New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Pullout resistance of reinforcement bar due to bearing capacity of expanded toe

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ABSTRACT: Effective measures are awaited for preventing the embankment or natural slope from the failure caused during large-scale earthquake in Japan. The reinforcing bar described in this paper has expanded toe and the capacity of bearing resistance enough to apply for the soft ground and can stabilize the slope. This paper describes the results of pullout tests using the reinforcing bar with expanded toe. It first shows the differences of pullout resistance between vertically installed reinforcing bars with expanded toe which have three types of diameter respectively. Secondary, it is verified that the value of pullout resistance of the reinforcing bar with expanded toe can be described as sum of the value of skin resistance and bearing resistance, and proposes the design method of ultimate pullout resistance through the pullout tests horizontally installed in the soil. Finally, safety factor of pullout resistance is proposed.

1 INTRODUCTION

Effective measures are awaited for preventing embankment slopes of highways and housing lots from the failure during large-scale earthquake. Conventional reinforcing methods, such as nailing, stabilize slopes by increasing the skin frictional resistance between the soil and grout, and require a relatively large number of long bars to be installed to stabilize the slope of embankments. This paper proposes a new method for stabilizing slopes of even small skin frictional resistance, which involves use of reinforcing bars with expanding toes. Several series of pullout tests using new type reinforcing bars with expanded toes were carried out to investigated 1) the differences in pullout resistance by differences in expanded toe diameter when the bars were vertically installed, 2) the validity of the method for assessing the pullout resistance of the reinforcing bars with expanding toes when installed horizontally, and 3) the safety factor and its adequacy. This paper describes the results of the study.

2 TESTING METHODS

2.1 *Vertical pullout test*

An overview of a reinforcing bar with expanded toe is shown in Fig. 1, whose toe consists of ten steel rods. The steel rods are compressed and spread radially when the inner steel pipe (rod section) is pulled out

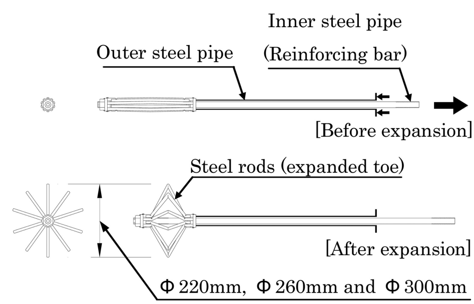

Figure 1. An overview of a reinforcing bar with expanded toe.

from the outer steel pipe, which serves as the reaction force. Grout can be poured through the inner pipe to the toe and to the bore hole.

Ground consisting of fine sand was built by heaping up 0.2 m spreading depth soil layers compacted by 700 kg weight vibration roller respectively in an indoor soil tank (width: 5 m, depth: 4 m), and vertical bore holes of a diameter of 65 mm and a length of 1400 mm were drilled. Reinforcing bars of a rod length of 1.0 m with expanded toes were inserted into the holes, and the toes were expanded using a hydraulic jack. Cement milk (W/C = 50%) was grouted and cured for seven days. A pullout test was conducted by controlling the load and using a center-hole type hydraulic jack. Loads to be applied in steps were determined by preliminarily

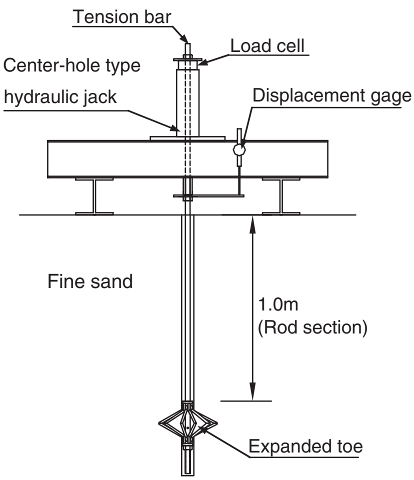

Figure 2. An overview of the vertical pullout test.

Table 1. Soil properties of fine sand (vertical pullout test).

Adopted parameters	Value
Cohesion, c	12.8 kN/m^2
Maximum friction angle, ϕ	34.2°
Wet unit weight, γ	17.1 kN/m^3
Water content	13.9 %
Maximum diameter of soil particle	4.25 mm
Fine content	11.1 %

calculating the loads that reach the ultimate pullout resistance in ten steps. The load was retained for five minutes at each step. During the test, the pullout resistance P and pullout displacement δ were measured at the heads of the reinforcing bars, and the test was stopped when δ reached 50 mm. An overview of the vertical pullout test is shown in Fig. 2, and the soil properties of the ground tested are shown in Table 1.

The toes were expanded to diameters of Φ220 mm, Φ260 mm, and Φ300 mm. Two bars were tested for each diameter, one of which was entirely grouted and the other was grouted only at the expanded toe section. All bars had a rod length of 1.0 m. To understand the ultimate skin friction force of the prepared ground, a pullout test was similarly conducted using reinforcing bar without expanded toes (Fig. 3). Test cases are shown in Table 2.

2.2 *Horizontal pullout test*

A slope was prepared in the indoor soil tank so as to have a slope length of 1.0 m and an inclination of 1:0.3. Bore holes of a diameter of 65 mm and a length of 2.4 m were drilled perpendicular to the slope surface, and the reinforcing bars were installed so that the

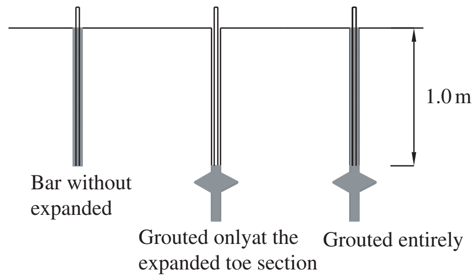

Figure 3. Type of reinforcing bars in vertical pullout test.

Table 2. Type of vertical pullout test.

Name	Type of toe	Grout filling
A	No expanded	Entirely
B-1	Φ 220 mm expanded	Entirely
B-2	Φ 260 mm expanded	Entirely
B-3	Φ 300 mm expanded	Entirely
C-1	Φ 220 mm expanded	Only expanded section
C-2	Φ 260 mm expanded	Only expanded section
C-3	Φ 300 mm expanded	Only expanded section

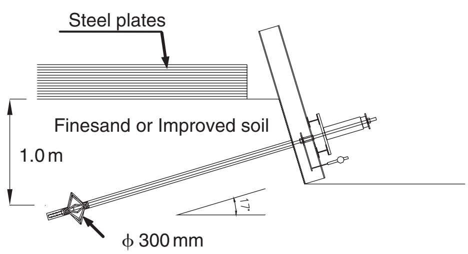

Figure 4. An overview of the horizontal pullout test.

expanded toes were 1.0 m from the ground surface. The diameter of the expanded toes was Φ300 mm, and the rod length was 2.0 m. An overview of the test is shown in Fig. 4. The pullout test was performed as in the vertical pullout test.

Two types of ground were tested: fine sand which was the same soil shown in Table 1 and improved soil prepared by mixing 1% of cement to the fine sand. Placing and spreading process was equivalent to vertical pullout test. The soil properties of the improved soil are shown in Table 3.

To understand the effects of the vertical stress σ_v acting on the expanded toe on the pullout resisting force P, the steel plates were loaded on the upper part of the slope to adjust the surcharge. Test cases are shown in Table 4. The ultimate skin friction force between the soil and grout was determined by conducting a pullout test of reinforcing bars without expanded toes on the same grounds.

Table 3. Soil properties of improved soil (horizontal pullout test).

Adopted parameters	Value
Cohesion, c	19.1 kN/m^2
Maximum friction angle, ϕ	30.0°
Wet unit weight, γ	18.1 kN/m^3
Water content	14.3%
Maximum diameter of soil particle	4.25 mm
Fine content	11.1%

Table 4. Type of horizontal pullout test.

Name	Surcharge	Type of soil
D-1	0 kN/m^2	Fine sand
D-2	26.1 kN/m^2	Fine sand
D-3	52.2 kN/m^2	Fine sand
E-1	0 kN/m^2	Improved soil
E-2	26.1 kN/m^2	Improved soil
E-3	52.2 kN/m^2	Improved soil

3 TEST RESULTS

3.1 *Vertical pullout test*

The relationship between the pullout resistance and displacement is shown in Fig. 5 for the reinforcing bars with and without expanded toes for each step. The reinforcing bars without expanded toes showed a peak of pullout resistance at a small displacement δ. On the other hand, the pullout resistance of the bars with expanded toes showed no clear peak but kept increasing. The P-δ curves of expanded toes can be fitted by hyperbolic curves as shown in Fig. 5 and the asymptotic line values were used as the ultimate pullout resistance P_u. The figure shows that the larger the diameter of the expanded toe, the larger the pullout load. This suggests that the differences in the projected area of the expanded toe toward the pulling direction affected the pullout resistance of the bar.

3.2 *Horizontal pullout test*

The relationship between pullout resistance P and pullout displacement δ in the horizontal pullout test with fine sand is shown in Fig. 6. As in the vertical pullout test, the values were subjected to hyperbolic approximation, and the results are shown in the figure with lines. The pullout resistance of the bars with expanded toes was larger than that of the reinforcing bars without expanded toes. The pullout resistance increased as the surcharge increased.

Calculated pullout strength P_d and the measured ultimate pullout resistance P_u of the reinforcing bars

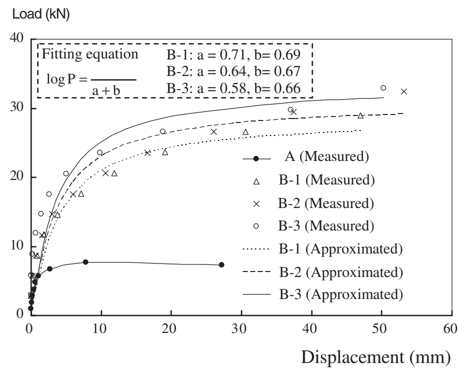

Figure 5. The relationship between the pullout resistance and displacement in vertical pullout tests.

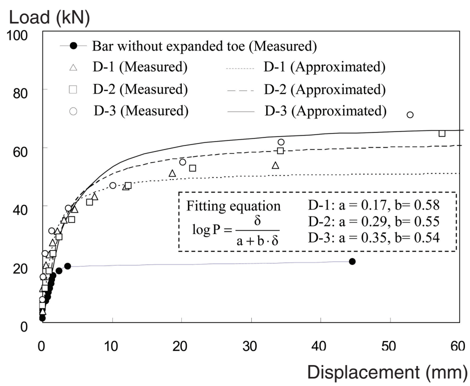

Figure 6. The relationship between the pullout resistance and displacement in horizontal pullout tests (fine sand).

with expanded toes are shown in Fig. 7. Here, the pullout strength P_d was calculated as the sum of the bearing resistance of the expanded toe and the skin frictional force between the soil and grout at the rod section, based on the results of the vertical pullout test, using the following equation:

$$P_d = \tau \cdot \pi \cdot D \cdot L + \left(c \cdot N_c + N_q \cdot q_p\right) \cdot A_p \quad (1)$$

where, τ is the ultimate skin frictional force between the soil and grout, D is the diameter of the grout, L is the length of the reinforcing bar, c is the cohesion of the soil, q_p is the horizontal confining pressure at the expanded toe, N_c and N_q are the bearing capacity factors, and A_p is the projected area of the expanded toe (toward the pullout direction). The calculated values are shown in Table 5 for each case.

The ultimate pullout resistance P_u measured in both soil conditions of fine sand and improved soil was larger than the calculated ultimate resistance P_d, which was the sum of the bearing resistance and the skin frictional force. The figure shows that the measured pullout resistance P_u increased as the surcharge was increased, showing a trend similar to that in which design pullout strength P_d increased as the horizontal confining pressure at the expanded toe increased. Then, the increment in pullout displacement during each steps (Δt) was put to be $\Delta\delta$ and the changes in logarithmic value during Δt was put to be $\Delta \log t$ to draw a curve that shows the relationship between $\Delta\delta/\Delta \log t$ and P by assuming that the pullout resistance at the break point was the measured pullout resistance at yield P_y. The relationship is a method used to judge the yielding load of piles.

Figures 8 and 9 show the relationships between the vertical stress at the toe section σ_v and the pullout resistance at yield P_y, the ultimate pullout resistance P_u, which were both measured in the fine sand and improved soil grounds, and the calculated pullout resistance P_d. The pullout resistance at yield P_y was 0.60 to 0.85 times of the ultimate pullout resistance P_u. Therefore, the pullout displacement at a load of about 1/2 of the calculated pullout force P_d is likely to be controlled small in practice, enabling a safety factor of 2.0 to be proposed for the design pullout force P_d.

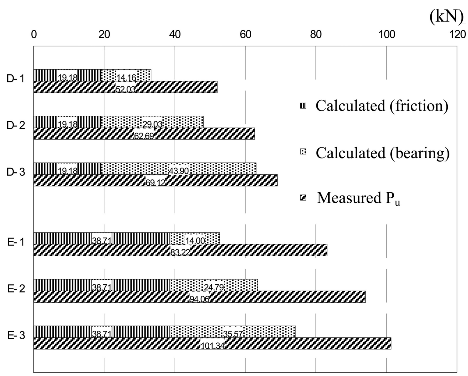

Figure 7. Calculated pullout strength P_d and the measured ultimate pullout resistance P_u.

4 CONCLUSIONS

A pullout test of reinforcing bars with expanded toes which were installed vertically to the ground showed

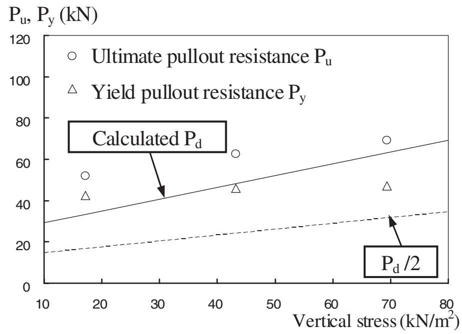

Figure 8. The relationships between the vertical stress at the toe section σ_v and the pullout resistance at yield P_y, the ultimate pullout resistance P_u (fine sand).

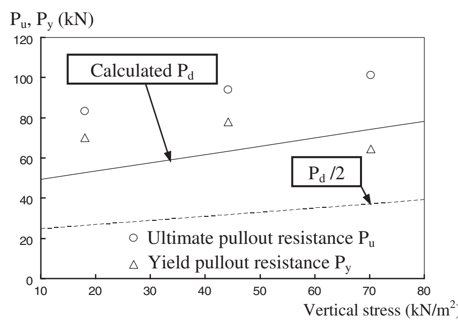

Figure 9. The relationships between the vertical stress at the toe section σ_v and the pullout resistance at yield P_y, the ultimate pullout resistance P_u (improved soil).

Table 5. Calculated values of ultimate skin frictional forces and ultimate bearing resistances.

Case	τ [kN/m^2]	$\tau \cdot \pi \cdot D \cdot L$ [kN]	K_a	N_c	N_q	q_p [kN/m^2]	$(c \cdot N_c + q_p \cdot N_q) \cdot A_p$ [kN]
D-1	49.96	19.18	0.28	5.1	30.2	4.80	14.16
D-2	49.96	19.18	0.28	5.1	30.2	12.12	29.03
D-3	49.96	19.18	0.28	5.1	30.2	19.14	43.90
E-1	94.78	38.71	0.33	5.1	18.4	6.02	14.00
E-2	94.78	38.71	0.33	5.1	18.4	14.72	24.79
E-3	94.78	38.71	0.33	5.1	18.4	23.42	35.57

*K_a: Coefficient of active earth pressure [$= (1 - \sin\varphi)/(1 + \sin\varphi)$] *L = 2.0 m, D = 0.065 mm, z = 1.0 m, $A_p = 0.067$ m^2.

that the ultimate pullout resistance increased as the projected area of the expanded toe increased.

A pullout test of reinforcing bars with expanded toes that were installed horizontally into two different kinds of ground resulted in the ultimate pullout resistance larger than the design pullout resistance, which was the sum of the bearing resistance of the expanded toe and the friction resistance at the rod section, showing that the method for assessing the pullout resistance was valid. The pullout resistance at yield was confirmed to be 0.60 to 0.85 times of the ultimate pullout resistance, and a safety factor of 2.0 was proposed for pullout resistance. Field pullout tests will be conducted to obtain precise data and assess the stability of reinforced soil structures.

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