New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Pullout resistance of strip embedded in cement-treated soil layer for reinforced soil walls

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ABSTRACT: This paper describes pullout resistance of a metallic strip embedded in a cement treated backfill soil. In this study, a test apparatus was newly developed to pullout a flat strip from a reinforced soil wall model such as the Terre Armee wall. A series of tests was performed on soil sample cured under different conditions of vertical stress, cement quantity and curing time. As a result, the pullout resistance of non-standard soil whose fine fraction content is over 25% increased remarkably by cement treatment technique.

1 INTRODUCTION

Earth reinforcement techniques are a useful and economical option for solving the problem of engineering on narrow tracts of land. With regard to reinforced soil walls, the Terre Armee method, which was invented by Vidal in 1963, has developed remarkably. A Terre Armee wall consists of facing (a concrete skin), reinforcement (metallic strips) and backfill soils. As shown in Figure 1, an earth retaining structure can be stabilized by the equilibrium between active earth pressure acting on the skin and the pullout resistance of strips embedded in the soil layer. Since frictional resistance is expected to be well mobilized on contact between the soil and strip, the fine fraction content and maximum grain size of backfill soil is regulated according to GRSW, RRR, Terre Armee, and MARW manuals (Miyata et al. 2001). The applicable backfill soil is sandy soil. However, the supply of sandy soil has recently been exhausted. Even if construction generated soil is fine-particle soil such as clay, it has been occasionally used by executing a chemical stabilization technique (JGS, 2006). The strength characteristics of cement-stabilized soil have not been sufficiently taken into account in the design and execution procedures for reinforced soil walls.

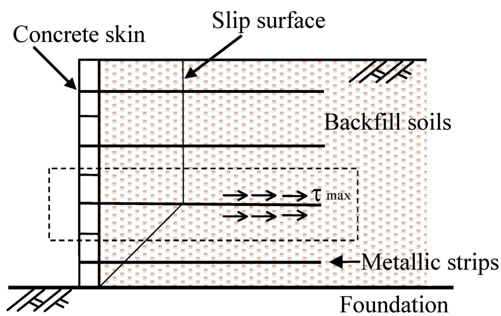

Figure 1. Concept of reinforcement mechanism in reinforced soil wall.

The aim of this study is to clarify the pullout resistance characteristic of reinforcement installed in a cement-treated soil layer. In this study, a test apparatus was newly developed to pull out a strip from a reinforced soil wall model. The validity of this apparatus was demonstrated through a comparison with previous in-situ test results. A series of tests was conducted with different conditions of vertical stress, cement quantity and curing time. This paper describes mechanism of pullout resistance mobilized on the contact between a strip and cement-treated soil based on the test results.

Table 1. Physical properties of soil samples.

Soil sample		Jiseiji clay	Kawakami silt	Nakayama sand	Shimonoseki sand
Natural water content	(%)	48.1	22.2	17.5	23.3
Density of soil particle	(g/cm^3)	2.834	2.638	2.739	2.624
Gravel fraction content	(%)	0.7	18.5	21.3	20.2
Sand fraction content	(%)	18.0	34.6	43.7	56.5
Silt fraction content	(%)	30.6	34.9	1.4	11.7
Clay fraction content	(%)	50.7	12.0	33.6	11.6
Fine fraction content	(%)	81.3	46.9	35.0	23.3
Liquid limit	(%)	76.2	43.5	37.6	–
Plasticity index		41.8	18.4	13.0	–
Soil classification		CH	SFG	SFG	SFG

2 BACKFILL SOILS IN DESIGN PROCEDURE OF REINFORCED SOIL WALL

The design procedure of the Terre Armee method is summarized as follows. Design conditions such as place, use, etc. are checked in detail. Earth pressures acting on the skin and strip are evaluated respectively. The spacing and length of strips is determined based on pullout resistance and the allowable tensile strength of the strip. Internal stability is examined by assuming a fixed slip line method (bi-linear). The overall stability and settlement of the foundation are checked. Backfill soils with high shear resistance and low compressibility are required. Soils having fine fraction content, $F_c < 25\%$ and maximum grain size, $D_{max} < 300$ mm are recommended and soils having $25\% < F_c < 35\%$ and $D_{max} < 75$ mm are accepted in the Terre Armee manual. If the fine fraction content of backfill soils is over 25% or their maximum grain size is over 300 mm, their physical properties can be improved by various chemical stabilization techniques. However, the increase of apparent cohesion in cement-stabilized soil is not sufficiently considered in the design procedure.

2.1 *Soil sample and cement stabilizer*

Soil samples used in the experiment were "*Jiseiji clay*", "*Kawakami silt*", "*Nakayama sand*" and "*Shimonoseki sand*". These soils were sampled at several construction sites in Yamaguchi Prefecture, Japan. The physical properties of the soil samples are listed in Table 1. The grading carves of soil samples are shown in Figure 2. The fine fraction contents of all samples except for Shimonoseki sand were higher than 25%. Since such samples could not be utilized as backfill soils, they were improved by application of cement stabilization. The used stabilizer was an ordinary general-purpose cement stabilizer.

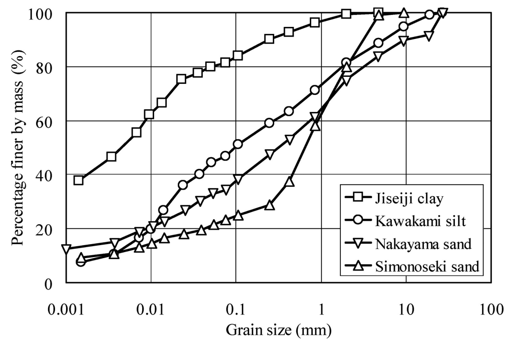

Figure 2. Grading curves of soil samples.

2.2 *Test apparatus*

A test apparatus was newly produced to simulate stress and deformation conditions of the soil around a strip as shown in Fig. 1. Actually the pullout resistance of a strip laid under a ground has been examined by an in-situ pullout test. However, an in-situ test could not be carried out on the completed state of the structure. The stress condition of the soil around the strip was not simulated in the execution process. Our apparatus was capable of measuring the horizontal pullout force of a strip in a soil layer with high accuracy. Figure 3 illustrates the essential features of the apparatus (see Photo 1). The apparatus is composed of a soil tank, a strip, a retaining wall, a loading plate for vertical pressure, two dial gauges for vertical and horizontal displacements, a load cell for horizontal force, a motor and gear box, and data recorder. The dimensions of the tank were 70 cm long ×20 cm wide ×30 cm high. The tank has double drainage layers on top and bottom. The wall was fixed through a series of tests. The strip used in the experiment was a flat type 6 cm wide and 0.5 cm thick. Except for Shimonoseki sand,

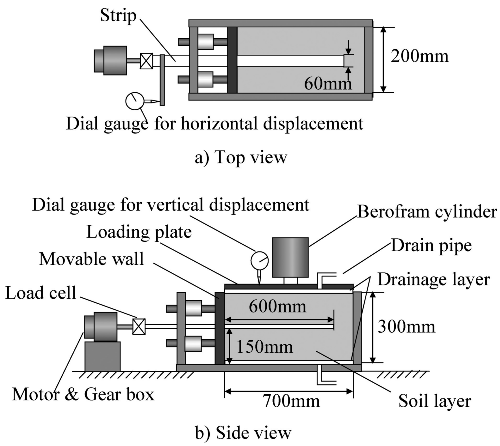

Figure 3. Schematic diagrams of test apparatus.

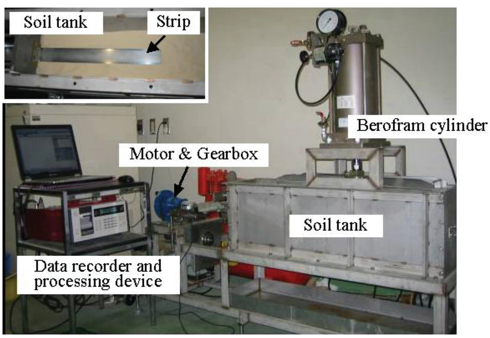

Photo 1. Overview of test apparatus.

Photo 2. Soil compaction by rammer.

the initial water content of the soil sample was prepared to be at its liquid limit. After the soil sample was compacted using a vibrator or a rammer in the tank, the top surface of the soil layer was leveled at a height 15 cm from the bottom (see Photo 2). A 60-cm strip was placed on the smoothed surface of the soil

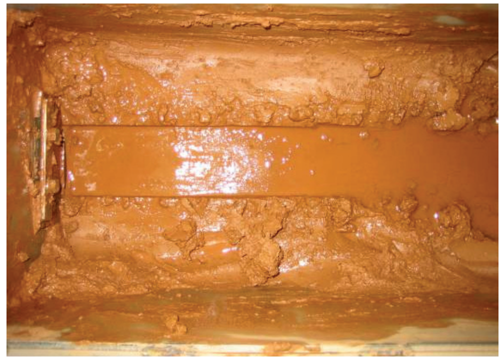

Photo 3. Condition of strip around clay after pullout test (Jiseiji clay).

layer. The strip was covered by the soil sample and consolidated by applying a constant vertical stress, σ_v, in the range of 50 kPa to 150 kPa. In the case of cement-treated soil, immediately after the soil sample was cured under a constant vertical stress during a curing period in a room with controlled temperature and humidity, the pulling out test was carried out. During the test, the horizontal force and displacement were measured. According to the preliminary test, it was shown that the rate effect was negligible in the range of 0.12 to 1.20 mm/min. The rate of the pullout test was uniformly set at 1.0 mm/min. The pullout test was finished when horizontal displacement reached about 10 mm. Photo 3 shows the condition of strip around Jiseiji clay after pullout test.

3 RESULTS AND DISCUSSIONS

3.1 *Typical behavior of untreated sample*

The test cases and results are listed in Table 2. Figure 4 shows the relationship between horizontal pullout stress, τ, and the horizontal displacement, δ, of the untreated sample (Shimonoseki sand). Here τ is derived from an equation dividing horizontal force by the surface area of the strip. As δ increased, τ increased monotonously. The $\tau \sim \delta$ curve for $\sigma_v = 100$ kPa becomes higher than that of $\sigma_v = 50$ kPa. This behavior was similar to that of other untreated samples. The maximum value of τ, τ_{max}, was determined based on the relationship between τ and δ. Figure 5 shows the relationship between τ_{max} and σ_v for test results including the in-situ test results quoted from a previous study (Ogawa et al. 1995). Figure 6 shows the relationship between F_c and τ_{max} of all data as mentioned above. As can be seen from Fig. 5, τ_{max} for Shimonoseki sand is the highest among those for our tested samples, but was low compared with previous data. It can be seen

Table 2. Test cases and results.

Test No.	Soil sample	Initial water content w_o (%)	Quantity of cement Q_c (kg/m^3)	Curing time T_c (day)	Compaction energy E_c(kJ/m^3)	Vertical stress σ_v (kPa)	Maximum pullout stress τ_{max} (kPa)	Unconfined compressive strength q_u (kPa)
1-1	Jiseiji clay	70.0	0	–	0	50	10.6	–
1-2						100	19.8	–
1-3			60	3		0	41.8	231.5
1-4			80			0	70.6	337.3
1-5			100	1		0	69.4	530.1
1-6				3		0	83.4	1009
2-1	Kawakami silt	40.0	0	–		50	6.8	–
2-2						75	11.9	–
2-3						100	16.4	–
2-4			60	1		0	19.6	314.4
2-5				3		0	37.1	402.7
2-6						50	65.3	657.3
2-7						100	78.8	744.0
2-8				7		0	42.2	455.2
2-9			80	3		0	56.3	776.0
2-10			100			0	67.1	1209
3-1	Nakayama sand	34.0	0	–		50	9.4	–
3-2						100	17.4	–
3-3			50	1		0	29.2	301.3
3-4						50	54.4	477.5
3-5			70			0	43.2	601.7
3-6			90			0	84.0	772.8
3-7		20.0	50		104.5	0	39.0	305.0
3-8					156.8	0	44.1	343.0
3-9					209.0	0	53.6	425.0
4-1	Shimonoseki sand	13.5	0	–	–	50	16.9	–
4-2					–	100	35.0	–

–: None in particular.

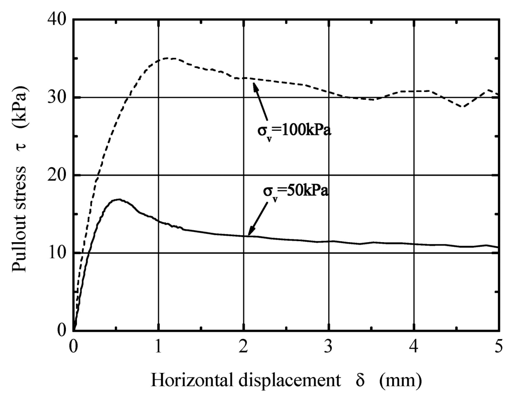

Figure 4. Pullout behavior of Shimonoseki sand without cement treatment.

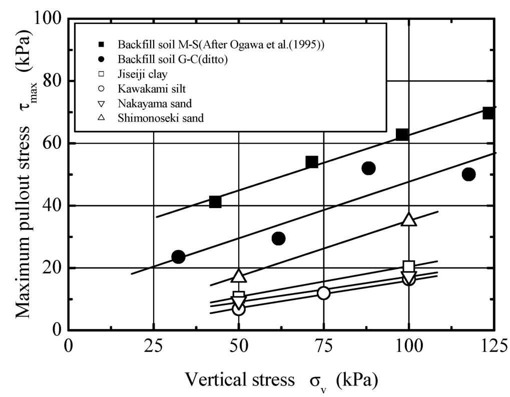

Figure 5. Comparison between laboratory and in-situ pullout tests.

from Fig. 6 that τ_{max} decreased as the fine fraction content increased. The results obtained by this apparatus are in good agreement with those by the in-situ tests.

3.2 *Typical behavior of treated sample*

Figure 7 shows $\tau \sim \delta$ curves of untreated and treated soil samples (Kawakami silt). The τ_{max} of the treated sample was much higher than that of untreated sample.

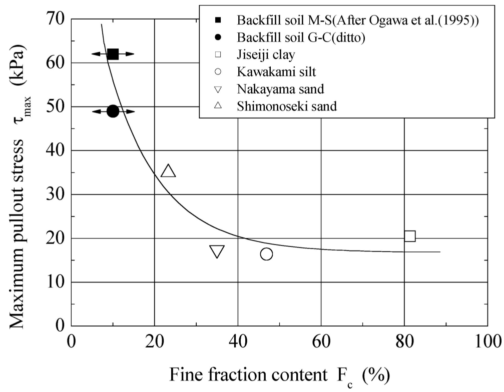

Figure 6. Relationship between F_c and $\tau_{\max}$.

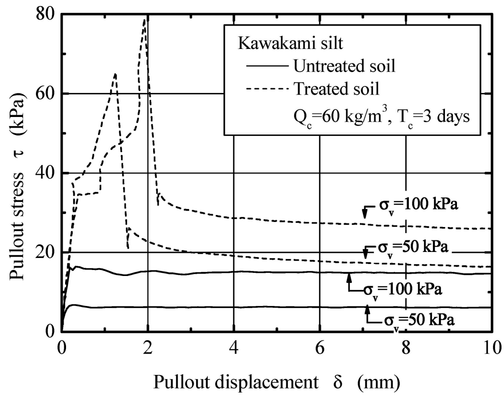

Figure 7. Pullout behavior of Kawakami silt with and without cement treatment.

In the case of $\sigma_v = 50$ kPa, the $\tau_{\max}$ of the treated sample was 10 times bigger than that of the untreated sample. In the case of $\sigma_v = 100$ kPa, the $\tau_{\max}$ of the treated sample was 5 times bigger than that of the untreated sample. This tendency may be due to an increase in the cohesion component of the pullout resistance. Immediately after exhibiting a peak value, the treated sample shows remarkable reduction of pullout resistance. This brittleness behavior may be attributable to exfoliation of the cemented part formed between the soil and the strip. After τ reached a peak value, the $\tau \sim \delta$ curve showed unstable behavior. It is suggested that this behavior may be due to step-by-step exfoliation. Figure 8 shows test results obtained from a non-standard sample (treated Kawakami silt) and a standard sample (untreated Shimonoseki sand). Shimonoseki is classified into the recommended backfill soils, because of its low fine fraction content ($F_c = 23.3\%$). In the case of $\sigma_v = 50$ kPa, $\tau_{\max}$ and the residual value, τ_{res}, of treated Kawakami silt become higher than those of untreated

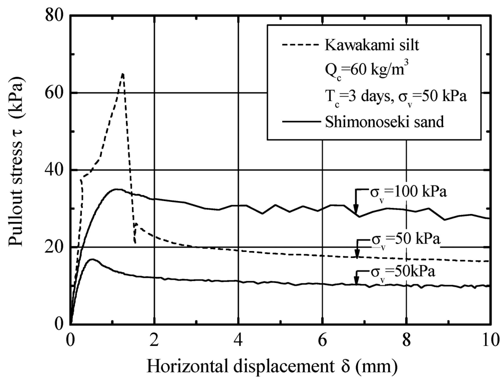

Figure 8. Pullout behavior of cement treated soil and recommended backfill soil.

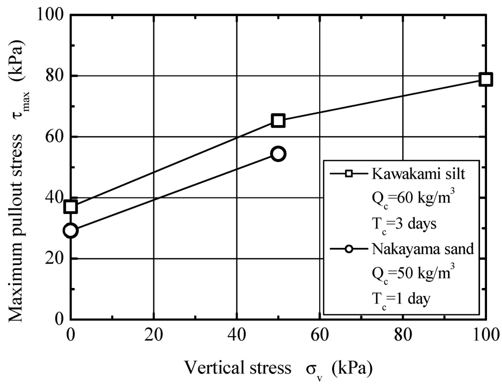

Figure 9. Relationship between σ_v and $\tau_{\max}$.

Shimonoseki sand. Therefore, the non-standard sample improved by cement stabilization could achieve as high a pullout resistance as a standard sample.

3.3 *Effects of vertical stress, cement quantity and curing time*

Figures 9 to 11 show the relationships of $\tau_{\max}$ to σ_v, cement quantity, Q_c, and curing time, T_c, respectively. As shown in Fig. 9, the $\tau_{\max}$ of cement-treated samples increases linearly with an increase in σ_v. The resistance increase may be due to the increasing contact area between the soil and the strip. As can be seen from Figs. 10 and 11, $\tau_{\max}$ increased with the increase in either Q_c or T_c. The resistance increase was due to the development of cementation. These results suggested that adhesion was newly generated in the soil around the strip.

Figure 12 shows the distributions of unconfined compressive strength, q_u^*, and the water content, w, in the soil layer. The strip is situated in the center part of the soil tank. The unconfined compressive strength

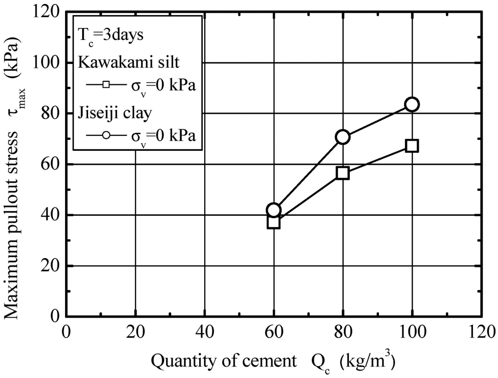

Figure 10. Relationship between Q_c and $\tau_{\max}$.

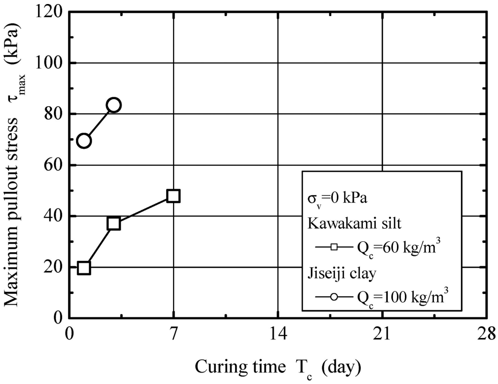

Figure 11. Relationship between T_c and $\tau_{\max}$.

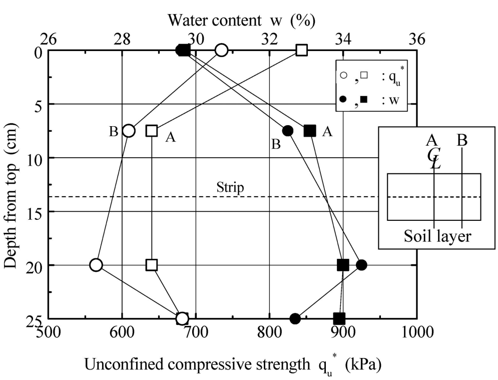

Figure 12. Distribution of q_u^* and w in soil layer.

was estimated from the index obtained by a soil hardness tester. The water content of the top and bottom becomes lower than that of the center part. On the other hand, the q_u^* of the top and bottom becomes higher than that of the center part. In fact, the measured unconfined compressive strength of the center part corresponds to

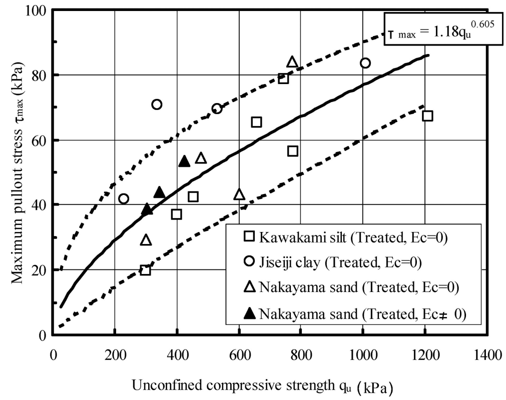

Figure 13. Correlation between q_u and $\tau_{\max}$ for various cement treated soil.

640 kPa. This tendency may be due to the process of consolidation near the drainage layer. Furthermore, the cementation in between soil particles was caused by gradual cement hydration, so that the pore water was constrained and entrapped.

3.4 *Correlation between of pullout resistance and unconfined compressive strength*

Figure 13 shows the correlation between $\tau_{\max}$ and q_u for treated samples of Jiseiji clay, Kawakami silt and Nakayama sand. The unconfined compressive strength was determined under the same conditions as the pullout test. The plotted data are obtained under different conditions of soil type, cement stabilizer content, curing time and applied vertical stress. Although the data are more or less scattered, $\tau_{\max}$ tends to increase with an increase in q_u. There seems to be a clear correlation between $\tau_{\max}$ and q_u. Considering the spacing and length of strips in the design stage, the pullout resistance of cement-stabilized soil may be accurately estimated from the results of an unconfined compression test on a soil sample.

4 CONCLUSIONS

The main conclusions of this study can be summarized as follows.

1) The pullout resistance measured by our apparatus was almost consistent with that by the in-situ test. The developed apparatus is suitable for evaluating the pullout resistance characteristics of strips in a soil layer.
2) The pullout resistance of non-standard soil whose fine fraction content is over 25% increased remarkably by cement stabilization. It was demonstrated that soil with a high fine fraction content can be utilized as backfill soil in reinforced soil walls.

3) The pullout resistance of cement-treated soil increased with increasing vertical stress. The increase of pullout resistance increased with increasing cement content and curing time. Stiff behavior soil may result from cementation developing in contact between the soil and the strip.
4) There seems to be a correlation between the pullout resistance and the unconfined compressive strength for cement-treated soil. Therefore, the pullout resistance can be estimated by conducting a conventional unconfined compression test.

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