World Conference on Timber Engineering
Oslo 2023

GROUND IMPROVEMENT EFFECT OF TIMBER PILES BURIED IN SOFT CLAY GROUND

Tadashi Hara[1], Yoshitaka Kubojima[2], Hidao Kato[3], Satomi Sonoda[4]

ABSTRACT: Promoting use of timber piles for ground reinforcement requires determining the effectiveness and sustainability of ground consolidation and compaction after burial, according to soil type. In this study, from simple soundings we determine penetration resistance near timber piles buried in a soft clay layer and its change over time to analyze the degree of solidification and extent of improvement. The results of a series of field tests showed that penetration resistance in a cohesive soil layer significantly increases in the vicinity of timber piles immediately after their installation, with the consolidation area concentrically expanding over time; that buried timber piles act as drainage columns and caused consolidation phenomena deep in the ground; and that the longer the piles have been buried, the greater the effects. Because the results of this study demonstrate the effectiveness and continuity of timber piles as ground reinforcement materials, we can expect their active use in the future to promote ground disaster prevention and contribute to global warming countermeasures by storing carbon in the ground.

KEYWORDS: Ground improvement, Timber pile, Soft clay layer, Penetration resistance

1 INTRODUCTION

Wood as a civil engineering material is easy to process and environmentally friendly. In a land environment where the population is concentrated on plains, ground-related damage such as loose or sunken road surfaces and sinking or tilting of structures is likely to occur, and damage will be frequent. There is great social interest in the use of wood as a ground improvement material and its application to disaster prevention, for example as a countermeasure against ground deformation and shaking in earthquakes. In Japan, abundant forest resources were actively utilized as civil engineering and construction materials until the period of rapid economic development in the 1950s, and large amounts of timber pile were buried in applications such as pile foundations to support structures and compact reclaimed ground. Even today, many structures have exceeded a service life of 50 years, withstanding earthquakes and other natural disasters as well as providing safety and security [1]. In Venice, which is known for its timber pile foundations, many structures supported by timber piles driven into soft ground (muddy soil) are still in service some four hundred years after their construction [2].

In cooperation with a private company, the authors developed the Log Piling Method for Liquefaction Mitigation and Carbon Stock (LP-LiC) as a measure to mitigate ground liquefaction damage in the event of a Nankai Trough earthquake, which has a high probability of occurrence [3]. Artificial materials for civil engineering are easy to handle and process and are in wide use, so actively utilizing historically popular wood in civil engineering works for disaster prevention will require grasping the presence or absence of cross-sectional loss due to biodeterioration of timber piles in the ground as well as the degree and sustainability of solidification of the ground after construction, according to the soil material in question.

In a study of sandy soil with high liquefaction potential, Yoshida et al. [4] performed model tests to verify the effectiveness of log casting for soil prone to liquefaction, finding that the circumferential friction force of logs greatly affects the bearing capacity of the soil. Hara et al. [5] conducted multiple sounding tests on reclaimed sandy soil improved by the LP-LiC method to investigate the effects of soil improvement depth and casting intervals. In a study focusing on the bearing capacity of timber piles, Yamauchi et al. [6] evaluated the effect of compacting sandy soil from laboratory soil tests by collecting soil samples around pine piles that had been used as bridge foundations for about 70 years. In field loading tests, Mizutani et al. [7] investigated the bearing capacity of cedar timber piles jacked into cohesive soil layers, finding that

[1] Tadashi Hara, Kochi University, Japan, haratd@kochi-u.ac.jp
[2] Yoshitaka Kubojima, Forestry and Forest Products Research Institute, Japan National Research and Development Agency, Japan, kubojima@ffpri.affrc.go.jp
[3] Hideo Kato, Forestry and Forest Products Research Institute, Japan National Research and Development Agency, Japan, kato_hideo@ffpri.affrc.go.jp
[4] Satomi Sonoda, Polytechnic University of Japan, Japan, timber.satomi@gmail.com

https://doi.org/10.52202/069179-0113

the values for the same shape were larger for steel, concrete, and timber piles, in that order. There have thus been several studies on the effects of compaction by timber piles, mainly in sandy soils at some point in time after burial. In contrast, there have been few field studies and experiments involving clayey soil layers, and there are few examples of studies through field investigations that systematically analyze the degree of soil solidification, the extent of improvement, and sustainability of the effects of buried timber piles.

In this study, we performed simple sounding tests to determine softness or hardness near timber piles buried in a soft clay layer and then analyzed changes in properties after piles were buried. Specifically, we evaluated the superiority of timber piles as a ground improvement material by summarizing changes in ground solidification due to timber pile burial, the extent of any improvement, changes in ground solidification immediately after installation, and the durability of effects from the viewpoint of penetration resistance and the elapsed time after installation.

2 GENERAL INSTRUCTIONS OUTLINE OF THE INVESTIGATION SITE AND BURIED TIMBER PILES

The study site was located on the premises of the Forestry Research and Management Organization in Tsukuba City, Ibaraki Prefecture (Figure 1). Figure 2 shows a geologic columnar section from the study site. The target site is a developed alluvial plain, in which soft layers with N values of less than 10 as obtained by standard penetration tests are distributed. Strata where the timber pile was buried consisted of andosol as the buried soil from ground level (GL) −0.50 to −4.5 m and former topsoil surface up to GL−–2.00 m, tuffaceous clay with similar properties from GL −2.00 to −4.70 m, and fine clay mixed with a small amount of medium to coarse sand from GL −4.70 to −5.80 m. Among the tuffaceous cohesive soils, there was extremely soft, clayey blue-gray cohesive soil with $N = 2$ around GL −3.00 to −4.70 m. There was no clear groundwater table throughout the entire formation, but the old

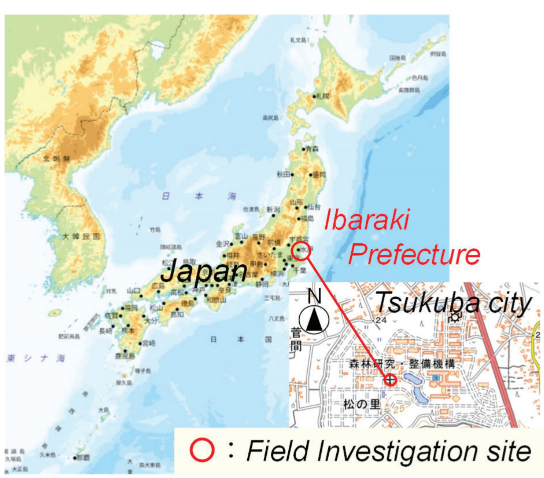

Figure.1: *Field investigation site (Tukuba city, Ibaraki Prefecture, Japan)*

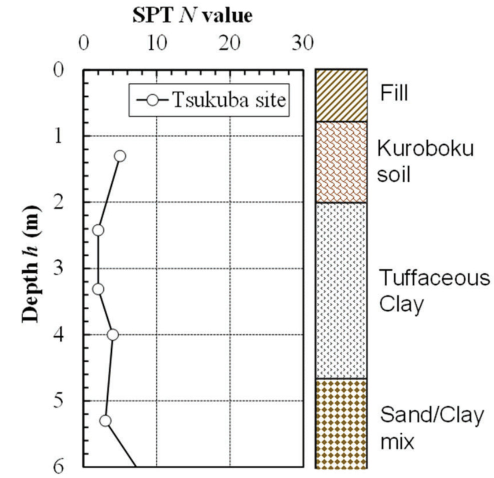

Figure.2: *Layer composition of the ground at the investigation site*

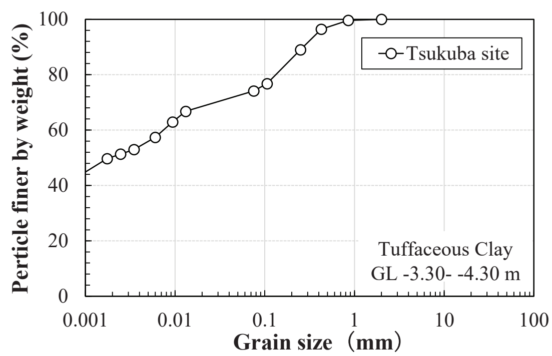

Figure.3: *Particle size distribution curve for tuffaceous clay*

topsoil and clay layers were saturated, and borehole logs showed perched groundwater at around GL −2.65 m.

Figure 3 shows a particle size distribution curve for tuffaceous clay collected from the site. The fine-grained content F_c is a large 74.1%, indicating that the soil is predominantly fine-grained. The plasticity index I_p obtained from liquid limit and plasticity limit tests was 60, indicating that the clay content was high.

Figure 4 shows a timber pile buried at the study site. Cedar logs (140 mm in diameter, 4.00 m long) from Fukushima Prefecture were used as timber piles. Young's modulus E_{fr} values for the timber piles as obtained by the longitudinal vibration method were 6.74, 6.76, 6.78, 8.21, and 9.50 GPa [8], showing some variation. The moisture content of timber piles pulled about one year after burial ranged from 74% to 149%, above the fiber saturation point at all sites and increasingly higher with greater depth than the average estimate (94%) prior to burial [9].

We buried the timber piles on 3 Dec 2020. After removing relatively hard pebbles from the ground surface at a depth of −1.00 m, we used a small pile borer (Komatsu BA-100) to continuously and statically jack-in the pile as shown in Figure 5, without prior excavation using an auger, until the pile mouth reached a depth of −0.30 m from the ground surface. The depth of the timber piles, including

Figure.4: *Timber piles buried in the ground*

Figure.5: *State of press-in timber piles*

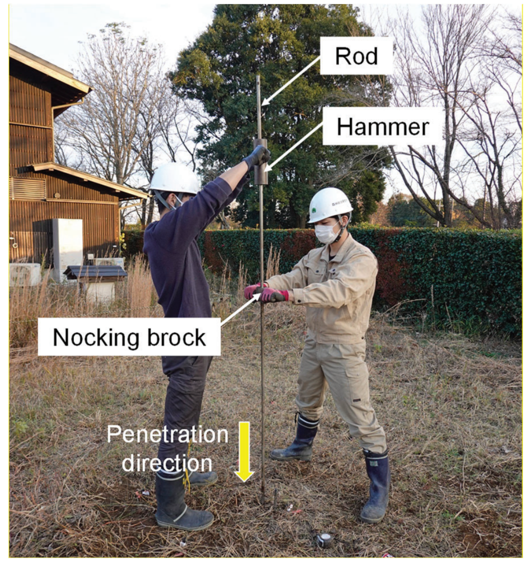

Figure.6: *Status of the Portable Dynamic Cone Penetration (PDCP) test*

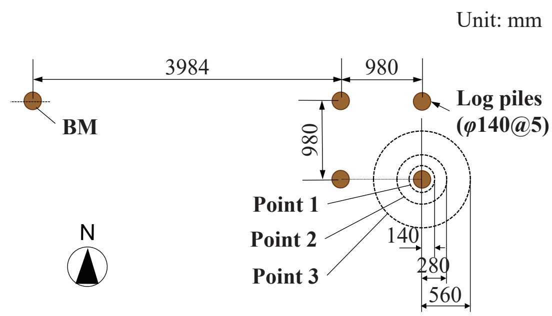

Figure.7: *Location of the build of the timber piles and place to perform PDCP test*

the pile length, was −0.43 m. Spacing between buried timber piles was about seven times the distance between centers of adjacent piles.

3 CHANGES IN PENETRATION RESISTANCE AND SOLIDIFICATION RANGE DUE TO BURIAL OF TIMBER PILES

We performed soundings using the portable dynamic cone penetration (PDCP) test [10] to determine changes in timber pile strength before and after burial. As Figure 6 shows, the PDCP test determines the degree of soil softness or hardness by determining the number of times N_d required to drive a cone attached to the tip of a rod 100 mm into the ground by dropping a 5-kg drive hammer from a height of 500 mm, allowing determination of a relative value for soil softness or hardness. Using continuous sounding blows, we obtained soundings every 100 mm from GL −1.00 to −5.50 m, which was a depth of −1.20 m below the tip of the timber pile (GL −4.30 m). As Figure 7 shows, we selected four basis measurements (BM) not subject to changes in ground properties due to the construction, located close to the sides of the timber piles, about 140 mm from the pile core (Point 1), about 280 mm away (Point 2), about 560 mm away (Point 3), and about 4 m west of where the timber pile was driven.

Figure 8 summarizes the relation between depth from ground surface h and penetration resistance N_d from the results of PDCP tests performed at Points 1, 2, and 3 one day after burial (4 Dec 2020). The same figure also shows BM results from 15 Dec 2020. The BM N_d values show that the ground at the investigation site is continuously below $N_d = 10$ up to about GL −3.50 m, indicating the characteristic properties of extremely soft clay soil, as shown in the results obtained from the standard penetration test in Fig. 2. Comparing the surveyed points, the data of Point 1 near the timber pile shows an increase at almost all layers immediately after the installation, while the data of Points 2 and 3 far from the timber pile shows an increase in a limited area, below GL −3.00 m, and a large change near GL −4.00 m, which is close to the tip of the pile. From this, we can infer that in areas where the timber pile and the ground are in close contact, clay around the

https://doi.org/10.52202/069179-0113

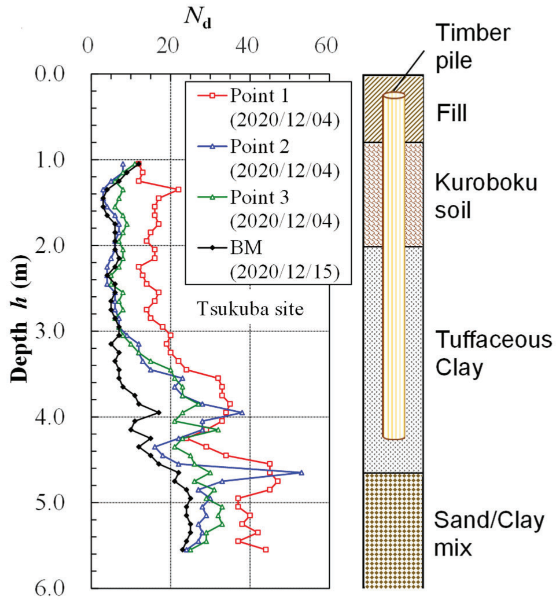

Figure 8: *Relationship between N_d value and Ground depth (1 day after build of a timber piles)*

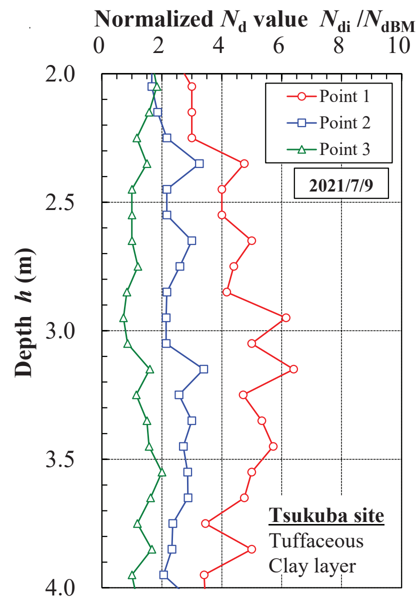

Figure 9: *Relationship between Normalized N_d value and ground depth (218 days after build of timber piles)*

circumference of the timber pile is temporarily disturbed and its strength is reduced during the timber pile burial, but near the pile and at the pile tip, interstitial water moves horizontally to the pile surface and, as seen in sandy soil, is absorbed by the timber pile shortly after installation [10], and consolidation of the clay layer occurs immediately. Values for N_d at GL −3.50 m and below show an increasing trend at all depths, whereas values from GL −5.00 to −5.50 m below the pile tip increase with depth, unlike in the standard penetration test results shown in Fig. 2. This is due to the compressive effect of the ground around the timber pile during jack-in and the increase in apparent penetration resistance due to friction between the penetration rod and the ground [11].

Figure 9 summarizes the results of penetration tests at Points 1 and 3 in tuffaceous clay (GL −2.00 to −4.00 m) about six months after burial (on 9 July 2021) with regards to the depth from the ground surface *h* and the normalized penetration resistance N_{di}/N_{dBM}. The normalized penetration resistance is the normalized value obtained by dividing the penetration resistance N_{di} obtained at each survey point (i = 1, 2, 3) by the BM penetration resistance N_{dBM}, and is a multiplier of the penetration resistance obtained at the reference point. The largest increase in penetration resistance of about four times is at Point 1, near the timber pile, but even at Points 2 and 3, which are far from the timber pile, the increase over time is about two times, indicating that the area solidified by pile burial extends in concentric circles.

4 CHANGES IN ELAPSED DAYS AND PENETRATION RESISTANCE

Figure 10 shows the results of PDCP tests at each study site one day (4 Dec 2020), one week (14–15 Dec 2020), three months (16 Mar 2021), six months (9 Jul 2021), about one year (30 Nov 2021), and about two year (6 - 7 Dec 2022) after the timber pile was buried, compared with results obtained on 23 Jun 2022, more than 10 years passed the burial on 15 Dec 2011. Although the results show different trends due to local ground variations, the penetration resistance after timber pile burial is globally greater than that of the BM, regardless of the burial period. The penetration resistance N_d at Point 1 shown in Fig. 10(a) increases significantly from relatively shallow depths immediately after construction, whereas those at Points 2 and 3 shown in Figs. 10(b) and 10(c) significantly increase near the timber pile tip at GL −3.00 to −4.50 m. Focusing on the passage of time after installation, at Point 1 in Fig. 10(a), N_d significantly increases immediately after burial in the clay layer near the ground surface below GL −1.50 m, and gradually increases with time after installation near the pile tip at around GL −4.00 m. The results at Point 2 in Fig. 10(b), which show a local increase of only N_d at depths below GL −3.00 m one day after burial, show a significant increase across all layers where the timber pile was buried about three months after burial, with that effect continuing for a long time as with Point 1. At Point 3 in Fig. 10(c), the increase in N_d is slower immediately after the construction than at Points 1 and 2, but gradually increases over time, and soil solidification extends across spread from the center to the tip.

Figure 11 shows PDCP test results obtained at the pile tip at GL −1.05 to −1.35 m, in the middle of the timber pile at GL −2.05 to −2.55 m, and at the pile tip GL −3.85 to −4.35 m as a function of days elapsed from installation and normalized penetration resistance, N_{di}/N_{dBM}. The plots in that figure show normalized penetration resistance values obtained every 100 mm and averaged for the depth of each section of interest. Compared with the

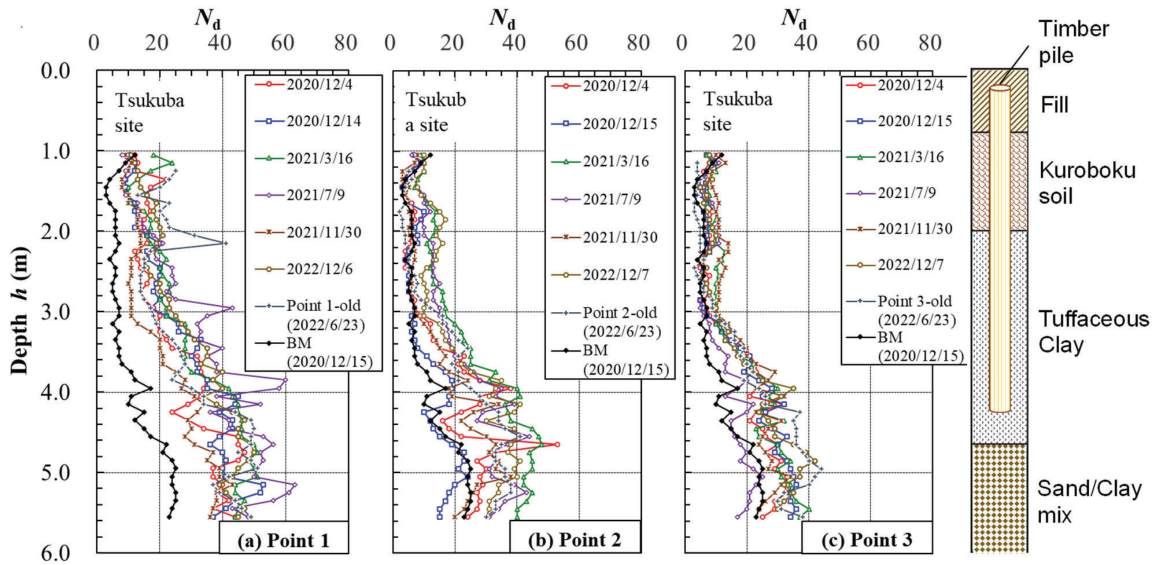

Figure 10: *Relationship between N_d value and ground depth (All investigations)*

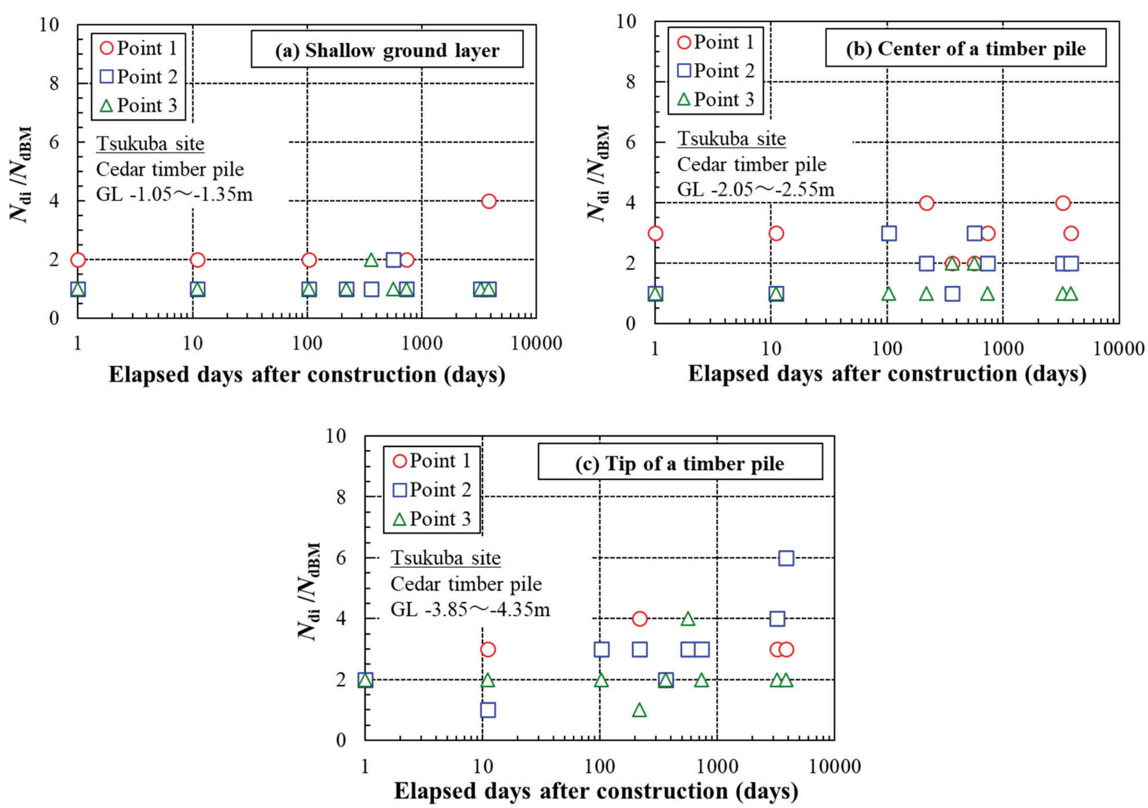

Figure 11: *Relationship between Elapsed days after construction and Normalized N_d value*

BM results, the penetration resistance increased at each depth after timber pile burial, and the effect continued throughout the burial period, but the increase in resistance was more pronounced near the pile at Point 1. Figure 11(c) shows that the increase in N_d at the pile tip was slower than in Figs. 11(a) and 11(b), but that penetration resistance rapidly increases after 200 days at Point 2, and after about ten years the resistance even at Point 3, which is farthest from the timber pile, is two times higher than the BM.

Figure 12 shows results obtained from a series of soundings as the relation between mean depth h and normalized

https://doi.org/10.52202/069179-0113

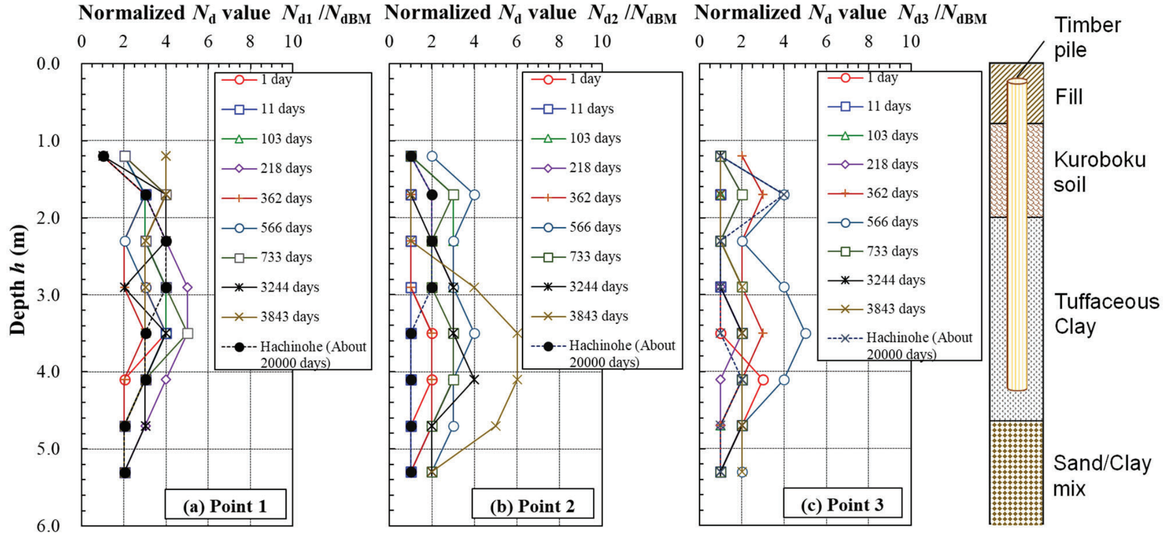

Figure 12: *Relationship between penetration resistance N_{di}/N_{dBM} and average depth (All investigations)*

penetration resistance N_{di}/N_{dBM}. The results in that figure show the normalized penetration resistance from GL −1.05 to −5.55 m as the relation between average depth and average value for normalized penetration resistance at 0.50 m intervals from GL −1.05 m near the ground surface. Although the degree of increase in the values varied depending on the surveyed location, consolidation of the soil based on the normalized penetration resistance values by timber piles embedded in clay were greatest in the center of the timber pile installation at GL −2.00 to −3.00 m for a period of about one year after construction. The trend for normalized penetration resistance about nine years after installation is different from the results from about one year after the installation. From GL −3.00 m at points 2 and 3, slightly deeper than at the center of the timber pile, the normalized penetration resistance of the piles increases in a bulbous manner, becoming greatest from the center of the pile to the tip at GL −3.00 to −4.00 m, and decreasing below about GL −4.00 m. This is presumably because in addition to horizontal interstitial water movement [11], the buried timber pile acts as a drain column that promotes drainage into the ground, where interstitial water in the deep clay layer, which has a higher confining pressure compared with the shallow layer, is absorbed by the wood, and over time consolidation develops from the pile tip. Compared with shallow layers in contact with planks, soil moisture is more easily absorbed by the timber pile in the deeper soil surrounding the wood surface at the pile tip. This accelerates consolidation, which is expected to progress over a wider area, spreading its effect to deeper soil where the timber pile is not buried. Figure 12 also shows results for a timber pile that was buried for approximately 55 years, installed using an impact method in reclaimed sandy soil with pile spacing similar to that in this study [13]. Although the characteristics of this soil are very different from that of the cohesive soil in this study, burial of the timber pile similarly tightens the soil, and the effect concentrically spreads out against the timber pile.

Increased resistance to ground penetration is considered to be influenced by the permeability of the soil type in question and the nature of soil particles. In sandy soils with high hydraulic conductivity, where liquefaction occurs more frequently than in clay soils, excess interstitial water pressure dissipates in a relatively short period at laying and consolidation effects by compaction are present immediately after burial, but this study showed that consolidation and compaction by timber pile burial continues on a yearly basis with higher effects near the timber pile.

5 CONCLUSIONS

From simple soundings, we continuously determined penetration resistance and its change in the vicinity of timber piles buried in a soft clay layer from immediately after burial, and we analyzed the degree and extent of solidification. The results of a series of field tests showed that penetration resistance in cohesive soil layers significantly increases near the timber piles immediately after their burial, that soil consolidation concentrically spreads over time, that buried timber piles act as drainage drain columns and promote the consolidation of cohesive soil, and that these effects are greater in soil in which piles have been buried for longer times. The results of model tests have shown higher water content and heightened consolidation phenomena with vicinity to timber piles, and that the vertical bearing capacity of piles increases with time since installation [14], both of which are consistent with the results of this study. This effect is not seen when using artificial materials such as steel or concrete. Consolidation of clayey soils presumably increases over time due to the combined effects of changes in soil microstructure caused by age effects and leaching of cementation materials from wood, in addition to the above-described accelerated consolidation associated with interstitial water movement into the timber pile immediately after burial. Through field surveys and laboratory tests, we will continue to quantitatively analyze factors promoting soil solidification to elucidate other advantages over artificial materials.

ACKNOWLEDGEMENT

This research was supported by JSPS KAKENHI Grant Number JP19k06170, 20H0305201 and 22H02408. We would like to thank the following people for their cooperation and assistance in this project: Mr. Daiki Nishimura, Mr. Toshiki Matsufuji, and Mr. Riku Ohara at Kochi University.

REFERENCES

[1] Hara, T.: Ground reinforcement technology and evaluation method using logs, *Wood industry*, 76(9), 361-365, 2021. (in Japanese)

[2] Shiono, N.: The Story of the City of the Sea ~ A Thousand Years of the Republic of Venice ~, *Shincho Bunko*, 53-55, 2009. (in Japanese)

[3] Hara, T.: Resilience Efforts in the Kochi Prefecture in Preparation for the Nankai Trough Earthquake, *Journal of Disaster Research*, 12(4), 755-765, 2017.

[4] Yoshida, M., Ishizaki, R., Kino, K., Shirota, T., Miyajima, M., Hamadda, M. and Numatra, A.: Shaking Table Tests on Improvement of Bearing Capacity of liquefiable ground by Piling Japanese Cedar Logs, P*roceedings of the 45th Japan National Conference on Geotechnical Engineering*, 1459-1460, 2010. (in Japanese)

[5] Hara, T., Sakabe, A., Numata, A., Mizutani, Y. and Ikeda, H.: Field Investigation on Liquefied Ground Reinforced by Log Piles, *Paper Reports on Use of Wood for Civil Engineering*, 11, 87-94, 2012. (in Japanese)

[6] Tamauchi, K., Miyata, T., Yamada, H., Matayoshi, K. and Matsumoto, K.: Characteristics of 70-Year-Old Timber Pile Foundation - Vertical Loading Ttest, Horizontal Reciprocal Loading Test -, *Bridge and Foundation Engineering*, 40(11), 29-46, 2006. (in Japanese)

[7] Mizutani, Y., Nakamura, H., Imano, Y. and Numata, A.: Supportability and durability of log piles in clay ground, *Paper Reports on Use of Wood for Civil Engineering*, 10, 62-68, 2011. (in Japanese)

[8] Kubojima, Y, Kato, H., Hara, T. and Sonoda, S.: Vibration phenomenon of logs buried in the ground (Part 4) Underground terminal conditions one year after construction, *The 72nd Annual Meeting of the Japanese Wood Society*, C15-P-13, 2022. (in Japanese)

[9] Kato, H., Kubojima, Y., Sonoda, S. and Hara, T.: Vibration and its application of wooden pile in the ground. Part 6. Underground moisture content for wooden piles one year after construction, *The 72nd Annual Meeting of the Japanese Wood Society,* C15-P-06, 2022. (in Japanese)

[10] Tezuka, D., Igarashi, C. and Hara, T.: Evaluation of the effect of soil and groundwater on ground improvement log piles contained preservative treated piles, *World conference on timber engineering,* WCTE 2021, WPC311,1-6, 2021.

[11] Tezka, D., Igarashi, C. and Hara, T.: Effect of change in properties of ground improvement log piles buried in the early stage, *Journal of JSCE*, 77(5), I_70-I_76, 2021. (in Japanese)

[12] Japanese geotechnical society: Ground survey method and explanation, Chapter 3 Portable cone penetration test, 274-279, 2013. (in Japanese)

[13] Hara, T., Igarashi, C., Tezuka, D., Horisawa, S. and Kato, H.: Evaluation of ground improvement effect and soundness of log piles buried in for an extended period, *World conference on timber engineering*, WCTE 2021, WPC603, pp.1-7, 2021.

[14] Suetsugu, D., Nasu, R., Koyama, A. and Fukubayashi, Y.: Effects of the shape on vertical bearing capacity of the timber pile installed in soft clay ground, *Journal of JSCE*, 77(5), I_77-I_83, 2021. (in Japanese)

https://doi.org/10.52202/069179-0113