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# INFLUENCE OF PILE WIDTH AND PILE STIFFNESS ON LATERAL SUBGRADE REACTION

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**ABSTRACT**: The coefficient of lateral subgrade reaction of a pile is generally given in proportion to −1/2 to −1 power of the pile width. However, since this relationship has been obtained from the experimental results of piles with relatively small diameters, its applicability to piles with large diameters is unclear. The influences of pile width and pile stiffness on lateral subgrade reaction are investigated by centrifugal model experiments. When the pile diameter is considerably large, the lateral subgrade reaction converges to a constant value. The validity is confirmed in comparison with the results of the in-situ horizontal load tests.

**Keywords**: *Pile, Lateral subgrade reaction, Pile width, Pile flexural stiffness, Centrifugal model experiment*

## 1. INTRODUCTION

The reference coefficient of lateral subgrade reaction of a pile (the coefficient of lateral subgrade reaction when horizontal displacement is 1 cm) decreases with an increase in pile width. According to previous studies, it is proportional to −1/2 to −1 power of the pile width $B$. In Recommendations for Design of Building Foundations by Architectural Institute of Japan (AIJ)[1)], the reference coefficient of lateral subgrade reaction of a pile is proportional to the −3/4 power of the pile width. However, as the pile width increases, the coefficient of lateral subgrade reaction decreases endlessly. Therefore, its application to very wide piles such as wall-type piles is difficult. As Sawaguchi[2)] pointed out, with an increase in the pile width, the stress state approaches a two-dimensional stress state and the resistance per unit pile width converges to a constant value. The previously proposed equations were obtained from horizontal plate loading tests up to approximately 1 m in diameter[3), 4)] and horizontal load tests of piles of relatively small diameter[5)]. Hence, the applicability of the equations to piles with larger pile width has not been clarified.

According to the elastic theory solution[6)], the coefficient of lateral subgrade reaction of a pile is affected by not only the pile width but also the flexural stiffness of the pile. However, in the design equations mentioned in major standards and criteria[1), 7), 8)], the influence of the flexural stiffness of the pile on the coefficient is not considered or its influence is assumed to be minor. There are few reports on the influence of the flexural stiffness of piles on the coefficient of lateral subgrade reaction, which is still unknown. Tsuchiya et al.[9], Ishibashi et al.[10], and Shimomura et al.[11), 12] conducted prior studies to investigate the change in the coefficient of lateral subgrade reaction with pile width. These studies are based on the results of in-situ horizontal load tests. In addition to the pile width and the flexural stiffness of the pile, the coefficient of lateral subgrade reaction of a pile is also affected by the soil stiffness, relative displacement between the pile and the ground, nonlinearity of the pile stiffness, and pile installation method. Therefore, it is difficult to obtain a trend of the influence of pile width on the coefficient only from the results of in-situ horizontal load tests. In this study, the influences of pile width and the flexural stiffness of the pile on the coefficient of lateral subgrade reaction of piles were investigated by centrifugal model experiments to clarify the experimental conditions. The equations obtained by the results of the model experiments were applied to the results of in-situ horizontal load tests to confirm the validity of the equations.

## 2. COEFFICIENT OF LATERAL SUBGRADE REACTION OF A PILE IN THE CURRENT GUIDELINES

Equations (1) and (2) show the coefficient of lateral subgrade reaction of a pile $k_h$ (kN/m$^3$) in Recommendations for Design of Building Foundations by AIJ[1]. The coefficient of lateral subgrade reaction is proportional to the pile width $B$ raised to the −3/4 power, and the flexural stiffness of the pile is unaffected. These matters are the same as in the standard for highway bridges[7] and that for railways[8].

$$k_h = k_{h0}\bar{y}^{-1/2} \tag{1}$$

in which $\bar{y}$: dimensionless horizontal displacement of a pile (dimensionless value of displacement $y$ in cm), $k_{h0}$: reference coefficient of lateral subgrade reaction (kN/m$^3$), (the coefficient of lateral subgrade reaction when horizontal displacement $y$ is 1 cm)

$$k_{h0} = \alpha E_s \bar{B}^{-3/4} \tag{2}$$

in which $\alpha$ : constant according to the evaluation method of the modulus of deformation of ground (m$^{-1}$), $\bar{B}$: dimensionless pile width (dimensionless value of pile width $B$ in cm), $E_s$: deformation modulus of ground (kN/m$^2$).

Equation (3), which is an equation of elasticity theory (so-called Francis equation[6]), is used in dynamic analysis.

$$k_h B = \frac{1.3E_s}{1-\nu_s^2}\left(\frac{E_s B^4}{E_p I_p}\right)^{1/12} \tag{3}$$

in which $E_p$: Young's modulus of the pile (kN/m$^2$), $I_p$: cross-sectional secondary moment of the pile (m$^4$), $\nu_s$: Poisson's ratio of the ground, $B$: pile width (m).

The cross-sectional secondary moment of a pile is expressed in terms of the pile width $B$ (m) and the pile depth $t$ (m), hereinafter referred to as the pile thickness, $I_p = \kappa B t^3$ ($\kappa$ is 1/12 in the case of rectangular cross-section, and π/64 in the case of solid circular shape). Therefore, Eq. (3) can be rewritten as follows.

$$k_h = \frac{1.3E_s}{1-\nu_s^2}\left(\frac{E_s}{\kappa E_p}\right)^{1/12} B^{-\frac{3}{4}} \cdot t^{-\frac{1}{4}} \tag{4}$$

From Eq. (4), according to the elasticity theory, $k_h$ is proportional to $B^{-3/4}$ and is proportional to $t^{-1/4}$. In the case of a solid circular pile, $t = B$, so $k_h$ is proportional to $B^{-1}$.

## 3. CENTRIFUGAL MODEL EXPERIMENTS

### 3.1 Outline of experiments

Centrifugal model experiments were conducted to investigate the influence of pile width and flexural stiffness of the pile on the coefficient of lateral subgrade reaction of a pile. The experiments were performed at a centrifugal acceleration of 40 g. The experimental model is shown in Fig. 1. A rigid soil container of dimensions 690 × 510 × 450 mm (length × width × height) (27.6 × 20.4 × 18 m at the prototype scale) was used in the experiments. A layer of Toyoura sand with a thickness of 375 mm (representing 15 m at the prototype scale) was prepared using the air pluviation method. The relative density of the layer exceeds 90% ($\rho$ = 1.63 g/cm$^3$). The relationship between the effective overburden pressure and the velocity of S-wave in the layer is also shown in Fig. 1.

The piles were constructed from stainless-steel ($E_p$ = 1.93 × 10$^8$ kN/m$^2$) with a rectangular cross-section to allow for separate consideration of the influences of pile width and pile flexural stiffness. The restraint condition of the pile tip was set to almost pin joint.

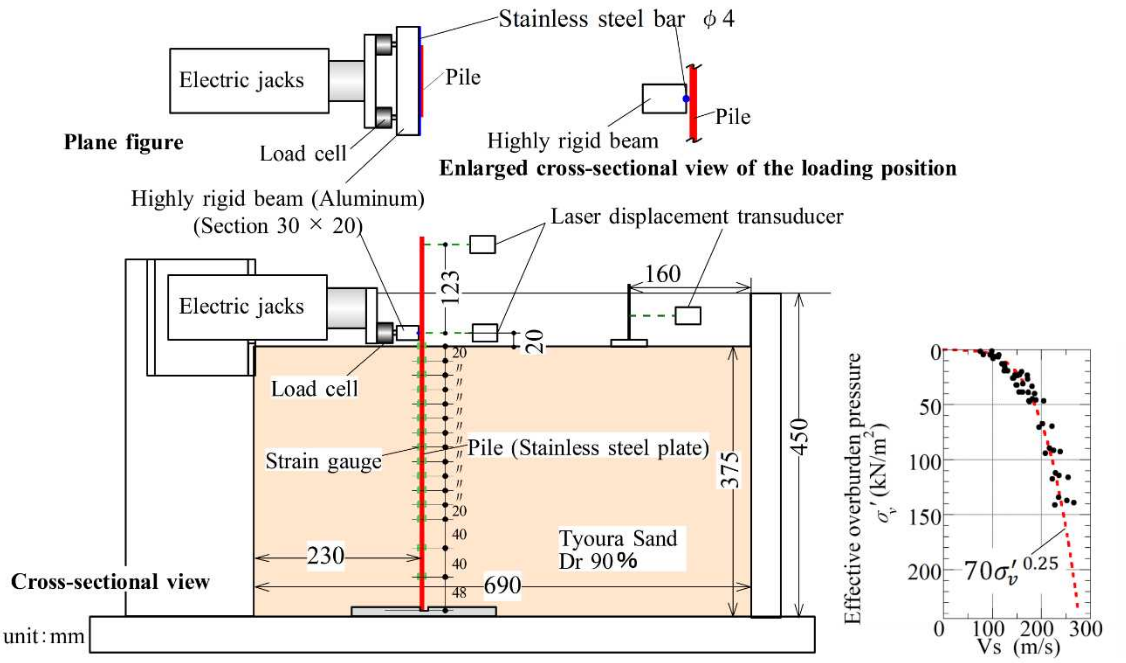


Fig.1 Experimental model

The experimental cases are shown in Table 1. To consider the influences of pile width and flexural stiffness of the pile separately, two series of experiments were conducted. Initially, a series of experiments with equal flexural stiffness per unit pile width and different pile widths was conducted, and subsequently with equal pile width and different flexural stiffness of pile (pile thickness) was conducted. In cases where the pile width was more than 20 cm, Teflon sheets were attached to the side walls of the soil container to remove the effect of friction on the walls. Case B51t4 corresponds to the two-dimensional condition (infinite pile width) because the pile width is equal to the soil container width. The flexural stiffness of the pile is equivalent to a 400 mm diameter, 6 mm thick steel pipe pile for case B1t4 and to a 1,200 mm diameter, 16 mm thick steel pipe pile for case B3t12.

The horizontal load was applied at a height of 20 mm above the ground by an electric jack at a speed of 0.5 mm/min. As shown in Fig. 1, a highly rigid beam with a length equal to or longer than the pile width was placed between the load cell and the pile to ensure that the deformation of the pile would be equal in the plane. The restraint at the pile tip was also set to be almost a hinge, so that no planar torsion was applied to the pile. A stainless-steel rod of the circular cross-section was embedded in this rigid bar to ensure that the height of the loading point remains constant even if the pile is bendingly deformed. The loading was terminated when the bending strain of the pile reached approximately 3,000 μ.

The measured parameters were horizontal load, pile head displacement (measured at two heights to measure the pile head rotation angle), ground surface displacement, and pile bending strain at 15 cross-sections. The bending strains of the pile were measured at the center of the pile as shown in Fig. 1.

Table 1 Experimental cases ( ) : the prototype scale

| Case name | Pile width $B$ | Pile Thickness $t$ | Note |
|---|---|---|---|
| B1t4 | 1 cm (0.4 m) | 4 mm (0.16 m) | |
| B2t4 | 2 cm (0.8 m) | | |
| B3t4 | 3 cm (1.2 m) | | |
| B5t4 | 5 cm (2.0 m) | | |
| B10t4 | 10 cm (4.0 m) | | |
| B20t4 | 20 cm (8.0 m) | | |
| B51t4 | 51 cm (∞) | | two-dimensional condition |
| B3t1 | 3 cm (1.2 m) | 1 mm (0.04 m) | |
| B3t2 | | 2 mm (0.08 m) | |
| B3t8 | | 8 mm (0.32 m) | |
| B3t12 | | 12 mm (0.48 m) | |

### 3.2 Experimental results and discussion

All experimental results are shown as the prototype scale.

#### *3.2.1 Influence of pile width*

Figure 2 shows the relationships between the loads per unit pile width and the horizontal displacements at the loading point for the cases when the pile thicknesses are the same (equal flexural stiffness per unit pile width) and the pile widths are varied. Fig. 3 shows the distributions of the bending moment per unit pile width in the depth direction when a horizontal load of 250 kN/m per unit width was applied.

In all cases, the pile bodies were within the elastic range under a horizontal load of 250 kN/m. The displacements of the ground surface at 6.4 m (160 mm in the model) from the wall of the soil container were significantly small, and the influence of the container size on the experimental results was negligible.

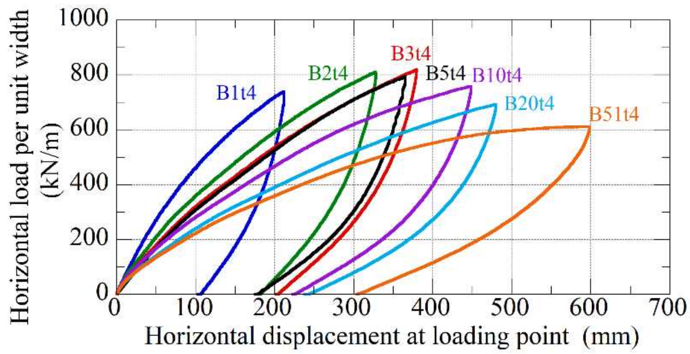


Fig. 2 Load−displacement relationships per unit pile width

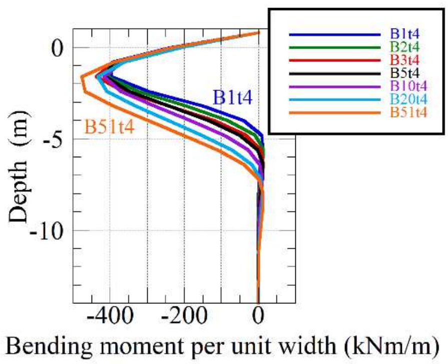


Fig. 3 Bending moment distributions of piles

Figure 2 shows that the displacement of a pile increases as the pile width increases even if the load per unit pile width is the same. Fig. 3 shows that, the larger the pile width, the larger the maximum bending moment of the pile and the deeper the depth at which the maximum bending moment is generated. From these results, it can be stated that the coefficient of lateral subgrade reaction near the ground surface decreases as the pile width increases.

Figure 4 shows the deformation area of the ground surface caused by the horizontal load test of a model pile under gravitational field using a rigid soil container of dimensions 1,800 × 800 × 800 mm (length × width × height)[13]. The area of ground displacement caused by horizontal loading of a pile extends outside the pile width. When the flexural stiffness of the pile per unit width is equal, the depth of the ground contributing to the horizontal resistance does not increase significantly with an increase pile width, as shown in Fig. 3. Furthermore, the displacement area of the ground outside the pile width does not increase in proportion to the pile width. Therefore, as the pile width increases, the contribution of the ground outside the pile width to the horizontal resistance of the pile decreases relative to the pile width. Hence, the coefficient of lateral subgrade reaction decreases as the pile width increases. However, the lower limit of the coefficient of lateral subgrade reaction is the value of the two-dimensional state.

The lateral subgrade reaction acting on the pile at each depth was obtained by second-order differentiation of the pile bending moment distribution in the depth direction. The horizontal displacement of the pile at each depth was calculated from the pile head displacement, pile head rotation angle, pin condition of the pile tip, the bending moment distribution of the pile. Figure 5 shows the relationship between lateral subgrade reaction and pile displacement at G.L. −0.8 m. The figure also shows that the lateral subgrade reaction decreases as the pile width increases, and that there is a lower limit to the reaction even when the pile width becomes considerably large.

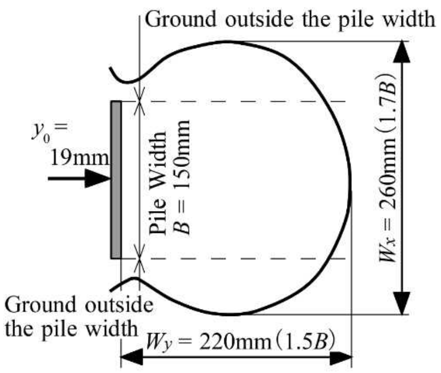


Fig. 4 Deformation area of the ground surface (added to Hamasaki et al. [13])

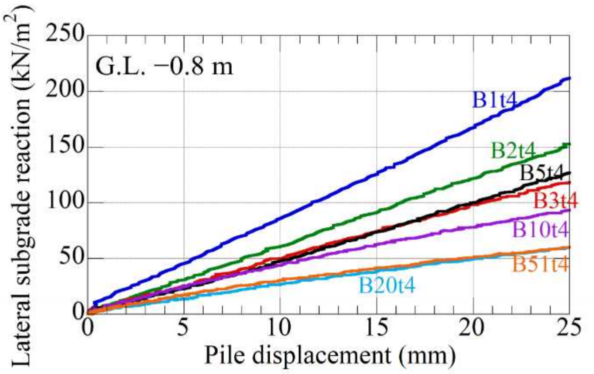


Fig. 5 Relationships between lateral subgrade reaction and pile displacement

Figure 6 shows the relationship between the lateral subgrade reaction and pile width at G.L. −0.8 m and G.L. −1.6 m for pile displacements of 2, 5, 10, and 25 mm. Although the lateral subgrade reaction decreases with an increase in pile width, the lateral subgrade reaction tends to converge to a constant value with increasing pile width, since the values for 8 m width and two-dimensional condition (infinite pile width) are almost the same.

Figure 7 shows the change in lateral subgrade reaction with pile width at G.L. −0.8 and −1.6 m as a ratio to the value for pile width $B$ = 0.4 m (B1t4). The figure also shows lines where the lateral subgrade reaction is proportional to the −1 to −1/4 power of the pile width $B$. From these figures, it can be stated that the decreasing tendency of lateral subgrade reaction due to pile width is not significantly affected by pile displacement $y$ or depth. When the pile width is less than approximately 1 m, the lateral subgrade reaction decreases in proportion to the −3/4 to −1/2 power of the pile width as mentioned in the previous studies. However, when the pile width is larger than 1 m, the previous studies clearly underestimate the lateral subgrade reaction. The lateral subgrade reaction for pile widths of 1 m or grater is approximately proportional to the −1/4 power of pile width $B$. The lower limit of the lateral subgrade reaction in the two-dimensional state was approximately 0.3 times the value for a pile width of 40 cm in the experiment.

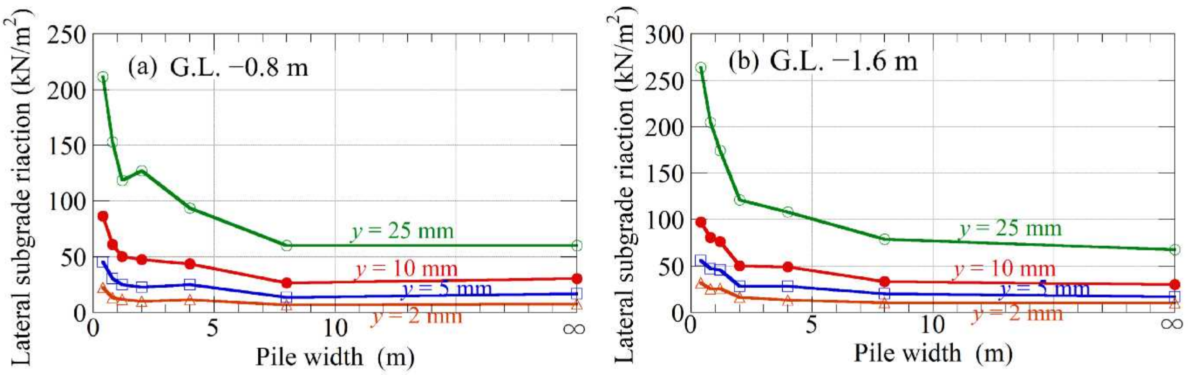

Fig. 6 Relationships between pile width and lateral subgrade reaction

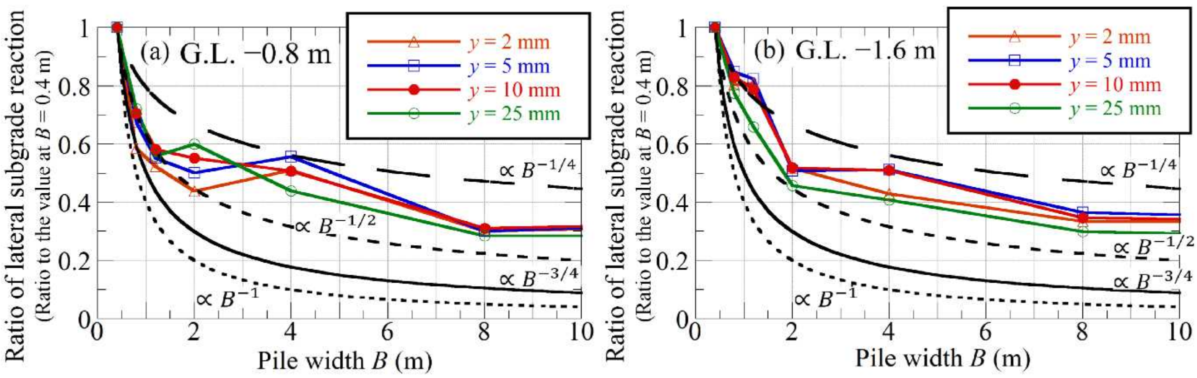

Fig. 7 Relationship between pile width and ratio of lateral subgrade reaction
(ratio to the value at $B$ = 0.4 m)

### *3.2.2 Influence of flexural stiffness of pile*

Figure 8 shows the relationships between the horizontal loads and the horizontal displacements at the loading point for the cases where the pile widths are 1.2 m and the thicknesses of the piles $t$ (flexural stiffness of piles) are different. As the flexural stiffness of the pile increases, a larger force is required to deform the pile. Therefore, the horizontal load for the same horizontal displacement increases. The horizontal load at the loading point with a horizontal displacement of 10 mm was 8.2 times the load at $t$ = 4 mm and 37.5 times the load at $t$ = 12 mm compared with that of the load at the pile thickness of $t$ = 1 mm. The elastic theoretical equations for piles with the uniform modulus of deformation of ground and unconstrained pile heads give horizontal loads of 2.8 and 6.4 times, respectively. As shown in the S-wave velocity distribution in Fig. 1, the stiffness of the ground increases with depth in this model. The larger the flexural stiffness of the pile, the greater the influence due to the deeper soil appears on the horizontal resistance of the pile. Therefore, the horizontal load is expected to be larger than that by the elastic theoretical solution.

Figure 9 shows the distributions of bending moment of pile per 1 m width at 10 mm displacement of loading point and the distributions of deformation of pile calculated from the bending strains of the pile and boundary conditions. The larger the flexural stiffness of the pile, the deeper the deformation of the pile reaches into the ground. The depth of generation of the maximum bending moment was approximately −0.4 m in B3t1 and approximately −3.5 m in B3t12. Similarly, the first immovable point of the pile becomes deeper as the flexural stiffness of the pile increases.

Figure 10 shows the change in the relationships between lateral subgrade reactions and pile displacements due to the difference in flexural stiffness of piles at G.L. −0.8, −1.6, and −2.4 m. Only the data before the pile yielded are shown in Fig. 10. If the displacement of the pile below the relevant depth is significantly small, the graph is not shown because of the large error in the calculated value of lateral subgrade reaction. Figure 10 shows that the influence of flexural stiffness of the pile on the relationship between lateral subgrade reaction and pile displacement is relatively small.

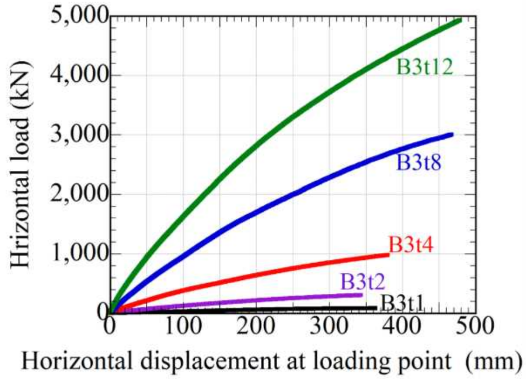


Fig. 8 Relationships between the horizontal loads and the horizontal displacements at the loading point

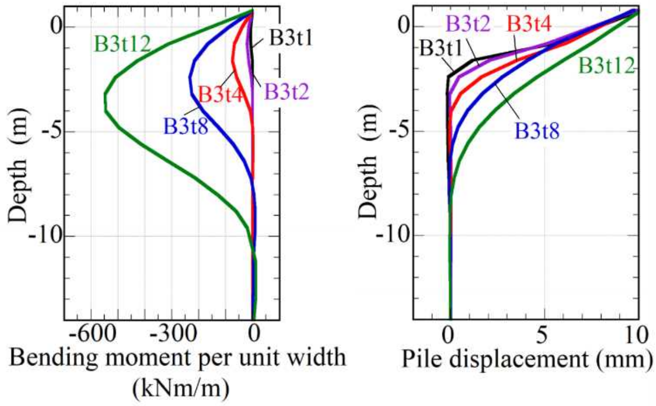


Fig. 9 Bending moment and displacement distribution of a pile

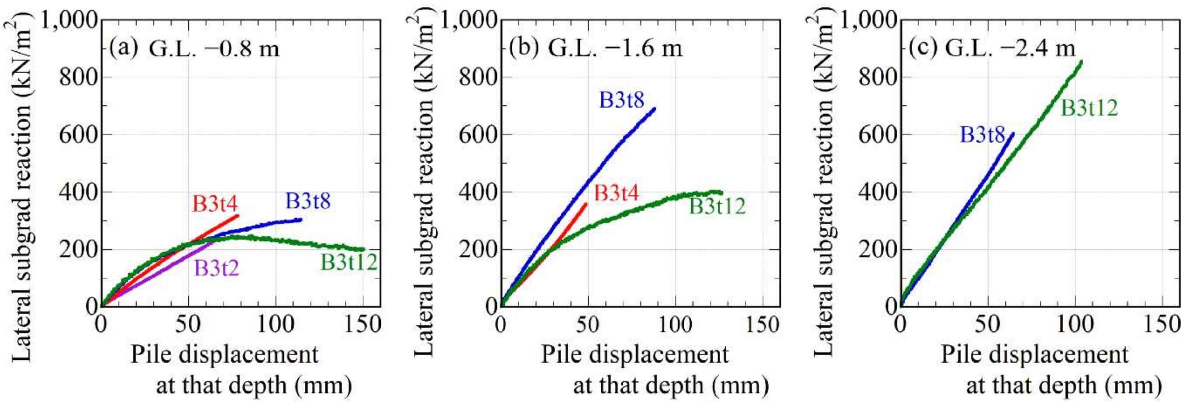


Fig. 10 Relationship between lateral subgrade reaction and pile displacement at each depth

Figure 11 shows the variation of lateral subgrade reactions with pile thickness at the depths of G.L. −0.8 and −1.6 m. This figure shows the ratio of the lateral subgrade reactions for each case to that of B3t4 with a pile thickness of 160 mm. The "*y*" in the figures represents the horizontal displacement of the pile at that depth. The line based on elasticity theory (proportional to the −1/4 power of pile thickness *t*) is also shown in Fig. 11. In both depths, the ratio of the lateral subgrade reaction did not decrease with the increase in the flexural stiffness of piles (pile thickness) in this experiment. However, it remained approximately the same or, on the contrary, tended to increase slightly. The change in the ratio of the lateral subgrade reaction due to the increase in pile displacement is small.

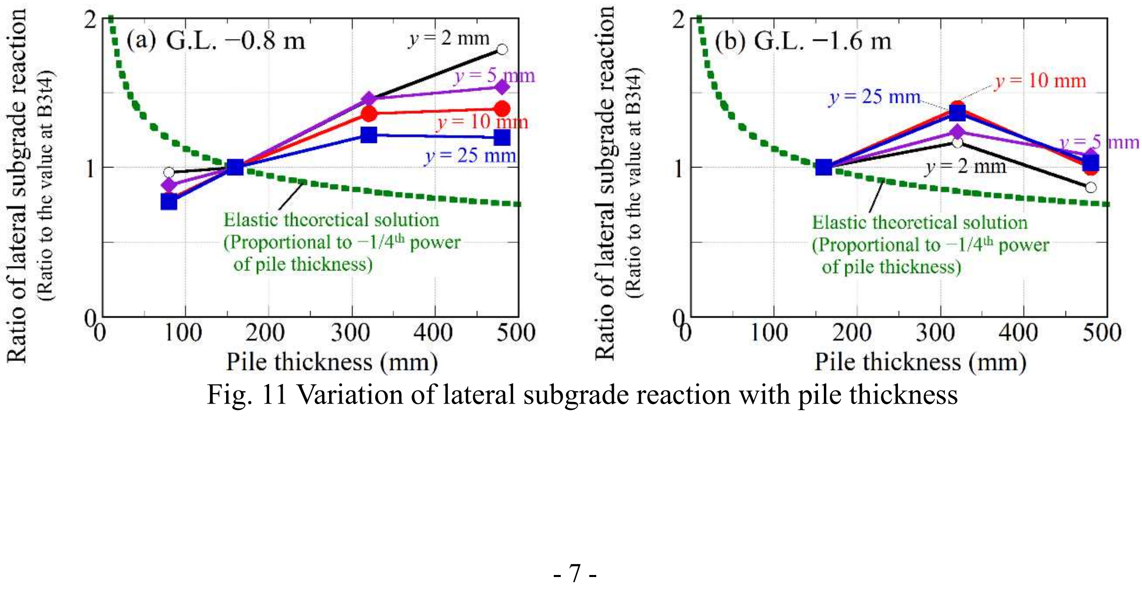


Fig. 11 Variation of lateral subgrade reaction with pile thickness

It is hypothesized that the lateral subgrade reaction did not decrease with an increase in the flexural stiffness of the pile because multiple slip surfaces are formed sequentially as the horizontal load increases. Sano et al.[14] used an X-ray CT scanner to visualize the horizontal resistance mechanism of pile foundations in three dimensions. Figure 12 shows the observed development pattern of the slip surfaces. The slip surface begins to form at a shallow position, and with the increase in loading, a new slip surface is formed from a deeper position. When the flexural stiffness of the pile increases, deformation occurs at a deeper position even if the pile head displacement is the same, as shown in the right-side figure of Fig. 9.

As shown in Fig. 13(a), in the elastic ground, when the deformation of a pile causes horizontal displacement of the ground at a certain depth $z$, it also causes horizontal displacement of the ground at other depths (hereinafter referred to as displacement by influence). The coefficient of lateral subgrade reaction at other depths (especially at shallow depths) decreases due to displacements by influence. Once a slip surface is created, the ground displacement becomes discontinuous at the slip surface. Therefore, as shown in Fig. 13(b), the displacement by influence from the deeper part of the sliding surface to the shallower part of the slip surface is greatly reduced. As shown in Fig. 12, the lateral subgrade reactions at each depth are less affected by the displacements at other depths due to the formation of multiple slip surfaces with horizontal loading. Therefore, it is considered that the influence of the flexural stiffness of the pile on lateral subgrade reaction was hardly appeared in the experimental results.

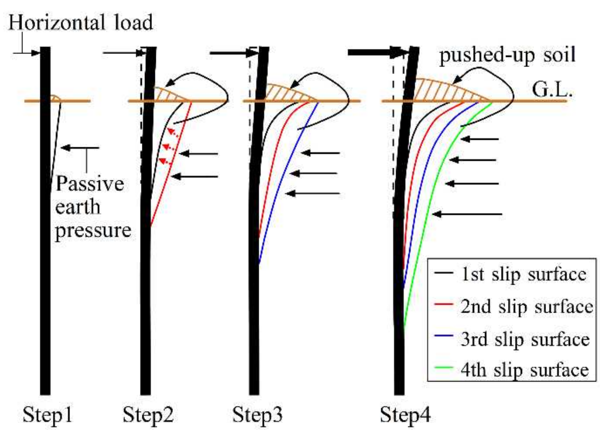


Fig. 12 Development pattern of slip surface of ground in front of pile[14]

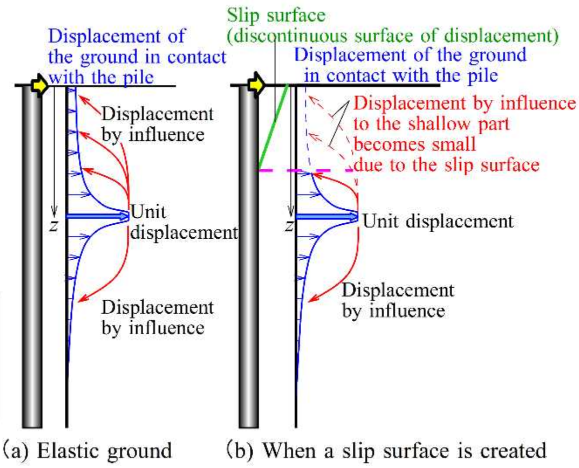


Fig. 13 Change in displacement by influence due to slip surface

### 3.3 Proposed Equation for Evaluating Coefficient of Lateral Subgrade Reaction

Based on the experimental results, the influences of pile width and flexural stiffness of the pile on the coefficient of lateral subgrade reaction are proposed as follows:

- For piles with a width of 1 m or less, the coefficient of lateral subgrade reaction is proportional to the −3/4 power of the pile width $B$, following the previous studies.
- For piles with a width of 1 m or larger, the coefficient of the lateral subgrade reaction is proportional to the −1/4 power of the pile width $B$. However, the lower limit of the coefficient of lateral subgrade reaction is 0.6 times that for a pile width of 1 m (≈0.3 times the coefficient of lateral subgrade reaction for a pile width of 0.4 m).
- The flexural stiffness of the pile does not affect the coefficient of lateral subgrade reaction of the pile.

Equation (5) reflects this proposal in the equation for the reference coefficient of lateral subgrade reaction $k_{h0}$ (kN/m$^3$) of a single pile in Recommendations for Design of Building Foundations by AIJ. The coefficient of 0.0316 is a constant ( = $100^{-3/4}$) to adjust the calculation results because the unit of pile width $B$ was changed from cm to m. The relationship between the coefficient of lateral subgrade reaction and displacement is based on Eq. (1).

$$k_{h0} = 0.0316\alpha E_s \bar{B}^{\lambda} \tag{5}$$

in which $k_{h0}$: reference coefficient of lateral subgrade reaction (kN/m$^3$), $\alpha$ : constant according to the evaluation method of the modulus of deformation of ground (m$^{-1}$), $E_s$: modulus of deformation of ground (kN/m$^2$), $\bar{B}$ : dimensionless pile width (dimensionless value of pile width $B$ in m), $\lambda$ : −3/4 ($\bar{B} \leq 1$), −1/4 ($\bar{B} > 1$), However $\bar{B}^{\lambda} \geq 0.6$.

A comparison between the proposed equation and the experimental results is shown in Fig. 14. The reference pile width was set to 1 m, the value $B$ = 40 cm was expressed as $0.4^{-3/4} = 1.988$. Since the equation was proposed based on the experimental results, it is only natural that they would agree. Eq. (5) gives a good representation of the change in the lateral subgrade reaction with pile width.

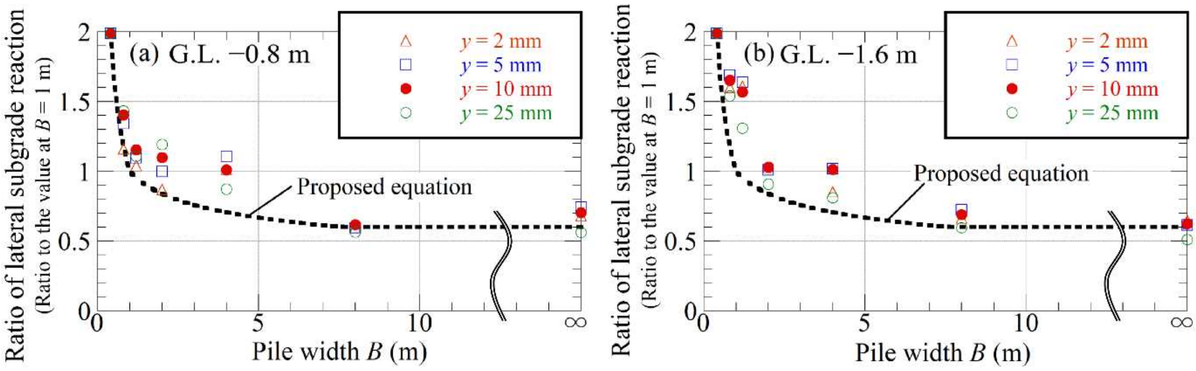


Fig. 14 Comparison of the proposed equation with experimental results

## 4. VERIFICATION BY PREVIOUS IN-SITU HORIZONTAL LOAD TEST RESULTS

The validity of the proposed equation was verified by comparing it with the results of previous in-situ horizontal load tests[15)–23)]. Table 2 shows the horizontal load tests of the piles used for verification. The tests were selected mainly for pile widths of 1.5 m or greater. These tests were included some data to confirm the applicability to small diameter piles. The coefficients of lateral subgrade reaction were calculated using Eq. (5) and Eq. (1). $\alpha$ was set to 80. The deformation modulus of ground $E_s$ (kN/m$^2$) was set to 700 $N$ ($N$: N-value) for sandy soil and 210$c_u$ for clayey soil ($c_u$ is the undrained shear strength of clayey soil). If the results of the borehole lateral load test were available, the deformation modulus of ground $E_{sbh}$ obtained from the tests was adopted. The results of the load test of No.3 in the table are the average values of $E_s$ of each layer, because there are sandy and clayey soil layers near the pile head. If there is no description of the elastic modulus of a pile, $E_p$, in the literature, it is assumed to be 2.1 × 10$^7$ (kN/m$^2$).

Figure 15 shows the comparison between the proposed reference coefficients of lateral subgrade reaction and those calculated backward using the beam theory for elastic floor[25)] from the loads applied at a pile head displacement of 10 mm in the in-situ horizontal load tests. The vertical axis is normalized by dividing by the reference coefficient of lateral subgrade reaction at a pile width of 1 m, which is calculated by Eq. (5). In the case where the pile body cracked before the pile head displacement reached 10 mm and the flexural stiffness of piles changed, the reference coefficients of lateral subgrade reaction was calculated from the displacement at the time of the crack and the coefficients of lateral subgrade reaction based on the relationship in Eq. (1). Although the coefficients of lateral subgrade reaction might vary slightly due to the accuracy of the evaluation of the subgrade stiffness, the proposed method provides a good representation of the coefficients of lateral subgrade reaction of large diameter piles and wall-type piles in load tests.

Table 2 Horizontal load tests of piles used for verification

| No. | Pile width $B$ (m) | Cross-section of pile | Soil | $N$ | $c_u$ (kN/m$^2$) | $E_{sbh}$ (kN/m$^2$) | $E_p$ (kN/m$^2$) | Condition of a pile head | Reference No. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.0 | Circular solid | C | | 26 | | $2.1 \times 10^7$ | Free | 15 |
| 2−1 | 3.0 | Circular solid | S | 10 | | | $2.2 \times 10^7$ | Free | 16 |
| 2−2 | 2.0 | | | | | | | | |
| 3 | 3.0 | Circular solid | S<br>C | 7 | 35 | | $2.8 \times 10^7$ | Free | 17 |
| 4 | 0.3185 | Circular pipe $t = 6.9$ mm | S & C | 12 | | | $2.1 \times 10^8$ | Fixed | 18 |
| 5−1 | 0.8 | Circular solid | S | | | 8,550 | $2.57 \times 10^7$ | Free | 19 |
| 5−2 | 1.2 | | | | | | | | |
| 6 | 1.0 | Circular solid | S | | | 6,280 | $3.0 \times 10^7$ | Free | 20 |
| 7−1 | 2.2 | Rectangle $t = 0.6$m | S | | | 6,500 | $2.1 \times 10^7$ | Free | 21 |
| 7−2 | 4.4 | | | | | | | | |
| 7−3 | 6.6 | | | | | | | | |
| 8−1 | 2.4 | Rectangle $t = 1.2$m | C | | 50 | | $3.1 \times 10^7$ | Free | 22 |
| 8−2 | 5.0 | | | | | | | | |
| 9 | 2.3 | Rectangle $t = 0.8$m | C | | 20 | | $2.1 \times 10^7$ | Free | 23 |

S: sandy soil, C: clayey soil

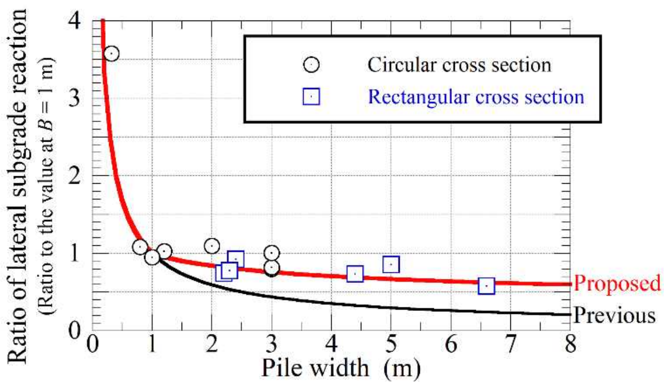


Fig. 15 Comparison of proposed equation for variation of lateral subgrade reaction with pile width and results of in-situ horizontal load tests of piles

## 5. CONCLUSIONS

Through the centrifugal model experiments, the influences of pile width and flexural stiffness of piles on the coefficient of lateral subgrade reaction of a pile were discussed, and the following conclusions were obtained.

(1) The previous equation, in which the coefficient of lateral subgrade reaction of a pile is proportional to the −3/4 power of the pile width, underestimates the coefficient when the pile width is greater than 1 m.

(2) Even if the pile width is very large, the coefficient of lateral subgrade reaction can be expected to be approximately 0.6 times that for pile width of 1 m.

(3) The influence of the flexural stiffness of a pile on the coefficient of lateral subgrade reaction of a pile is minor.

(4) Based on the results of the centrifugal model experiments, the equation was proposed to provide the coefficient lateral subgrade reaction proportional to the −3/4 power of the pile width up to 1 m, and proportional to the −1/4 power of the pile width above 1 m. The proposed equation is in good agreement with the results of in-situ horizontal load tests of large diameter piles.

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