the pile head displacement at 2 or more points.

(3) In general, sensors should be used to measure the load transfer from the beginning to the end of the bidirectional pile load test. If necessary, measure the load transfer after installing the sensors in the reinforcing mesh, immediately after constructing the piles, and for a certain amount of time while curing the piles.

### 2.2.7 Preparing the implementation plan

(1) Before performing the test, develop an implementation plan based on the contents of the basic plan and the results of the field survey.

(2) The implementation plan shall include the purpose of the test; ground conditions; the planned maximum test load; the specifications, location, and construction method of the test piles; the assembly diagram of the testing equipment; the specifications of the bidirectional pile loading device; measures to process the displacement of the exposed rod after the test; the quantity and specifications of the sensors for measuring the load transfer; the installation diagram of the sensors for measuring the load transfer, measurement items; the configuration, specifications, and installation location of measuring equipment; the loading method; the measuring period; the configuration of test elements; the items of field records; how to organize the results; the schedule; and precautions to observe during the test.

### 2.2.8 Test pile design

(1) The body of the test pile shall be sufficiently strong against the planned maximum test load.

(2) Determine the length of the test pile by considering the assembly of the loading device, the installation of the control beam, and the length of the overhang to attach the measuring equipment.

(3) The structure of the test pile shall ensure that the load of the bidirectional pile loading device is transferred to the pile body.

### 2.2.9 Constructing and curing test piles

(1) When installing the bidirectional pile loading device on the test pile, be careful not to cause eccentricity, inclination, and dropping, as this will obstruct the test.

(2) In principle, the test piles should be constructed in the same manner as the main piles. In addition, it should be ensured that the load of the bidirectional pile loading device is transferred to the fore-end of the pile.

(3) Install the sensors for measuring the load transfer at a location where the friction bearing capacity of each ground layer can be verified.

(4) While constructing the test piles, be careful not to damage measuring components such as the valve system for loading including the pressurizing hose and the displacement rod protection pipe for measuring the displacement of the upper and lower plates.

(5) Install the bidirectional pile loading device at the fore-end of the pile or at any arbitrary location.

(6) Record the status of constructing test piles in detail.

(7) Cure for a sufficient period of time to restore the strength of the disturbed ground due to constructing test piles and to cure the concrete and cement paste properly. If necessary, measure the strength of the concrete according to the curing period for reference by using concrete specimens from the construction of test piles.

(8) During the curing period, be careful not to apply loads, impact, and vibration that may have adverse effects on the test piles.

### 2.2.10 Installing the test equipment and environmental maintenance of the test site

(1) Install the test equipment according to the implementation plan.

(2) Cover the test equipment with protective devices and install drains around the test site to prevent adverse effects from weather conditions.

(3) Review the effects of vibration from construction, machines, and vehicles near the test site, and if necessary, develop measures to minimize the influence.

### 2.2.11 Test equipment configuration

(1) The test equipment consists of a bidirectional loading device, a loading system, a measuring device, and an axial load transfer measurement system.

(2) The bidirectional loading device consists of a jack, a pump, and a valve, that are installed at the

fore-end of the test pile or at a suitable position.

(3) The measuring device consists of a measuring system, control point, and control beam. The measuring system consists of sensors capable of measuring loads, displacements, and deformations, an automatic measurement system (data log, switch box for channel expansion, computer), and a displacement rod for measuring pile displacement.

(4) The axial load transfer measurement system consists of sensors for measuring axial load and an automatic measurement system.

### 2.2.12 Bidirectional loading device and loading system

(1) The jacks used in the bidirectional loading device must be tested and calibrated. To increase the accuracy of the load and the reliability of the test, completely assemble the pressure sensor and hose to be actually used, and test to a pressure of at least 1/2 of the nominal capacity of the compression tester.

(2) For large capacity tests and important tests, inspect and calibrate the bidirectional loading device equipped with assembled upper and lower plates. At this time, test and calibrate up to 50% of the nominal capacity of the assembled bidirectional loading device.

(3) The bidirectional pile loading device shall have sufficient load capacity for the planned maximum test load, and shall have sufficient stroke to cope with the displacement of the test pile.

(4) When using multiple hydraulic jacks, apply the same specifications for associated control.

(5) The valve system including the hose for loading shall have sufficient internal pressure capacity without any damage.

(6) The pump shall have sufficient discharge capacity to cope with the loading capacity of the bidirectional loading device and the set loading rate.

(7) Secure enough flow space in order to facilitate concrete placement on the upper and lower plate sectional areas, excluding the sectional areas where multiple jacks are installed.

(8) Since pile head and end displacement after the bidirectional load test correspond to the displacement of the exposed jack rod, which may lead to pile settlement in the future, the test pile can be used as a main pile after taking measures to ensure that the displacement of the exposed rod is 0.

### 2.2.13 Measuring instruments

(1) Use tested and calibrated measuring instruments according to the purpose of the test.

(2) In principle, pressure sensors should be used as the load sensors, and installed as close to the bidirectional pile loading device as possible.

(3) Install sensors for measuring displacement in the proper position and orientation.

(4) When installing sensors and displacement rods for measuring displacement, make sure that they are not disturbed by the progress of the test and the displacement and deformation of the test

piles.

(5) For the load test, install the sensors for measuring axial load at proper intervals in the longitudinal direction to confirm the load transfer for each ground layer of the ground where the test piles are constructed, and install at least 1 sensor for each ground layer.

### 2.2.14 Control point and control beam

(1) Install the control point on a main pile or temporary pile.

(2) If using a main pile as the control point, use a pile located at least 2.5 times the diameter away from the test pile and reaction pile, respectively.

(3) If using a temporary pile as the control point, use a pile installed at a location at least 5 times the diameter of the test pile or more than 2 m away from the test pile.

(4) Install the control beam exactly at the control point so that any deformation caused by temperature changes does not have a significant effect on the measurements.

(5) The control point and control beam shall be sufficiently rigid to not be influenced by ground vibrations.

### 2.2.15 Loading method

(1) Select the standard loading method or the repeated loading method as the loading method, but use the repeated loading method if possible. For the repeated loading method, adjust the number of iterative cycles if necessary.

(2) During the initial loading, load as slowly as possible to confirm the separation of the temporary fixing device to fix the jack and the self-weight of the pile.

### 2.2.16 Loading stage when installing loading devices in multiple stages

(1) If the length of the pile is too long or it is difficult to verify the bearing behavior of the pile with a single bidirectional loading device, perform the test by installing the bidirectional loading device in multiple stages. Here, in terms of the loading order, the test of the loading device installed on the fore-end of the pile should be performed first, then tests of the loading devices on the upper section. Additional tests can be conducted at the discretion of the person conducting the test.

(2) If installing 2 or more stages of loading devices, determine the testing order in a way that will clearly verify the bearing behavior of the pile.

### 2.2.17 Measurement items

(1) Select the items to measure from among the following according to the purpose of the test.

① Time

② Load by loading stage

③ Downward/upward displacement of the pile head and bidirectional pile loading device
④ Displacement of the fore-end and mid-section
⑤ Strain of the pile body (strain or stress of sensor measuring the load transfer by depth)
⑥ Displacement of the ground around the pile
⑦ Other

### 2.2.18 Measuring period

(1) All of the data should be measured automatically, and the automatic measurement system should continuously measure all of the measurement items in real time, from the beginning to the end of the test.

### 2.2.19 Starting, stopping, and ending the test

(1) Start the test after organizing conditions such as environmental maintenance of the test site, preparation of each device, and the climate conditions.
(2) If any problems occur to the test equipment or pile, stop the test immediately. Resume the test after the cause has been resolved and it is deemed that the test can be continued.
(3) End the test once the purpose of the test has been achieved or when it is deemed that the test cannot be continued.

### 2.2.20 Field records

(1) During the test, record the following items in the field.
① The year, month, day, and time of starting, stopping, and ending the test
② The names of the testing personnel
③ Climate condition
④ The arrangement and specifications of the test equipment and test pile
⑤ Photos of the test equipment and test conditions
⑥ Remarks (The context, cause, and how the situation was handled when there is a difference from the planned testing method)
⑦ Cracks of surrounding ground due to the test
⑧ Status from the start and end of grouting after completing the test: Describe in detail

### 2.2.21 Organizing the test results

(1) Use the measured data to plot relationship curves such as the load-time, bottom plate displacement of the bidirectional pile loading device-time, load-bottom plate displacement, load-elastic recovery of bottom plate, load-residual displacement of bottom plate, upper plate displacement-time, and the load-upper plate displacement curves.
(2) The characteristics obtained by measuring the bottom plate displacement of the bidirectional pile

loading device include the ultimate end resistance and the vertical ground reaction coefficient of the fore-end of the pile, which are determined through the following methods. In addition, if the bottom plate of the bidirectional pile loading device is close to the fore-end of the pile, the load of the bidirectional pile loading device can be considered as the end resistance, and the bottom plate displacement as the end displacement.

① The ultimate end resistance is the value at which the end resistance reaches a maximum. However, the end displacement should be within 10% of the diameter of the fore-end.

② Calculate the vertical ground reaction coefficient at the fore-end of the pile based on the secant gradient of the end resistance-displacement curve per unit area of the pile fore-end.

(3) The characteristics obtained by measuring the upper plate displacement of the bidirectional pile loading device include the yield resistance of the skin friction resistance, the ultimate resistance, and the shear ground reaction coefficient of the pile surface, which are determined through the following methods.

① The yield resistance of the skin friction resistance refers to the load at the clear deflecting point shown in the log $P_j$-log $S_{ju}$ curve, which is comprehensively determined using the $S_{ju}$ -log t method, $\Delta S_{ju}/\Delta \log t - P_j$ method, and the point at which the residual displacement rapidly increases. Here, $P_j$: One-direction load, $S_{ju}$: upper plate displacement, t: elapsed time at the new loading stage.

② The ultimate skin friction resistance is the load at which the skin friction resistance reaches a maximum. However, the displacement of the pile head shall be within 10% of the diameter of the fore-end.

③ Calculate the shear ground reaction coefficient of the pile surface using the secant gradient of skin resistance-displacement curve per unit area.

④ If you measured the strain of the pile body, plot the distribution of axial strain and axial force. From the distribution of axial force, evaluate the characteristics of skin resistance and end resistance for each section.

### 2.2.22 Analyzing and interpreting the results

(1) Prepare and analyze the pile head equivalent load-settlement curve using the load-bottom plate displacement and load-upper plate displacement curves.

(2) If necessary, prepare a modified equivalent load-displacement curve to obtain characteristics corresponding to the static load test method of the head loading method.

(3) When preparing the equivalent load-displacement curve, use only the measured downward and upward reaction forces; do not use the reaction force estimated through extrapolation. However, you may use the extrapolated pile head equivalent load if the ground at the end is too soft to support sufficient loading even if its load capacity is high enough; here, discretion must be used, as this is not based on test results.

(4) Prepare and analyze the distribution chart of axial load using the distribution chart of skin friction according to the depth.

(5) If the loading device is installed in 2 or more stages, prepare the pile head equivalent load-settlement relationship and the distribution chart of axial load according to the purpose of the test and the order of loading.

#### 2.2.23 Report

(1) State the purpose of the test, overview and characteristics of the ground, the specifications of the test piles, construction records, test equipment, arrangement and quantity of sensors for measuring load transfer, the loading and measuring methods, the displacement of the exposed jack rod and the test results (bearing capacity analysis, distribution of axial load, and the distribution of average friction stress by ground layer).

### 2.3 Dynamic load test

#### 2.3.1 Purpose

(1) The purpose of the dynamic load test is to measure the bearing capacity of the piles, confirm the quality of the piles and establish pile driving management standards, so make correct measurements in the field in order to perform analysis based on accurately measured data.

#### 2.3.2 Pile driving equipment

(1) Use general pile drivers or similar equipment to apply impact force to the piles. These should be capable of inducing pile penetration that can produce a static resistance in the substrate exceeding the design bearing capacity, or capable of applying impact energy to a pile for a minimum of 3/1,000 seconds (3 ms).

(2) The position of the pile driver shall be in the axial direction relative to the pile head, and pile driving shall be performed at the center of the pile.

#### 2.3.3 Dynamic behavior measuring instruments

(1) Include a transducer that can independently measure the acceleration and deformation over time at specific locations along the pile axis during pile driving.

(2) Securely attach at least 2 instruments, one to measure acceleration and the other to measure deformation, on the opposite side of the center axis of the pile.

(3) You may use bolt tightened, glued, or welded measuring instruments.

#### 2.3.4 Accelerometer

(1) Use accelerometers and converting devices that are capable of converting to velocity by

integration for analysis.

(2) Use accelerometers with a resonance frequency of at least 2,500 Hz, and attach at least 2 symmetrically in the circumferential direction with respect to the center axis of the pile.

(3) For concrete piles, use accelerometers that are linear within the range of at least 9.81 N and 1,000 Hz; for steel pipe piles, use accelerometers that are linear within the range of at least 9.62 Ng and 2,000 Hz.

### 2.3.5 Strainmeter

(1) The strainmeter shall provide linear results across the entire range of deformability. The strength to install on the pile or the natural frequency of the strainmeter shall be at least 2,000 Hz.

(2) Convert the measured strain into force by using the pile net sectional area and the dynamic modulus of elasticity at that location.

(3) The dynamic modulus of elasticity of steel is (200~207) × 106 kPa.

(4) The dynamic modulus of elasticity of concrete and wood piles can be estimated from the measurements obtained through performing compression tests according to KS F 2438 and KS F 2206.

(5) Alternatively, the elastic modulus ($E = \rho c^2$) of concrete, wood, and steel piles can be calculated by multiplying the unit weight (density of the pile material) by the square wave velocity (the velocity at which the compression wave propagates along a pile).

### 2.3.6 Pile driving analyzer

(1) You need a device that receives measured data from the accelerometers and strainmeters attached to the piles, converts it into displacement and force, and displays the results on a screen (mainly LCD).

(2) This equipment shall be capable of acquiring and processing data, in addition to converting signals, and shall have data processing functions suitable for waveform analysis programs.

(3) This equipment consists of a signal storage device, a data processing device, a converted data storage device, and a screen output device.

### 2.3.7 Selecting test piles and arranging the heads

(1) Select the test piles, in which the length of the ground section should be about 3 D (D: diameter of the pile). To prevent eccentricity, the pile head should be completely smooth, without any protrusions.

### 2.3.8 Selecting gauges

(1) In terms of gauges used in the dynamic load test, there are types in which the strainmeter and accelerometer are separated or integrated, so select the same type. In other words, use the

separated type separately and the integrated type integrally.

(2) For spiral type large-diameter steel pipe piles and large-diameter cast-in-place piles, attach multiple gauges to acquire accurate data.

(3) The gauges must be tested and calibrated by the manufacturer or an authorized certification institute within the validity period determined by each manufacturer. If there is no specific regulation, use gauges that have been tested and calibrated within the last 2 years.

### 2.3.9 Attaching the gauges

(1) Attach the gauges symmetrically (180°) to the pile in pairs, and separate the gauges by at least 1.5 D (D : pile diameter or diagonal length) from the pile head. Use bolts, glue, or welding equipment to attach the gauges securely in order to prevent their movement.

### 2.3.10 Entering initial values

(1) Pile length

① Entire length of the pile

② Length from the head to the position at which the gauge is installed

③ Penetration length from the surface to the fore-end of the pile

(2) Pile area

① Total area based on the outer diameter of the pile

② Net sectional area excluding the inner diameter from the outer diameter of the pile

③ Modulus of elasticity of the pile

④ Unit weight of the pile

⑤ Elastic wave velocity

⑥ Damping factor of the ground

⑦ Gauge correction factor

### 2.3.11 Gauge inspection

(1) The initial state of the gauge is related to the reliability of the dynamic load test, which can be broadly divided into confirming the gauge correction factor and the state of attachment. If the output of the gauge is outside the allowable range or if the waveform is unstable, check or replace the gauge attached to the pile.

### 2.3.12 Mounting the hammer

(1) Mount the hammer on the pile to strike it. Align the axial lines of the hammer and pile to prevent deviations.

### 2.3.13 Pile driving and data evaluation

(1) After 3 ~ 5 times of initial pile driving, check for deviations by referring to the difference in the left and right load graphs displayed on the pile driving analyzer.

(2) In the event of deviations, move the pile driver and resume pile driving, then check for final deviations.

(3) Ensure the proportionality of measured data to obtain good quality data.

(4) Save the measured data by confirming and entering the final penetration length.

### 2.3.14 Analyzing the test results

(1) Selecting the analysis waveform: The criteria for selecting the analysis waveform is the occurrence of displacement so that proportionality is good and sufficient bearing capacity is expressed and can be established by referring to the compressive force of the pile head, the maximum tensile stress on the pile, and the maximum pile driving energy.

(2) Matching: After reproducing and analyzing the waves measured in the field indoors, show the results of the measured waves and the reproduced and analyzed waves together.

### 2.3.15 Organizing the test results

(1) The test results shall include the following.

① Site name

② Drill log of the test location or adjacent location

③ The name, hammer weight, and drop height of the pile construction equipment

④ Hammer cushion, pile cushion, lead type

⑤ Calibration certificate for gauges used (valid period)

⑥ Type of test piles, construction method, construction date, test date

⑦ Design load of the test pile

⑧ Length, diameter, thickness, and sectional area of the test pile

⑨ Description of gauge installation and the test procedure, including locations

⑩ Test date, the order of driving test piles, and penetration depth during initial driving or restriking

⑪ Gauge installation position, unit weight, elastic wave velocity, elastic modulus, damping factor

⑫ Description of the end of test pile driving and the start of restriking during initial driving or restriking

⑬ Hammer performance, compressive stress at the head and fore-end of the pile

⑭ Description of the integrity

⑮ Final penetration at the end of pile driving

### 2.3.16 Analyzing the results

(1) The analysis of the test results shall include the following.

① Description of calculating the bearing capacity of the test pile: Confirmation on initial pile driving or restriking, and description on the end of test pile driving and the start of restriking in terms of restriking

② Estimated skin friction force and end bearing capacity based on the results of analyzing the measured and calculated waves

③ Distribution of skin friction force according to the penetration depth

④ Dynamic coefficient of subgrade reaction at the fore-end and skin of the pile (quake, damping)

⑤ Driveability analysis during the end of initial driving

## 2.4 Vertical pullout load test

### 2.4.1 Purpose

(1) The purpose of the test is to obtain data on the pullout resistance characteristics of the pile due to static loads, or to confirm the validity of the previously determined design pullout bearing capacity of the pile.

### 2.4.2 Basics

(1) The test plan considers the purpose of the test, ground conditions, the load conditions on the piles used, construction method of the piles used, the specifications, quantity, and layout of the piles used, the position of the pile head, test period, and construction cost, and determines the planned maximum test load; the specifications, quantity, and location of the test piles; the test equipment; the loading and measuring method; and the basic requirements of the implementation system.

### 2.4.3 Planned maximum test load

(1) The planned maximum test load shall at a minimum be the expected ultimate pullout bearing capacity of the pile according to the purpose of the test, or the design pullout bearing capacity considering the factor of safety.

(2) If the conditions of the test pile differ from the design conditions of the main piles, determine the planned maximum test load by considering the effect of the pullout bearing capacity due to the difference.

### 2.4.4 Specifications, quantity, and location of test piles

(1) In principle, the test piles should be installed with the same specifications as the typical main pile.

(2) If the strength of the pile material is sufficient and the displacement of the piles after the test does not have an adverse effect on the structure, the test piles may be used as the main piles.
(3) Determine the quantity and location of the test piles based on the purpose of the test.

### 2.4.5 Test equipment

(1) The reaction resistors include reaction piles and reaction plates, and either can be applied.

### 2.4.6 Loading and measuring methods

(1) Loading methods include the incremental loading method and the continuous loading method. In the former, the number of loading stages, the number of cycles, and the load holding time must be determined, while for the latter the number of cycles and the loading rate must be determined.
(2) Determine the items to measure and the measuring equipment according to the purpose of the test.

### 2.4.7 Preparing the implementation plan

(1) Before performing the test, develop an implementation plan based on the contents of the basic plan and the results of the field survey.
(2) The implementation plan shall include the purpose of the test; ground conditions; the planned maximum test load; the specifications, location, and construction method of the test piles; the assembly diagram of the testing equipment; the specifications of the hydraulic jack; design calculation of the reaction device; the specifications and construction method of the reaction resistor; the final pullout displacement; measurement items; the configuration, specifications, and positions of the measuring equipment; the loading method; the measurement period; the composition of test elements; items to record in the field; how to organize the results; the progress schedule; and the precautions to observe during the test period.

### 2.4.8 Test pile design

(1) The materials of the test pile shall be sufficiently strong against the planned maximum test load.
(2) Determine the length of the test pile by considering the assembly of the load and reaction system, the installation of the control beam, and the length of the overhang to attach the measuring equipment.
(3) If necessary, reinforce the test pile head by considering the influence of the eccentricity of the load.

### 2.4.9 Constructing and curing test piles

(1) In principle, the test piles should be constructed in the same manner as the main piles.

(2) Record the status of constructing test piles in detail.
(3) Cure for a sufficient period of time to restore the strength of the ground disturbed by the construction of test piles and to cure the concrete and cement paste properly.
(4) During the curing period, be careful not to apply loads, impact, and vibration that may have adverse effects on the test piles.

### 2.4.10 Installing test equipment and environmental maintenance of the test site

(1) Install the test equipment according to the implementation plan.
(2) Cover the test equipment with sheets and install drains around the test site to prevent the adverse effects of direct sunlight, rain, and wind.
(3) Review the effects of vibration from construction, machines, and vehicles near the test site, and if necessary, develop measures to reduce the influence.

### 2.4.11 Test equipment configuration

(1) The test equipment consists of a loading device, a reaction device, and a measuring device.
(2) The loading device consists of a hydraulic jack, a pump, and a joint with the test pile.
(3) The reaction device consists of a reaction resistor, a loading platform, and its joint members.
(4) The measuring device consists of a measuring instrument, a control point, and a control beam. The measuring instrument is composed of sensors that measure load, displacement, and deformation, and an automatic measuring system that displays and records the measurements.

### 2.4.12 Loading device

(1) The loading device shall be sufficiently safe against the planned maximum test load.
(2) The hydraulic jack shall be equipped with a circular bottom plate by default, and shall only use hydraulic jacks that have been tested and calibrated.
(3) The hydraulic jack shall have sufficient load capacity for the planned maximum test load, and sufficient stroke to cope with the displacement of the test pile and reaction device.
(4) Install the hydraulic jack so there is no eccentricity in relation to the test pile.
(5) When using multiple hydraulic jacks, apply the same specifications for associated control.
(6) The pump shall have sufficient capacity to cope with the load capacity of the hydraulic jack and the configured load speed.
(7) The joint with the test pile shall be sufficiently safe against the planned maximum test load.

### 2.4.13 Reaction device

(1) The reaction device shall have sufficient resistance against the planned maximum test load.
(2) Install the reaction resistor symmetrically with respect to the test pile.
(3) The spacing between the test piles and reaction piles, or the spacing between the center of the

test piles and reaction plates shall be at least 3 times the maximum diameter of the test pile, or at least 1.5 m.

(4) When using main piles as reaction piles, be careful not to damage the main piles.

(5) The loading platform shall be safe against bending, shear, ground pressure and buckling, and the structure shall not overturn.

### 2.4.14 Measuring device

(1) Use tested and calibrated measuring instruments according to the purpose of the test.

(2) Install sensors in the proper position and orientation.

(3) When installing sensors, ensure that the sensors are not disturbed by the displacement and deformation of the test pile, loading device, and reaction device according to the progress of the test.

### 2.4.15 Control point and control beam

(1) Set the control point on a main pile or temporary pile.

(2) If using a main pile as the control point, use a pile located at least 2.5 times the diameter away from the test pile and reaction pile, respectively.

(3) If using a temporary pile as the control point, use a pile installed at a location at least 5 times the diameter of the test pile or more than 2 m away from the test pile, and at least 3 times the diameter away from the reaction pile.

(4) The control point shall be at least 2.5 m away from the reaction plate.

(5) Install the control beam exactly at the control point so that any deformation caused by temperature changes does not have a significant effect on the measurements.

(6) The control point and control beam shall be sufficiently rigid so as not to be influenced by ground vibrations.

### 2.4.16 Loading method

(1) Select the standard loading method or the repeated loading method as the loading method.

### 2.4.17 Measurement items

(1) Select the items to measure from among the following according to the purpose of the test.

① Time

② Load

③ Displacement of the pile head

④ Displacement of the fore-end, underground section, and the loading point

⑤ Strain of pile material

⑥ Horizontal displacement of the pile head

⑦ Displacement of the reaction device
⑧ Displacement of the ground around the pile
⑨ Other

### 2.4.18 Implementing the test

(1) The testing personnel shall consist of a test manager and a person in charge of loading, measuring, and safety management.

(2) Duties of the testing personnel

① The test manager shall assign the responsible personnel based on the implementation plan and manage the overall process in order to safely achieve the purpose of the test.

② Before starting the test, each responsible person shall check the safety of the test equipment and confirm that each device operates normally.

③ The person in charge of loading shall operate the loading device based on the specified loading method.

④ In addition to organizing and illustrating main data to understand the test status, the person in charge of measuring shall measure the required measurement items at the set times.

⑤ The person in charge of safety management shall focus on the safety and environmental maintenance of the test equipment during the test.

### 2.4.19 Starting, stopping, and ending the test

(1) Start the test after organizing conditions such as environmental maintenance of the test site, preparation of each device, and the climate condition.

(2) If any problems occur to the test equipment or pile, stop the test immediately and resume the test after resolving the cause when it is deemed that the test can be continued.

(3) End the test once the purpose of the test has been achieved, or when it is deemed that the test cannot be continued.

### 2.4.20 Field records

(1) While conducting the test, record the following items in the field.

① The year, month, day, and time of starting, stopping, and ending the test
② The names of the testing personnel
③ Climate condition
④ The arrangement and specifications of the test equipment and test pile
⑤ Photos of the test equipment and test conditions
⑥ Cracks in the surrounding ground due to the test
⑦ Remarks (The context, cause, and how the situation was handled when there is a difference from the planned testing method)

### 2.4.21 Organizing the results

(1) Organize the measured data and plot relationship curves such as the load-time, displacement-time, load-displacement, load-elastic recovery, and load-residual displacement curves.

(2) Obtain the characteristics related to the vertical bearing capacity of the pile according to the purpose of the test. Characteristics include the yield bearing capacity, ultimate bearing capacity, and the vertical spring constant of the pile head, which are determined through the following methods.

① The yield bearing capacity refers to the load at the clear deflecting point indicated by log P-los S, which is comprehensively determined using the S-log t method, $\Delta S/\Delta t - P$ method, and the point at which the residual displacement rapidly increases.

② The ultimate bearing capacity is the load at which the penetration resistance reaches a maximum. However, the fore-end displacement shall be within 10% of the diameter of the fore-end.

③ Calculate the vertical spring constant of the pile head based on the secant gradient of the load-displacement curve.

(3) If you measured the strain of the pile, plot the distribution of axial strain and axial force. Based on the distribution of axial force, evaluate the characteristics of skin resistance and end resistance for each section.

### 2.4.22 Report

(1) State the purpose of the test, the overview of the ground and soil conditions, the test process, the specifications and construction records of the test piles, testing equipment, the loading and measuring methods, and the test results in the report.

(2) For ground conditions, add detailed information such as ground survey and soil test data.

## 2.5 Horizontal load test

### 2.5.1 Purpose

(1) The actual allowable load between the pile and the ground can be measured using the horizontal load test, and the interaction between the pile and ground with respect to the horizontal load is measured to provide the data required to approve matters related to research, foundation design, maintenance, and specifications.

(2) The main purpose of the horizontal load test of piles is to reflect the results directly or indirectly in the design of the pile foundation.

### 2.5.2 Load test plan

(1) Since the overall plan of the load test changes depending on the purpose, scale, and surrounding environment, consider the following in advance when planning the test.

① Ground conditions

② Pile conditions

③ External force conditions

④ Design conditions

⑤ Repeated calculation

### 2.5.3 Types of load tests

(1) The standard load test shall be performed with the pile head in a free state.

(2) The following load tests shall be performed on a multi-cycle basis with a constant loading speed.

① Repeated load test of (+)(-)

② One-way load

③ Classification according to design load and load cycle

### 2.5.4 Selecting the test pile

(1) For the test pile, examine the specifications of the piles and the ground around the pile and choose the typical pile.

### 2.5.5 Location of test piles

(1) In principle, the ground around the test pile shall be horizontal and free of disturbance.

(2) There should be no structures, embankments, and reaction piles within the range that could affect the deformation of the test piles.

### 2.5.6 Curing period of test piles

(1) Cure the test piles for a sufficient period of time to restore the strength of the ground disturbed by the construction of piles, and to cure the concrete and cement paste properly.

### 2.5.7 Reinforcing the pile body

(1) Reinforce the load point of the test pile to prevent local damage and deformation.

(2) Consider the stability of the loading device during reinforcement.

### 2.5.8 Test method

(1) The height of the load point shall be set as the position closest to the state in which the pile is actually subject to the load of the structure.

(2) Determine the loading method by considering the following.

① The type of structure, type of external force, and the purpose of the test.
② Select repeated loading or one-direction loading as the loading method.
③ Loading methods are shown in Table 5.4-1 and Table 5.4-2.

**Table 5.4-1 Repeated loading method**

| Category | When the load is increased | When the load is reduced |
|---|---|---|
| Load stage | More than stage 8 | More than stage 8 |
| Loading rate | $\frac{\text{planned maximum load}}{8\sim20}$(Ton/minute) | $\frac{\text{planned maximum load}}{4\sim10}$(Ton/minute) |
| Load duration | 3 minutes for each load stage | 3 minutes for each load stage |

**Table 5.4-2 One direction loading method**

| Category | When the load is increased | | When the load is reduced |
|---|---|---|---|
| Load duration | Initial load, hysteresis load | 3 minutes | 3 minutes |
| | 0 load | 15 minutes | |

(3) The loading method shall be based on multiple cycles with a constant loading speed. However, depending on the purpose of the test a single loading may be applied.

### 2.5.9 Planned maximum test load, planned maximum displacement

(1) The purpose of the test is related to the design method, to confirm the allowable horizontal load and the allowable horizontal displacement in terms of the elastic design method.
(2) If the test conditions are close to the design conditions, the allowable horizontal load and allowable horizontal displacement shall be the planned maximum test load and the planned maximum displacement, respectively.
(3) In terms of the ultimate design method, the purpose of the test is to confirm the internal force and deformation performance of the pile and the bearing capacity of the ground.
(4) If the load test is performed until the failure of the pile and ground, set the planned maximum test load and the planned maximum displacement by considering the ground conditions and the constraints of the pile. The test equipment shall also be capable of this.

### 2.5.10 Measurement items

(1) Measure the following items.
① Time, climate, temperature
② Load
③ Displacement of the load point

④ The inclination angle of the pile head
⑤ Displacement of the reaction pile
⑥ The status of the surrounding ground
⑦ Bending deflection of the pile body
⑧ Bending angle of the pile body
⑨ Earth pressure

### 2.5.11 Measurement interval

(1) The measurement interval shall be as specified in Table 5.4-3 and Table 5.4-4 according to the measurement items and loading method.

**Table 5.4-3 Measurement interval (One direction loading method)**

| Measurement item | Measuring time when the load is increased | | Measuring time when the load is reduced |
|---|---|---|---|
| Load | Initial load, hysteresis load | 0 min, 2 min | 0 min |
| | 0 load | 0, 2, 4, 8, 14 min | |
| Displacement, pile head inclination angle | Initial load, hysteresis load | 0 min, 2 min | 0 min |
| | 0 load | 0, 2, 4, 8, 14 min | |
| Other | Initial load, hysteresis load | 0 min | 0 min |
| | 0 load | 0, 8, 14 min | |

**Table 5.4-4 Measurement interval (Repeated loading method)**

| Measurement item | Measuring time when the load is increased | | Measuring time when the load is reduced |
|---|---|---|---|
| Load | Each load stage | 0 min, 2 min | 0 min |
| Displacement, pile head inclination angle | Each load stage | 0 min, 2 min | 0 min |
| Other | Each load stage | 0 min | 0 min |

Note 1) Pile strain, bending angle of pile body, earth pressure, displacement of reaction pile, observation of surrounding ground, etc.

### 2.5.12 Completing testing

(1) The test is complete when the following is true.
① The planned maximum test load has been reached
② The planned maximum displacement has been reached
③ The required records have been obtained and the purpose of the test achieved

### 2.5.13 Load device

(1) Operate the load device safely by considering the purpose of the test, method, planned maximum test load, type of pile, and the surrounding conditions.

(2) The load device consists of a loading device and a reaction device.

(3) Unless otherwise specified, the horizontal loading device shall follow the method described below, and shall be designed so that the reaction load can be loaded horizontally.

(4) To minimize the eccentric load, the load device should be located on the vertical axis of single and group piles. For horizontal load tests of group piles including inclined piles or an inclined pile structure, apply the horizontal load at the intersection of the longitudinal axis of the pile.

### 2.5.14 Loading device

(1) The loading device shall have a capacity of at least 120% of the planned maximum test load, and shall be capable of complying with the expected deformation of the test piles.

### 2.5.15 Reaction device

(1) The reaction device shall be safe and have sufficient resistance under the planned maximum test load.

(2) When loading a single pile or a group pile, establish a proper reaction system by using one or more hydraulic cylinders and structures.

(3) Adjacent foundation piles are often used as reaction devices, and structural foundations are rarely used.

### 2.5.16 Measuring instruments

(1) The measuring instruments shall have the appropriate capacity and degree according to the purpose of the test.

(2) The test shall not be influenced by vibrations caused by work and traffic and weather conditions.

### 2.5.17 Load measuring device

(1) Use a load cell or a hydraulic pressure sensor to measure load, and avoid measuring using only a pressure gauge.

### 2.5.18 Displacement measuring device

(1) In general, displacement measuring devices consist of a control point, a control beam, and a displacement meter.

(2) Install the control point within a range that is not affected by the displacement of the test pile and reaction pile.

(3) The control beam shall be sufficiently rigid according to the spacing of the control points, and a

support method that is not affected by external temperature changes must be selected.

(4) Install the displacement meter in the forward direction in order to accurately measure the displacement.

### 2.5.19 Other measuring devices

(1) When measuring the flexural strain and earth pressure, choose the proper equipment according to the purpose of the test and review the installation method.

### 2.5.20 Organizing the test results

(1) Plot the load-displacement curve and the load-time curve for the pile head, in addition to the relationship between the load and the inclination angle of the pile.

(2) For multi-cycle load tests, plot the load-elastic recovery and load-residual displacement curves as well.

### 2.5.21 Using the results

(1) When estimating the behavior of a pile under horizontal force during a load test, consider the difference between the pile and load conditions in the actual structure and load test.

### 2.5.22 Report

(1) In addition to summarizing the test method, test equipment, and results, organize the report so that people can easily understand the overview of the ground, the construction conditions of the test piles, and the test process.