Excavation Behaviour of Soft Marine Clay Deposit in South Korea

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ABSTRACT

In this paper, it is demonstrated that the shear strength of soil around jet grouting pile may be increased with the elapsed curing time of grouting cement. Because soil around pile initially experiences the disturbance due to the jet grouting work process, the soil gains the strength as grouting cement is cured and the soil is stabilized. In addition, excavation behaviour of marine clay at sheet pile wall and strut excavation site is analyzed using measured data from inclinometers, load cells, and strain gauges. The time to install supporting system and not only depth to but also area of excavation are very important factors for analyzing excavation behavior of soft marine clay.

KEYWORDS

jet grouting pile, grouting cement, curing time, excavation behaviour, soft marine clay, sheet pile wall, supporting system

INTRODUCTION

A sewage treatment plant having the site area of 160 m × 520 m, was constructed on soft marine clay deposit in the southern coast of Korea. The average thickness of soft clay deposit was about 15 m, and the range of shear strength of this clay was 15 KPa to 35 KPa varying with depth.

To construct pumping station and sedimentation basin of the plant, deep excavation, 59.3 m × 31.5 m in size, was made to a depth of 10.5 m using sheet pile wall system with struts and anchors. On September, 1996, a total of 460 jet grouting piles were constructed within the excavation area to increase the resistance against basal heave failure of soft clay deposit due to excavation. Before the excavation, the field and laboratory tests were carried out to determine change in shear strength of improved soil with the elapsed curing time. The horizontal displacements of sheet pile wall and changes of strut load were monitored as the excavation proceeded.

SUBSOIL CONDITION AT THE SITE

Subsoil at the site was clay with low plasticity(CL) and had natural moisture content of about 45% as shown in Figure 1. Atterburg limits range from 15% to 22% for plastic limit and from 35% to 45% for liquid limit.

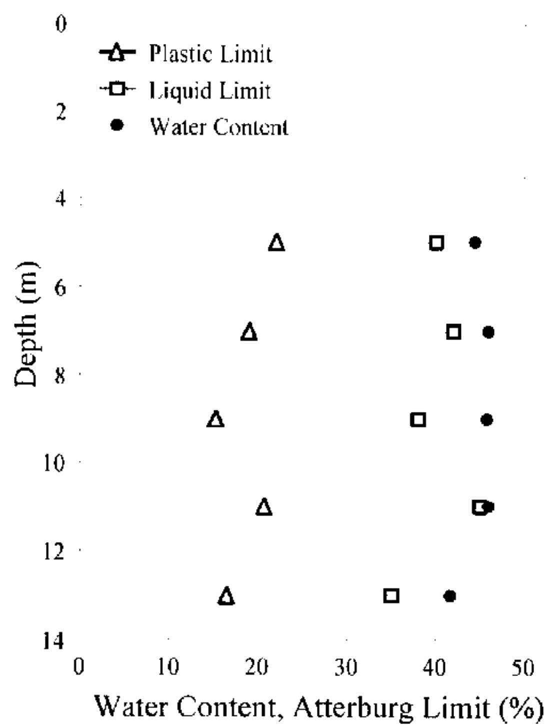


Fig. 1 Variations of water content and Atterburg limits with depth

The undrained shear strength(c_u), determined from field vane test, ranges from 15Kpa to 35Kpa shown in Figure 2.

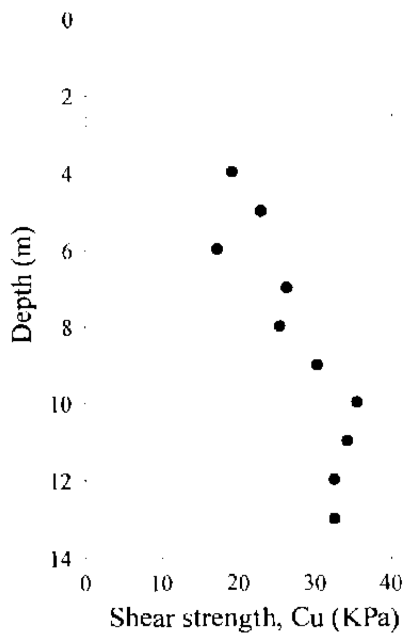


Fig. 2 Undrained shear strength profile of marine clay

JET GROUTING PILES

Jet grouting pile foundation was adopted to support superstructures and to protect basal heave failure of soft marine clay while the excavation proceeded. Jet grouting pile with 1m in diameter was constructed in the ratio of one pile per $4.0m^2$ area, giving the replacement ratio of 20%. The effect of the elapsed curing time was studied by carrying out the vane test in the middle of four piles at three different elapsed times, 10 days(location A1), 20 days(location A2) and 50 days(location A3) as shown in Figure 3. For the discussion purpose, the shear strength ratio(SSR) is defined as the ratio of shear strength of clay after the improvement to shear strength before the improvement.

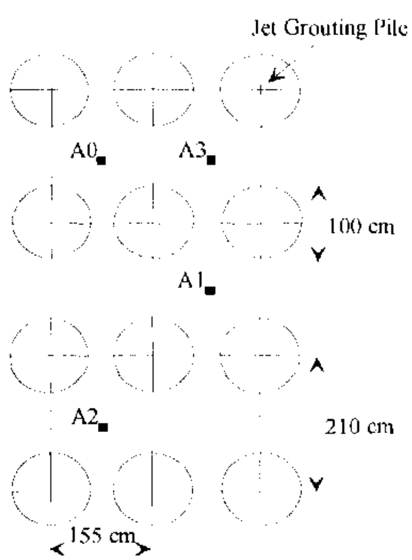


Fig. 3 Field vane test locations for curing time effect

Figure 4 shows shear strength ratio determined for different curing times with depth. For the short elapsed time(A1 and A2 case), the values of SSR are in general less than one, except the upper part of the layer, while the subsoil has gained the shear strength over the entire depth at the longer elapsed time(A3 case). It is apparent that the soft marine clay initially experienced the disturbance due to the jet grouting work process, resulting in the decrease in shear strength from the original value. However, the clay gained the strength as grouting cement was cured and the clay was stabilized.

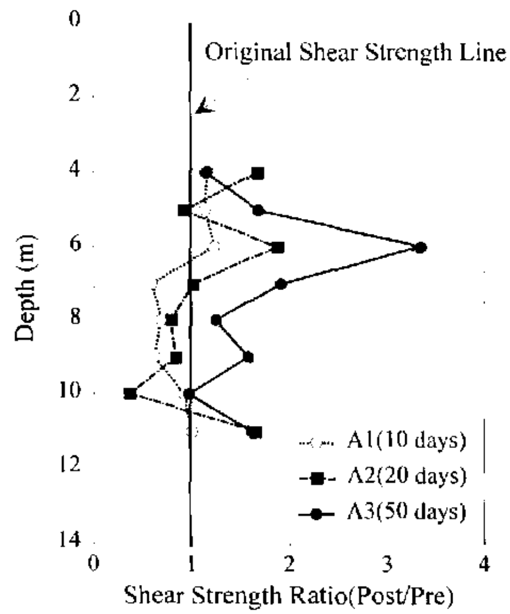


Fig. 4 Variation of Shear strength ratios at different curing time with depth

EXCAVATION BEHAVIOUR

Sheet pile wall system with struts was installed for the excavation of soft marine clay deposit with the maximum depth of 10.5m, and jet grouting piles were constructed to increase the stability against basal heave failure of soft clay deposit during excavation. In order to monitor excavation behaviour, the inclinometers, load cells, strain gauges, piezometers at 3 locations were installed. The site plan and locations of installed instruments are shown in Figure 5.

In this paper, the analysis results of measured data at BH1 area are presented . The excavation process at BH1 area is shown in Figure 6, and the final excavation depth was 5m near sheet pile wall and 7.5m in the middle of excavation. The horizontal displacements of sheet pile wall with depth during the excavation near BH1 area are shown in Figure 7. The maximum displacement of 7.6cm after the final excavation was monitored at around 6m depth, a little lower than the final excavation level(5m) near the wall and this deep movement may be attributed to the deeper excavation(7.5m) in the middle.

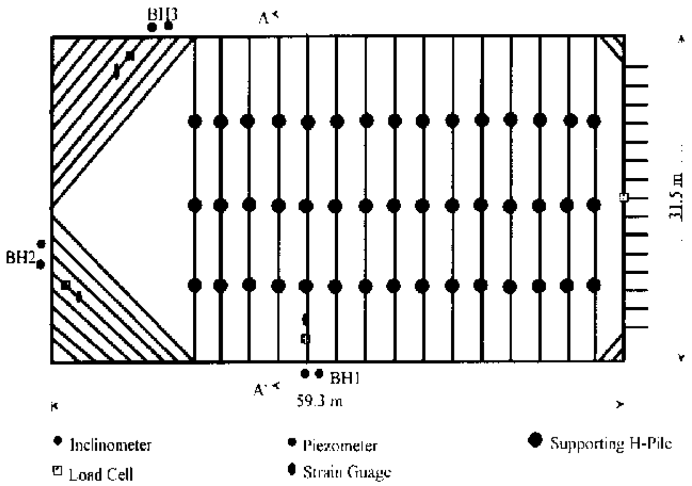


Fig. 5 Site plan and locations of installed instruments

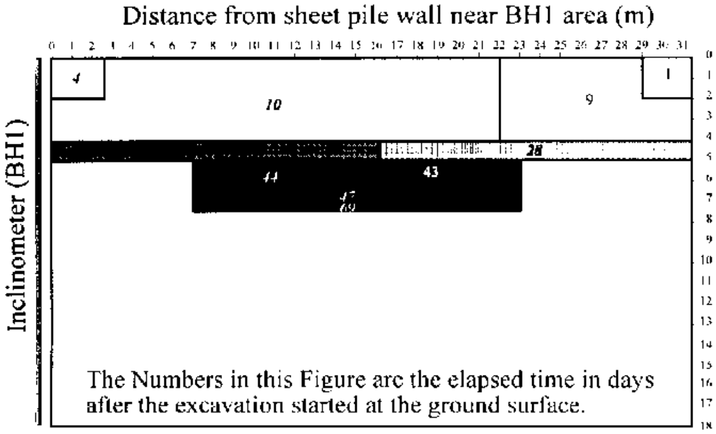


Fig. 6 Excavation process at BH1 area(Section A-A' in Figure 5)

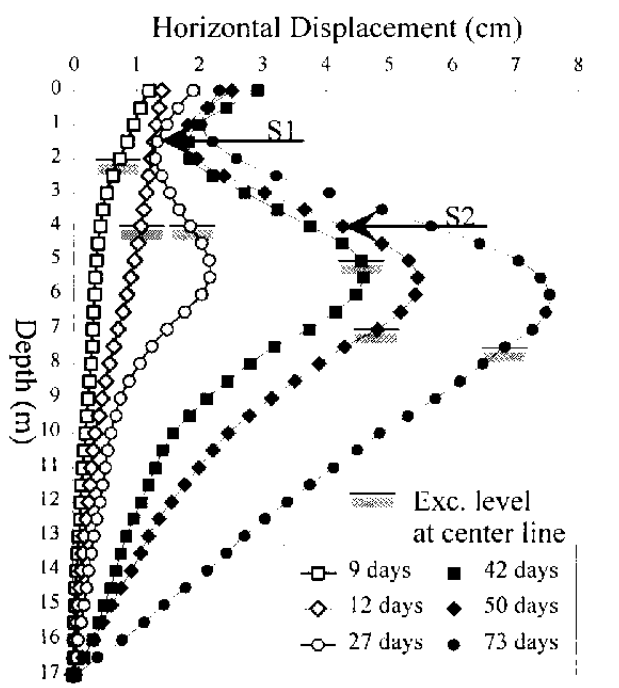
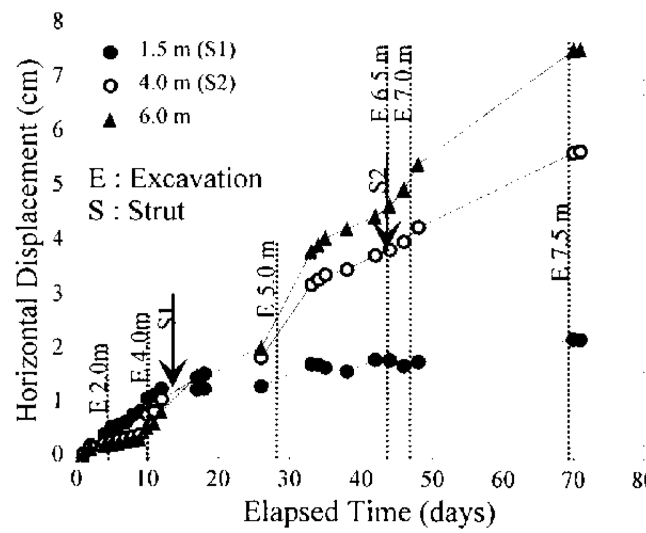
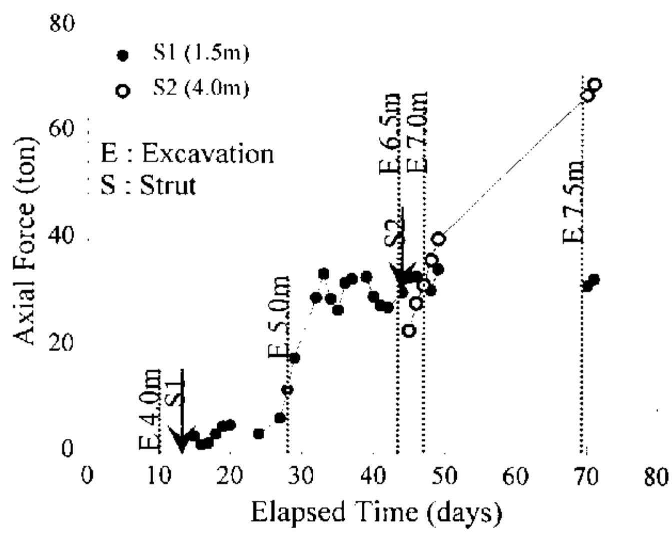


Fig. 7 Horizontal displacement of sheet pile wall at BH1

Horizontal displacement profile for 27 days was substantially different from that for 12 days, though the excavation depth during this period remained same. This substantial difference in the horizontal displacement may be attributed to the difference in the spatial area of the excavation in front of BH1 area. At 12 days, the excavation to 4m depth was made to the corner of BH1 area, giving 3-D constraint effect from the surrounding soil. The excavation was made to overall area toward BH2 area at 27 days, resulting in the possible failure of subsoil near sheet pile wall below the strut No. 1. With the additional one meter excavation without strut at 42 days, horizontal displacement at lower part of the excavation was sharply increased, but the displacement at the strut 1 level was restrained substantially. This behaviour may be also noted from Figure 8, where horizontal displacements at three depths and axial forces on two strut levels were plotted against the elapsed time after the excavation started.



(a) Horizontal displacement at strut 1 & 2, and 6m depth



(b) Axial force of struts with excavation process

Fig. 8 Horizontal displacement and axial force at BH1

Strut 1 was installed at 1.5m depth 3 days after 4m excavation, and strut 2 at 4m depth more than 15 days after 5m excavation. Horizontal displacements at the three levels, measured at the time of 13 days in Figure 8(a) when the excavation was made to 4m and strut 1 was installed, were about 10mm. The increase in displacement at strut level 1 for the entire excavation period from 13 days was not considerable, but there was rapid increase in the axial force on strut level 1 during excavation to 5m, reflecting the constraining effect of strut No. 1. The displacements at depths of 4m and 6m were sharply increased, when the excavations were made in the vicinity at 28 days, 43 days and 47 days. It is interesting to note that the strut at level 2 was not effective in restraining the horizontal displacements after the installation of strut No. 2(at 43 days). However, the strut at level 2 was experienced a sharp increase in the axial force at the same time period(after 43 days). This ineffectiveness of strut at level 2 may be explained by the progressive increase in failure zone from the initial failure at 4m excavation depth and the excessive displacement before the strut installation(about 30mm). From these result, it may be observed fact that the displacement pattern may be sensitive to the construction sequence, especially excavation and strut installation timing.

CONCULUSIONS

The following conclusions can be drawn from this research :

1. The soft clay strengthening effect by jet grouting pile was developed after stabilizing period, more than 30 days. Because jet grouting pressure in the initial construction step disturbed soil around pile and grouting cement infiltrated to the clay, shear strength of clay was increased slowly with curing time of grouting cement and stabilization of soil.

2. Not only depth to but also area of excavation influences largely to displacement of sheet pile wall and axial force on strut. Therefore, 3-dimensional effect of excavation must be considered for rational analysis.

3. The supporting system, strut, for excavation of clay soil constrains generally the horizontal displacement of sheet pile wall. Because excavation behaviour of subsoil is very sensitive to construction sequence, the excess displacement due to delay of installation of strut develops subsoil failure. And the constraining effect of strut can not be almost displayed after subsoil failure.

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