Deformation behavior around foundation pile in the Mietsu Naval Facility World Heritage Site: Model tests on Kawasaki clay

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ABSTRACT

The deformation behavior around the foundation piles is examined based on the movement of soil particles in a laboratory model of Kawasaki clay penetrated by a foundation pile. The experiment results are compared with measurements of the changes of natural water content and undrained shear strength around the pile in the small boat docks section (SBD) to infer the installation method of the cedar foundation piles preserved in the SBD.

Keywords: Ariake clay, foundation pile, Kawasaki clay, Mietsu Naval Facility, model test, World Heritage

1 INTRODUCTION

In the nineteenth century the Saga clan established a Western-style navy and built Western-style ships based on Western naval knowledge and technologies that it had acquired at the Tokugawa government’s Nagasaki Naval Training Institute. The Mietsu Naval Facility (MNF) provided the optimal location for developing such operations. The MNF is thought to have closed down after the abolition of the feudal clans and the establishment of prefectures at the beginning of the Meiji era, and the site was used as a maritime academy from 1902 until 1933. During this time, no major changes were made to the ground surface; therefore, a number of remaining structures, which can provide insights into the nature of the MNF when it was in operation, have been well preserved underground.

Archaeological surveys and document reviews carried out since 2009 indicated that the Mietsu Naval Dock (MND) was the operations base for the Saga clan navy from 1859 to 1871; that it was the place where the *Ryofu-maru*, Japan’s second steamship, was completed through the independent efforts of the Saga clan; and that at the end of the Edo period, it was the first place in Japan where Western-style ships were repaired using a combination of Western and traditional Japanese technologies. In 2015 the MNF was registered as a world heritage site as part of the group of sites named the World Heritage Sites of Japan’s Meiji Industrial Revolution: Iron and Steel, Shipbuilding and Coal Mining.

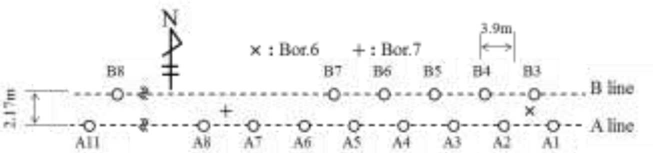
The small boat docks section (SBD) of the MNF contains traces of large wooden buildings, and excavation of the remains commenced in January 2017. As part of an engineering investigation of the remains, the consolidation properties of a clay sample were obtained through tube sampling. The undrained shear strength c_u was obtained from a cone penetration test of the vertical walls of the trench cut around one of the piles and changes in the natural water content w_n were measured around the cedar foundation pile. However, the loading history and the installation method of the cedar foundation piles preserved in the SBD are not clear.

In this paper, the deformation behavior around the foundation piles is examined based on the movement of soil particles in a laboratory model of Kawasaki clay penetrated by a foundation pile. The experiment results are compared with measurements of the changes of w_n and c_u around the pile in the SBD to infer the installation method of the cedar foundation piles preserved in the SBD.

2 SOIL PROPERTIES OF THE SMALL BOAT DOCKS SECTION SITE

Figure 1 shows the layout of the foundation piles found during the excavation at the SBD. Piles A1–A11 are 1.5-m-long cedar piles stripped of bark with a diameter of 20 cm. Piles B1–B11 consist of groups of three pine piles 10 cm in diameter with the bark. Two bore samples were taken using the tube sampling

Fig. 1. Layout of the foundation piles at the small boat docks section site



method according to Japanese standards JGS 1221-2013 at boreholes # 6 and 7 (Bor. 6 and 7) and three portable cone penetration tests (CPTs) according to Japanese standards JGS 1431 were taken between the cedar foundation piles. The SBD area comprises a clay layer with 70%–80% shells at a depth of 1.4 m (Tokyo Pail (T.P.) level of −0.7 m) from the excavated ground surface (Shogaki, et al., 2018). The 5-m-thick clay layer changes to sand at T.P. level −4.4 m. The number of standard penetration test blows (*N*-value) in the clay layer ranged from 3 to 5 (Shogaki, et al., 2018).

The c_u values obtained in the CPT from the penetration resistance are plotted against the elevation E in Fig. 2. The clay at the test site is Ariake clay. The c_u values at E = 1.5–1.8 m reached 25–50 kN/m^2 caused by the excavations down to about 2 m and hardened ground surface. The c_u values at E = 0.48–1.58 m are in the range of 10–20 kN/m^2 and the horizontal continuity of the Ariake clay in the SBD site is higher along the A piles (60 m) as shown in Fig. 1. At E = 0–0.3 m the CPT did not penetrate under the weight of two people (=1.08 KN); this layer corresponds to the clay layer with shells observed at boreholes # 6 and 7.

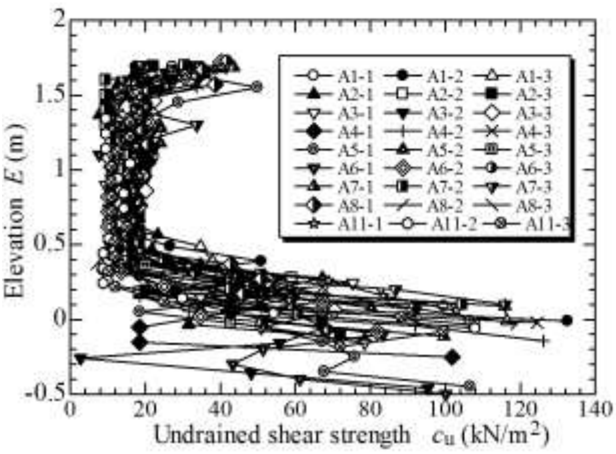


Fig. 2. Relationship between c_u and elevation for piles A1 to A11

3 CHANGES IN THE NATURAL WATER CONTENT AND STRENGTH OF THE SOIL AROUND THE PILE

The bottom of the excavated cedar piles is cut off horizontally (Photograph 1). A group of three pine piles in the B-line are about 2 m long and the bottom ends are cut at an angle of about 30° indicating these were driven piles. Figure 3 shows the layout of the site where the CPTs according to Japanese Geotechnical Standard (JGS 1431-2003) were conducted at the trench cut around pile A11. The tests were performed along five horizontal levels at the excavated surface. The test results of the CPT for lines (a) and (e) on the southern wall of the trench are shown in Figs. 4 (a) and (b), respectively. The penetration depth (D_p) is 40 cm. The construction method of the piles of line A can be

Photo. 1. Bottom end of the cedar pile (A11)

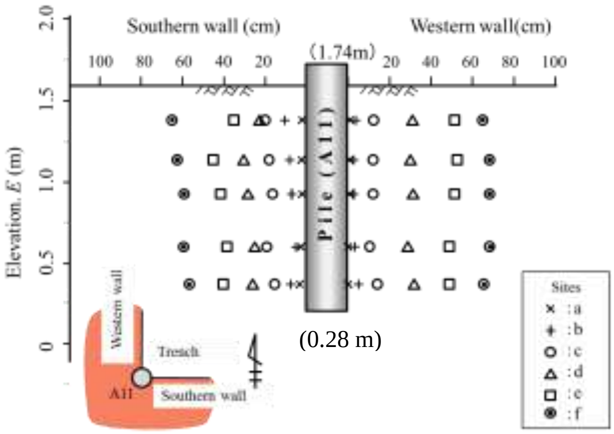
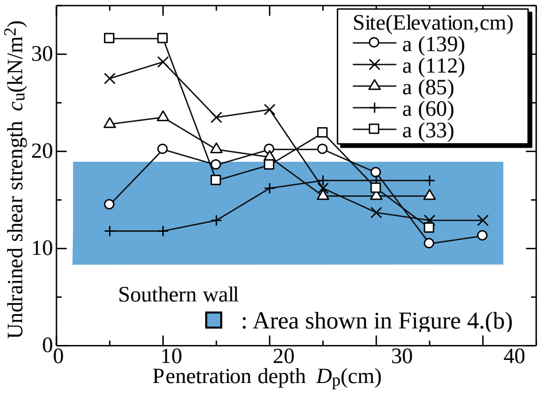
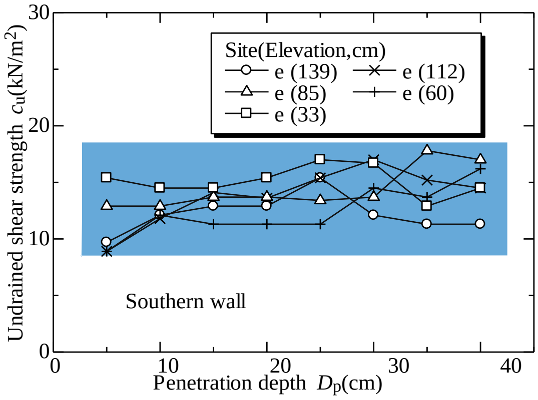


Fig. 3. Layout of the CPT measurements around pile A11



(a) at line (a) on the southern wall of the trench



(b) at line (e) on the southern wall of the trench

Fig. 4. Relationship between c_u and D_p around pile A11

inferred from these c_u results because the load history from the construction of the foundation piles may have remained as the variable strength of the soil around the foundation piles.

c_u decreases with increasing D_p along CPT line (a), 2 cm from the foundation pile (Fig. 4(a)). This means that the c_u values are greatest close to the foundation pile and the same as the plots of E = 33, 85 and 112 cm, 5–8 cm from the foundation pile. However, along CPT line (e), 50 cm from the foundation pile (Fig. 4(b)) c_u = 9–18 kN/m^2 and is almost constant at each elevation. The w_n values obtained from the southern and western walls are plotted against the distance from the surface of pile A11 (D_s) in Fig. 5. w_n decreases by about 30% from D_s = 60 cm to D_s = 2 cm. The decreasing w_n may reflect the draining effect of the cedar piles and/or the dissipation of the pore-water pressure caused by the movement of the soil particles driven by the penetrating pile. The c_u behavior in Fig. 4 corresponds to the

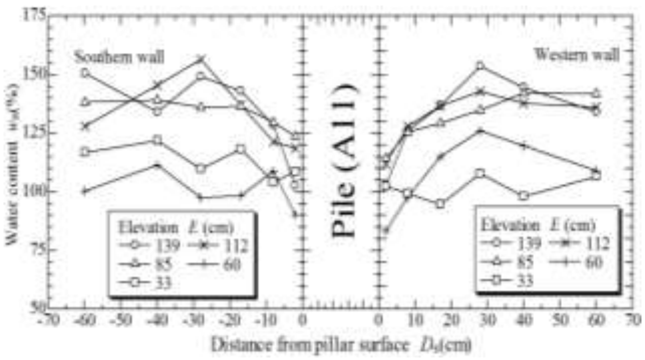


Fig. 5. Relationship between w_n and D_s around pile A11

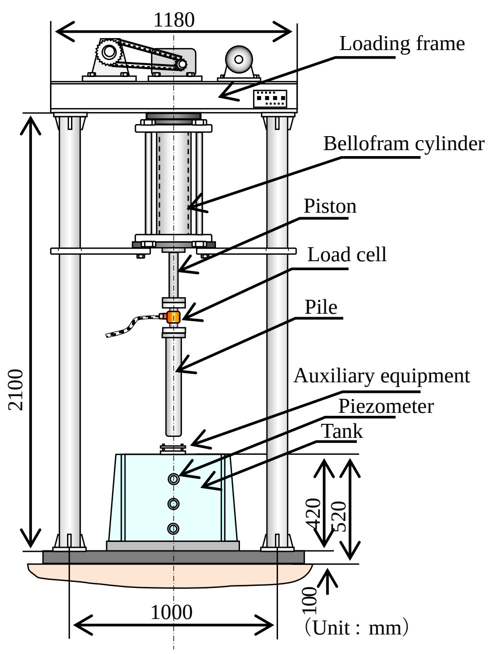


Fig. 6. Sketch of the tank and tube penetration apparatus

change of w_n. This is supported by the visual assessment that the soils around the piles were dense.

4 MODEL TEST ON DEFORMATION BEHAVIOR AROUND THE PILE CAUSED BY PENETRATION

To replicate the deformation around the piles we used Kawasaki clay in the model tests. The plasticityindex of Kawasaki clay is 68.5%; thus, it is classified as high-plasticity clay. The physical characteristics and grain-size properties of the Kawasaki clay are similar to those of the clay at the MNF (Shogaki, et al. 2018). The Kawasaki clay was consolidated from a slurry state with about twice the liquid limit to 44–109 kN/m^2 of the unconfined compressive strength q_u.

Figure 6 shows the tank and tube penetration apparatus used in the tests. The tank is 40 cm long, 30 cm wide and 40 cm tall, and is made of transparent acrylic sheets. Photograph 2 shows the water tank and the semicircular pile. The semicircular pile penetrates the clay in one continuous motion, driven by an air cylinder with a 32-cm stroke. The confining stress of 6.6 kPa was loaded by lead balls on the model ground surface (Photograph 2). The 6.6-kPa load corresponds to the effective overburden pressure (σ'_{vo}) in the saturated clay at a depth of 1.6 m. The test and analytical procedures for the setup of the model and the semicircular pile penetrations are the same as in Shogaki (2017).

The samples were obtained from a block sample before the vinyl pipe sampling from the model ground. The q_u values are 44–78 kN/m^2 and 51–109 kN/m^2 for q_u= 57 kN/m^2 and 77 kN/m^2 clay grounds, respectively. These q_u values are greater than q_u =24–41 kN/m^2 of the SBD site; however, better agreement may be achieved if the model ground was simulated as the soft clay ground of the SBD site.

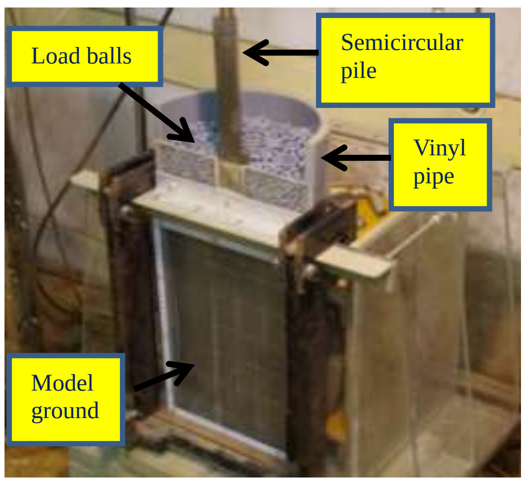


Photo. 2. Testing apparatus showing the tank and semicircular pile

5 DEFORMATION BEHAVIOR AROUND THE PILES CAUSED BY PILE PENETRATION

The walls of the semicircular pile adhered to the acrylic board by means of auxiliary equipment. Plastic star-shaped targets were laid at the front of the acrylic board. The star-shaped targets were 2.5 mm, 1.5 mm thick, and weighed 0.004 g. They were designed to move together with the clay. The targets were laid out at 1-cm intervals in the horizontal direction and 1.5 cm in the vertical direction. The disk-shaped targets on the model ground surface were made of iron. They were 1 cm in diameter and weighed 0.571 g.

It was confirmed in Shogaki (2017) that the friction between the clay and the acrylic wall should have little effect on the clay movement induced by the pile penetration.

Figure 7 shows the vertical displacement D_v at 1 cm-penetration for z = 16.5 cm, for a semicircular pile under q_u = 57 kN/m^2 clay at the ground surface. D_v at σ'_{vo} = 6.6 kPa is larger than at σ'_{vo} = 0 kPa. The vertical colored lines on the plots show the boundary for the movement of the targets due to pile penetration. The blue and red lines are for σ'_{vo} = 0 and 6.8 kPa, respectively, and the green line represents both boundary lines. They are located at a distance within 17.5 mm from the edge of the pile for other depths. The boundaries are slightly larger in the case of σ'_{vo} = 6.6 kPa. Based on the above results, the deformation around the pile caused by the penetration increased within the range of the pile diameter. This suggests that the decreasing water content and increasing shear strength were caused by increased pore-water pressure and dissipation. This behavior is also confirmed for soil at q_u = 77 kN/m^2 clay.

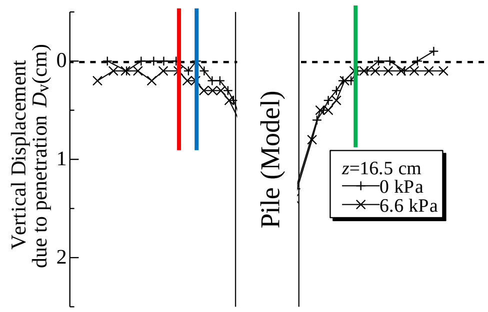


Fig. 7. Target movements during penetration test under q_u = 57 kN/m^2 clay (z = 16.5 cm)

6 ANALYSIS OF THE ACTUAL REMAINING WOODEN PILE IN THE SMALL BOAT DOCKS SECTION OF THE MIETSU NAVAL FACILITY

The w_n and c_u values obtained from the southern and western walls of the excavation at pile A11 are plotted against D_p in Fig. 8. The w_n values decreased by about 30% at D_p = 2 cm from D_p = 60 cm. The effect of the pile penetration on w_n and c_u can be recognized and is expressed as the boundary area outlined by the red

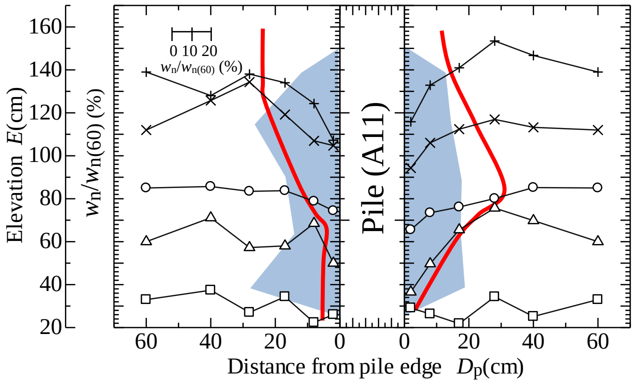


Fig. 8. Relationship between the change of w_n and D_p (q_u = 57 kN/m^2 clay)

lines in Fig. 8. The blue areas show areas influenced by the pile penetration taken from the result shown in Fig. 7 and adjusted according to the ratio of the diameter of the real A11 pile (20 cm) to the model pile (3.5 cm). The red lines and blue areas are in relatively good agreement for the clay samples with q_u = 57 kN/m^2. This behavior is also confirmed for soil at q_u = 77 kN/m^2 clay. Thus, based on the changes in c_u and w_n measured around A11 pile and the model test results, we conclude that the cedar foundation pile is a driven pile.

7 CONCLUSIONS

The conclusions obtained in this study can be summarized as follows.

1) The natural water content w_n decreased by about 30% at a distance of 2 cm from the pillar surface. This is likely caused by the draining effect of the cedar pile and/or the dissipation of the pore-water pressure caused by movement of soil particles as a result of pile penetration.

2) The deformation around the pile caused by pile penetration increased within the range of the pile diameter. This was likely due to the decreased water content and increased shear strength caused by increased pore-water pressure and dissipation.

3) The area influenced by the pile penetration as measured on site agree with the affected area in the model (adjusted to the model scale of 20:3.5) for both q_u= 57 and 77 kN/m^2 clays. This indicates that the cedar foundation pile was driven into position based on the changes in c_u and w_n measured around pile A11 and the model test results.

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