A SEISMIC RETROFITTING APPLICATION BY MEANS OF MULTI-HELIX MICROPILES

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Abstract

The Multi-helix Micropile method utilizes a unique method of directly screwing a small steel pipe pile with four helical plates into the ground. Fundamental features and a seismic retrofitting application of an existing pier foundation are described focusing on construction point of view.

Introduction

Conventional micropile methods are well-established piling techniques in Europe and the US [1)]. In general, these methods involve small-scale grouting anchors with a reinforcing bar and steel pipe in it. The most notable feature is that high bearing capacity can be attained, in compression as well as in tension, despite the relatively small pile dimensions. These methods also have the advantage of being widely applicable in various types of subsoil and under restricted working conditions.

Based on a joint study on seismic retrofitting technologies for existing foundations initiated by PWRI, several micopile methods including conventional ones have been developed in Japan. Reinforcing effects against existing foundations by means of micropiles have been verified through various model tests and numerical analyses [2)].

Since 1980's, diverse screw piles have been developed in Japan for supporting various structures. The diameter of piles ranges from 100 to 1,200mm, mostly with a single screw of 2 to 3 times the shaft diameter being attached to the shaft. Through various experiences in the application of several types of screw piles, the author's research group has proposed the Multi-helix Micropile (referred to as a MH-MP) method [3)] with basic concepts of simplicity, cost effectiveness and environmental friendliness in mind. Major features and application example of MH-MP method is briefly reported in this paper.

Components and features

(1) Basic Components

The MH-MP consists of a lead section with 4 helical plates welded to a central pipe shaft and shaft extensions (FIG.1). A bearing plate is welded at the pile top after being installed. The shaft diameter ranges from 114.3 mm to 267.4 mm, with the relatively larger diameter generally used for seismic retrofitting. Typical dimensions are shown in TABLE 1.The size of the helical plates increases as they are placed up the shaft of the lead section. The spacing between each helix remains constant at 1,330 mm regardless of the shaft

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diameter. Extension sections are connected to a lead section up to the desired length by welding or using mechanical joint. Apparently, MH-MPs have larger dimensions compared to helical screw piles utilized in the US [4)].

TABLE 1 Typical dimensions of MH-MP

Central pipe shaft		Helical plate at lead section		
Diameter D (mm)	Thickness t (mm)	Diameter D_w (mm)	Spacing (mm)	Pitch p (mm)
216.3	9.0 <	450 - 600	1,330	120
267.4	9.0 <	500 - 650	1,330	130

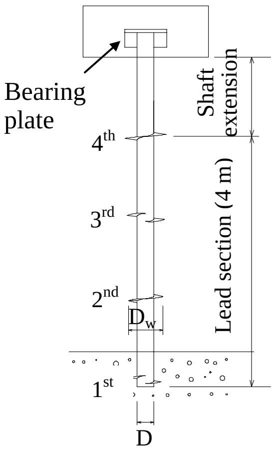

FIG. 1 MH-MP configuration

PHOTO 1 Piling rig with MH-MP

(2) Installation

PHOTO 1 shows an example of compact piling rig, in which the hydraulic motor yields a maximum torque of over 100kN･m. Pile is screwed into undisturbed soil by rotation without soil removal. It may be necessary to screw the MH-MP repeatedly both in clockwise and counter-clockwise directions for penetrating into dense stratum. The machine is applicable in restricted working conditions, and allows installing piles inclined at 30° both forward and backward. MH-MPs can be installed in environmentally sensitive areas.

Screwing helical foundations may cause minimal soil disturbance compared to conventional piling techniques. Penetration mechanism of helical screw piles has been investigated in Japan through various model tests. FIG.2 demonstrates a model for the movement of soil particles around a helical plate through the direct observation by video camera [5)]. During pile penetration, soils at lower edge of helical plate start moving towards the upper edge of the plate, causing surface resistance. Soil can be packed near the upper edge creating downward reaction force against the helical plate. In the meantime, the confining pressure around the plate may be loosened particularly beneath the plate. Both soil profile observation and earth pressure measurements tend to support this tendency.

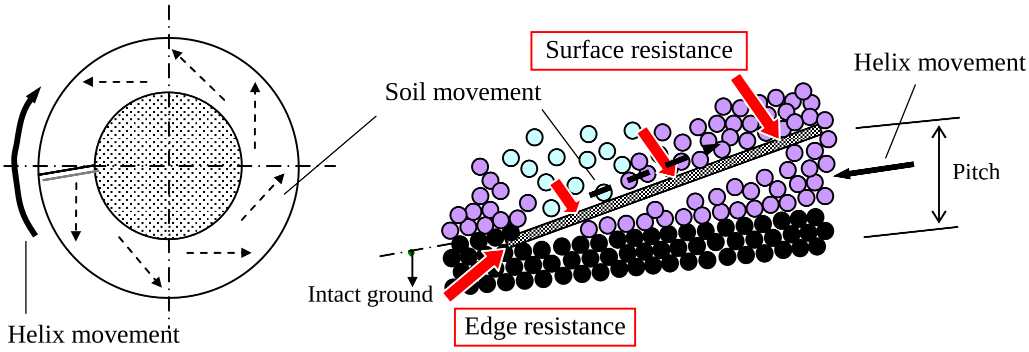

FIG.2 Penetration mechanism at a helical plate

It is well recognized that the similarity between the torque profile during installation of helical screw pile, including MH-MP, and the SPT N-value profile is remarkable. Torque record can be utilized to assure the quality control of the pile execution, which provides clear indication the desired bearing stratum with dramatic increase in the record. So far, no empirical torque factor to estimate bearing capacity has been proposed in Japan unlike the helical screw foundations in the US.

Afore-mentioned penetration mechanism is known to dominate the pile loading performance. Helical screw pile may be categorized into displacement piles such as driven piles in view of the basic penetration features. However, the load-settlement behavior of helical screw pile is more similar to non-displacement piles reflecting this unique penetration mechanism.

The MH-MP method realizes the following advantages:

1) No soil is removed from the ground.
2) No grouting is required.
3) Simple installation procedure and quality control
4) Adaptability to restricted working conditions
5) Easy, accurate installation of inclined pile
6) Limited disturbance to subsoil around pile vicinity
7) High capacity performance on reliable soil-pile interface

Performance test at Saitama site

(1) Test setup

A field test to investigate the performance of the MH-MP had been conducted at Saitama site located 50km north from Tokyo central. FIG.3 shows general layout of sounding tests with relevant piles. Subsoil conditions were investigated in advance by SPT, CPT and laboratory tests. SPT profile as shown in FIG.3 exhibits rather complicated alternation of strata. A dense, gravel stratum appears at around GL-15.5m. All piles were embedded with their toes reaching GL-16m. Specifications of four test piles are shown in TABLE 2.

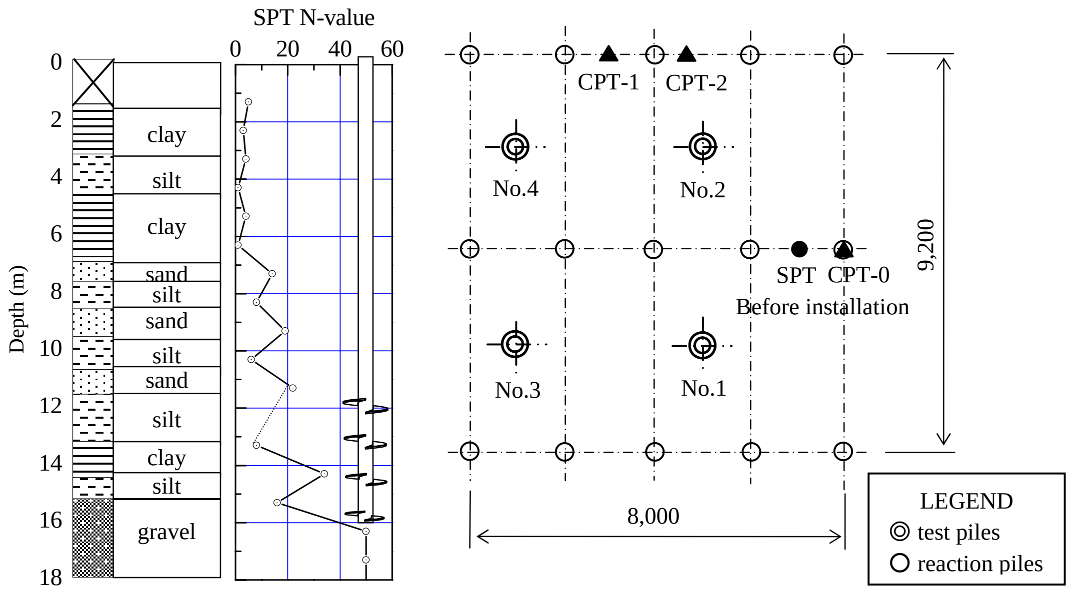

FIG. 3 General layout and soil profile by SPT

TABLE 2 Specifications of test piles

Test No.	Diameter D (mm)	Helix diameter D_w (mm)	Helix pitch p (mm)	Length L (m)	Loading direction
1	216.3	450 – 600	120	16.0	Compression
2	267.4	500 – 650	130		
3	216.3	450 – 600	120		Tension
4	267.4	500 – 650	130		

(2) Installation record

For MH-MP installation, the torque (T) is continuously measured during installation as the pile penetrates into the ground. FIG.4 presents installation records of four test piles along with SPT. It can be noted that the torque profiles compare well with SPT N-value profile. The torque profile reflects the soil profile. It is quite easy to confirm from torque profile that the pile toe rests on the bearing stratum. The torque record serves as an indicator of the piling quality control. It could be seen that larger piles have higher torque than those for smaller piles reflecting penetration mechanism presented in FIG.2.

It is plausible that helical screw piling may provide less influence to the adjacent soil due to its penetration mechanism in comparison with bored and driven piles. An attempt to evaluate the influence was carried out employing CPT. As shown in FIG.3, sounding tests close to relevant piles, designated as CPT-1, CPT-2, were conducted a day after installing the piles distances of 0.5 m and 1.0 m respectively from the pile. These data are compared with CPT-0 conducted before pile installation in FIG.5 together with SPT. It appears that loose clayey soils become looser and sandy soils become denser after pile installation. However, generally no significant change can be seen in the results. Less influence to the adjacent soil may be favorable whenever piles ate to be installed nearby existing foundations and buried structures.

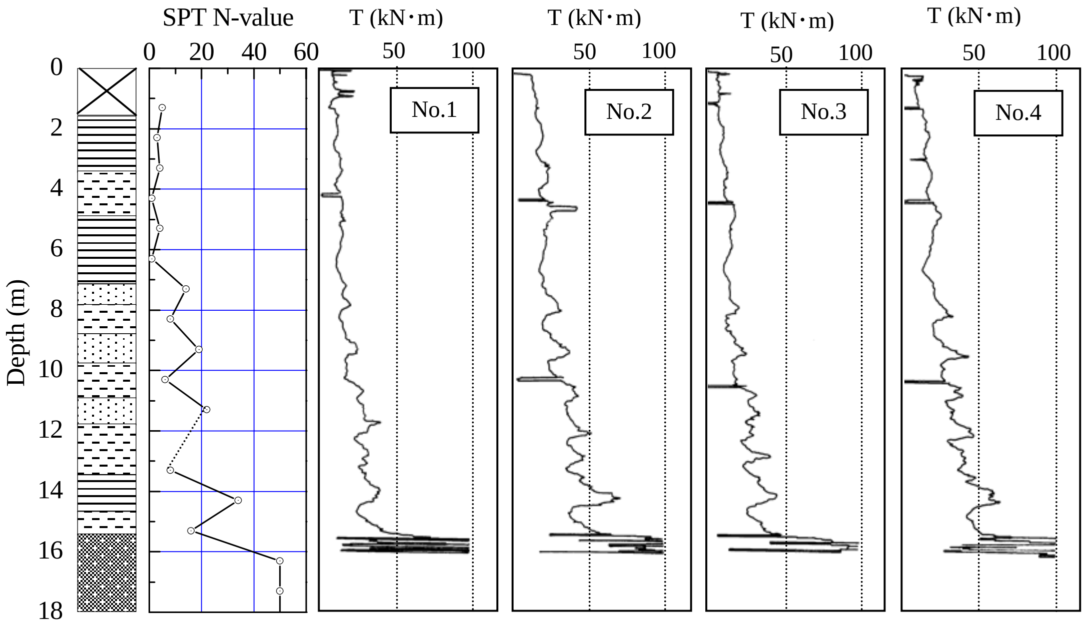

FIG.4　Torque profile compared with SPT profile

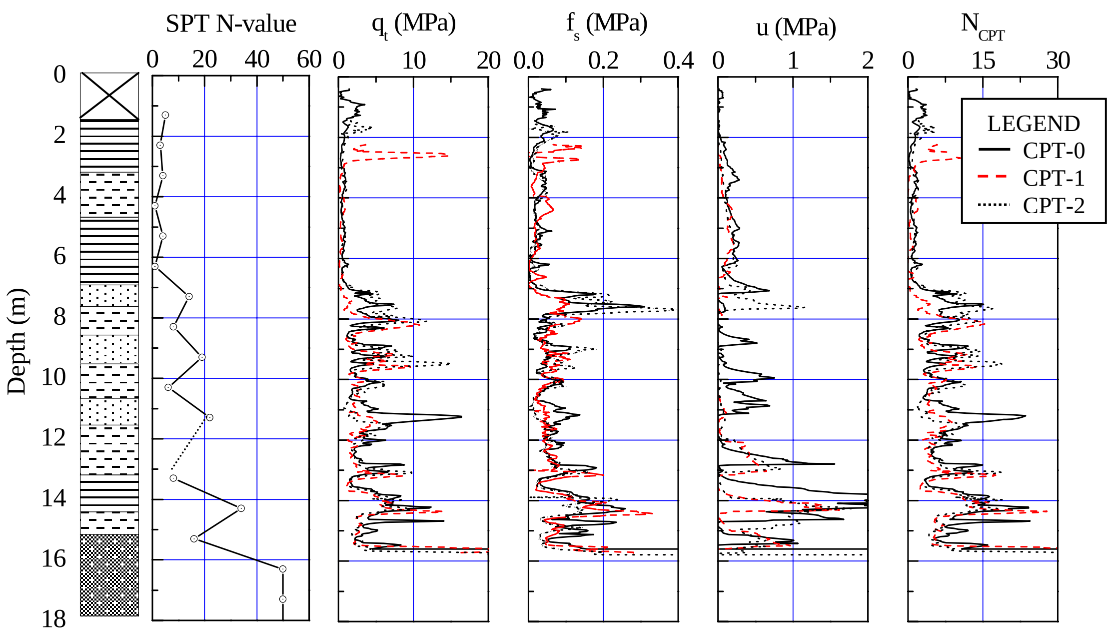

FIG.5　CPT profile before and after pile installation

(3) Load-displacement behavior

In order to evaluate the bearing capacities of the MH-MP, field load tests were conducted both in compression and tension. Load test results are shown in FIGs.6 and 7. By considering the s/D_w=0.1 criterion, the bearing capacity exceeds 2.4MN in compression, and 1.3MN in tension, while it also depends on the pile diameter. In compression, the load-settlement behavior tends to be ductile similar to non-displacement piles. It is apparent in FIG.7 that most of the load is resisted by the lead section implying the contribution of the end bearing resistance at each helical plates to the bearing capacity.

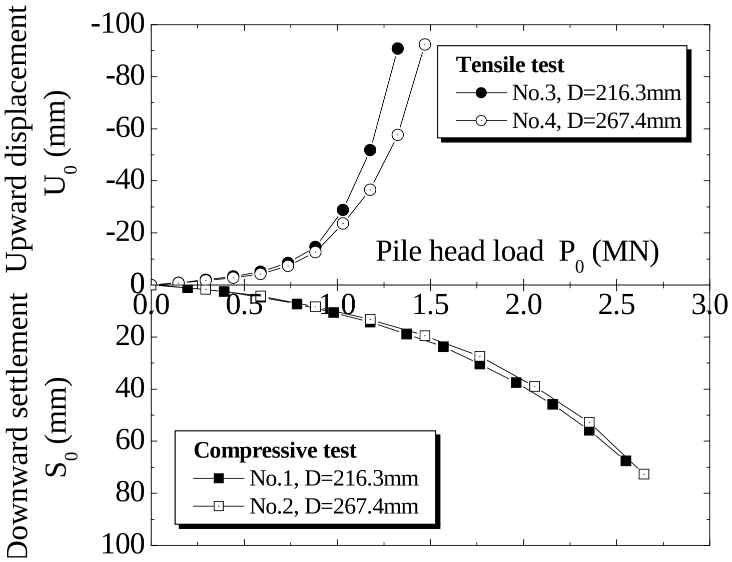

FIG. 6 Pile head load-displacement

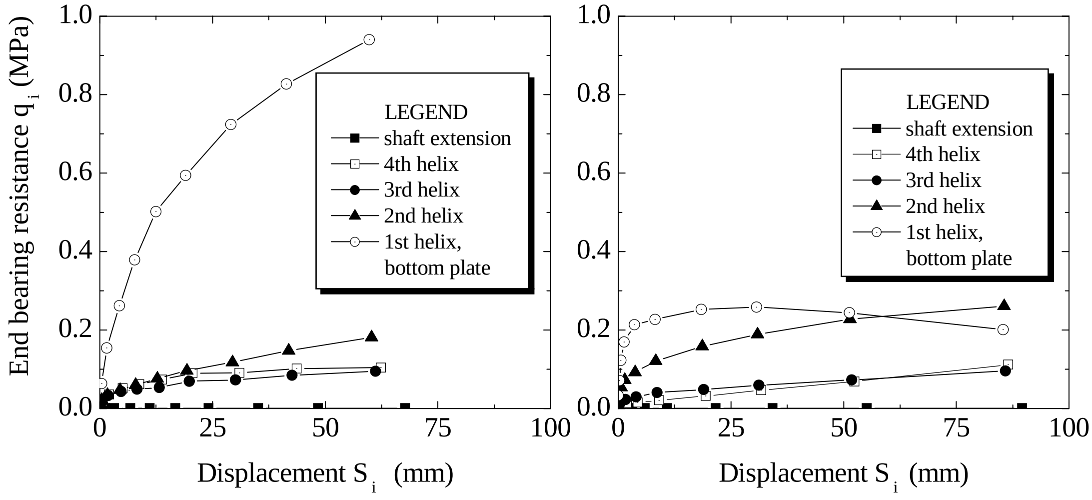

FIG.7 Unit end bearing resistance at each helix in compression and tension

Bearing capacity performance for design

Based on the field measurements, the bearing capacities both in compression and tension can be estimated from the empirical-based formula using SPT N-value (1). Bearing capacity of the MH-MP is composed of the sum of the end bearing resistances at the lead section and shaft resistance at extension sections, as follows.

$$R_u = \sum q_{wi} A_{wi} + U \sum L_i f_i \quad (kN) \quad \cdot\cdot\cdot \quad (1)$$

where, q_{wi} : unit end bearing resistance of helix/bottom plate = a・N (kPa)
A_{wi} : effective bearing area of helix/bottom plate (m^2)
U : perimeter of shaft (m)
L_i : effective length of shaft resistance (m)
f_i : maximum unit shaft resistance = b・N (kPa)
a, b : bearing coefficients
N : SPT N-value

The pressure resisted by each helical plates and/or bottom plate can dominate bearing capacity of MH-MP. Both unit end bearing resistance q_{wi} and unit shaft resistance f_i are evaluated in terms of SPT N-value. FIG.8 shows the example of the correlation between unit end bearing resistance and SPT N-value. Finally, different values of unit resistance for MH-MP are given with respect to end bearing (compression and tension) and shaft resistance in TABLE 3.

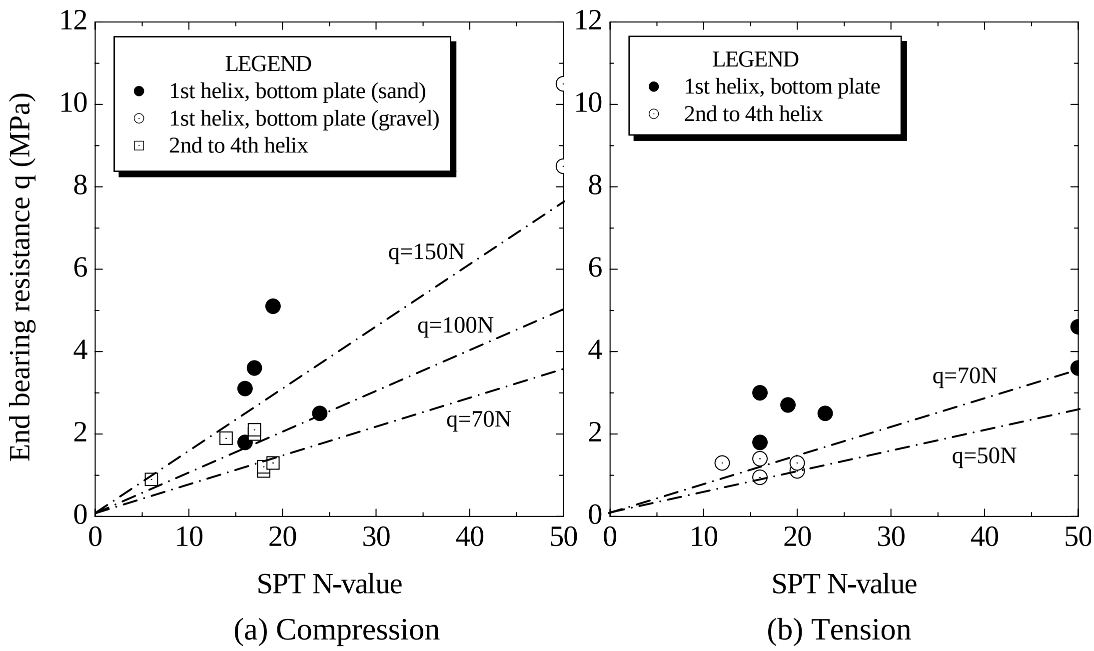

FIG. 8 Correlation between unit end bearing resistance and SPT N-value in compression and tension

TABLE 3　Coefficients of unit resistances

Loading direction	End bearing resistance q_{wi} (kPa)		Shaft resistance f_i (kPa)
	1st helix, bottom plate	2nd ～ 4th helix	
Compression	150N（gravel） 100N（sand）	50N（sand、clay）	1N（sand） 3N （clay）
Tension	70N（gravel、sand）		

Seismic retrofitting application at Yokohama site

Some piers supporting a bridge over JR line and a river in Yokohama were required to be reinforced against large earthquake (PHOTO 3). One of them was reinforced by the MH-MP method. FIG. 9 shows a plane geometry. Seismic retrofitting was designed using 20 piles inclined at 20.8° and positioned around the existing pier foundation consisting of four drilled shafts.

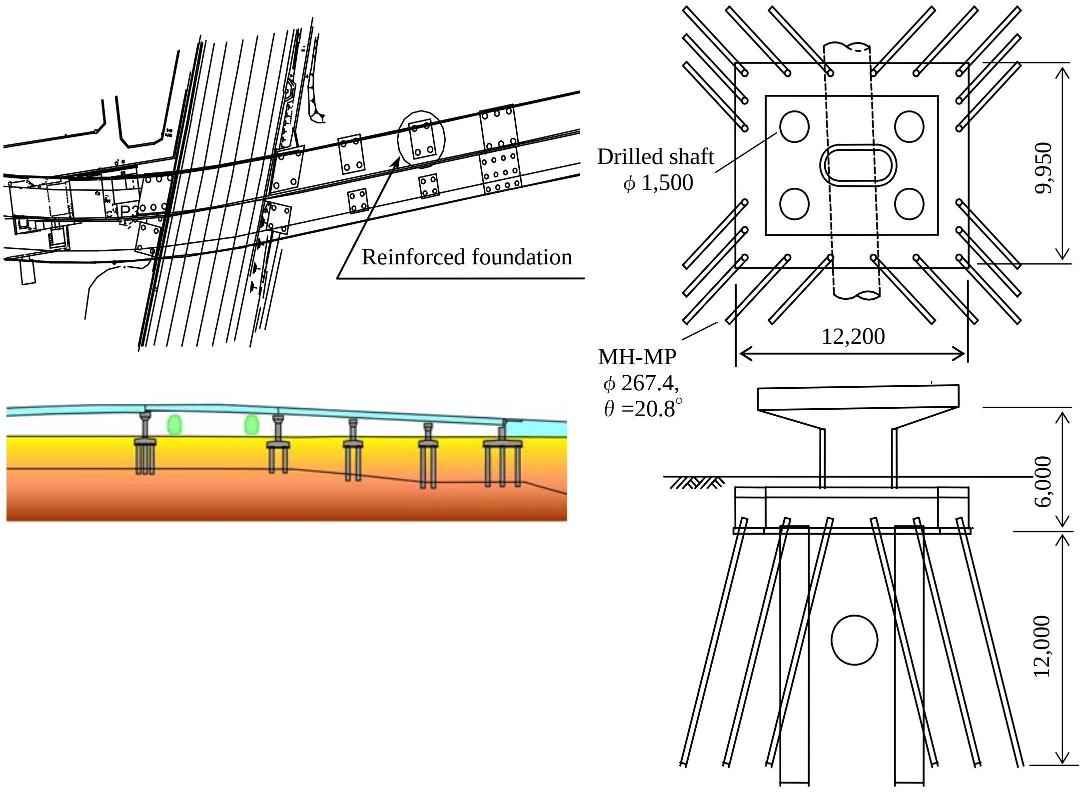

FIG. 9　Seismic retrofitting plan for the pier

Pile toe was embedded in the bearing stratum composed of hard clayey soil. In FIG.10 compares the torque profile at corner piles with the soil profile. It can be seen that all piles were properly placed at the bearing stratum. The installation involved clockwise and anti-clockwise rotation.

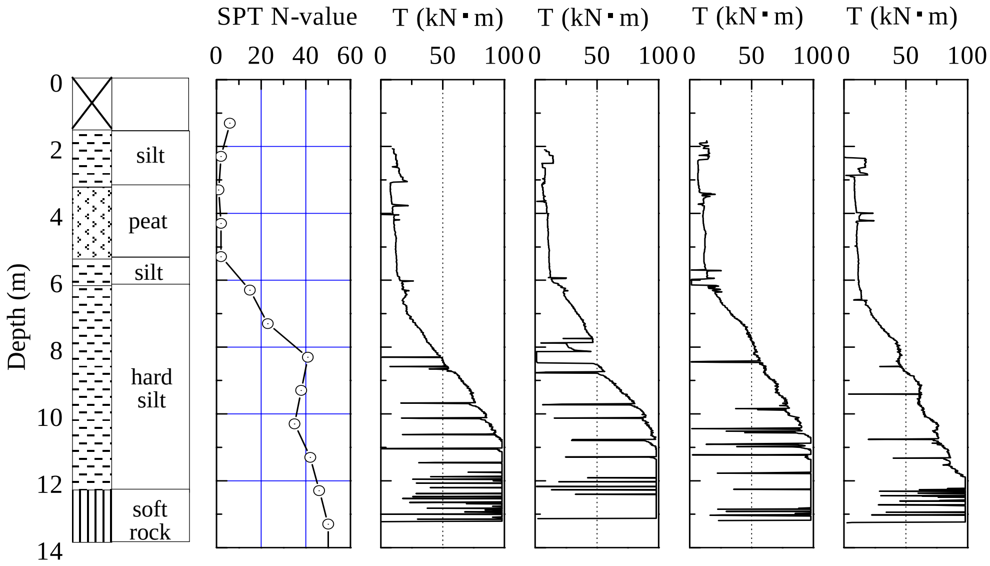

FIG.10 Torque profile of four corner piles

PHOTO 4 shows a scene during pile installation. Short segments of around 2.5 m were connected one by one by means of a mechanical joint. For seismic retrofitting, it is designed to connect many pile segments for installation under restricted working conditions. Though welding is commonly used for connection, a new mechanical joint was developed to assure the connection and to improve installation efficiency, regardless of the direction of rotation, and performance. Verification tests indicate that overall capacity is almost similar to normal steel pipe although the initial stiffness tends to be smaller.

PHOTO 4 Pile execution

PHOTO 5 Pile cap extension

After installation, execution accuracy in eccentricity, inclination and pile head level were checked and compared with the design values. FIG.11 illustrates the measured data of twenty piles by histograms. It was confirmed that all results satisfied the design conditions. Bearing plate on the pile head assures the tight connection between piles and extended pile cap (PHOTO 5).

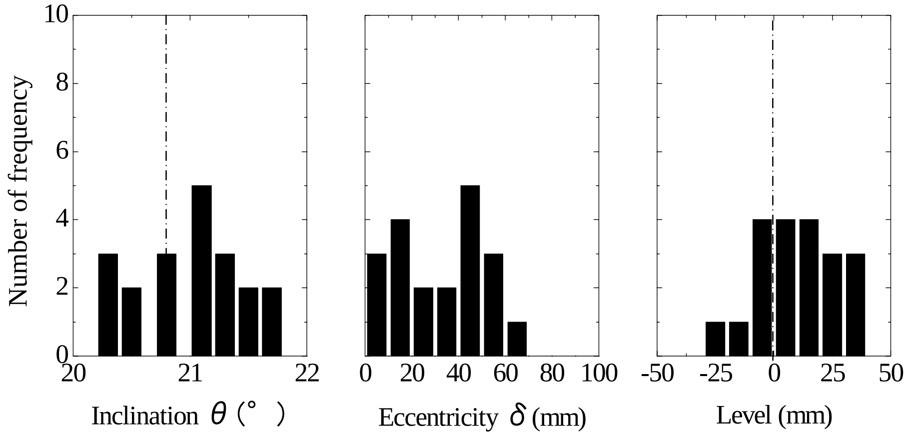

FIG.11 Measured accuracy after installation

Acknowledgments

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