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Measures to prevent heaving during the excavation of soft ground

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ABSTRACT: This paper describes the heaving phenomenon and the cause of that during the large-scale excavation in the soft ground which has been reclaimed just recently in Haneda area. In spite of efforts to stabilize the earth retaining wall by means of ground improvement of the excavation bottom, the symptom of heaving was observed. .By early detection of such symptom and adequate mesures, the work could be completed without incident.

1 INTRODUCTION

This work was the cut-and-cover excavation of a tunnel in reclaimed land as part of the Tokyo International Airport (Haneda) Offshore Expansion Project. It was a large-scale excavation 120m long, 31m wide, and 21m deep. As measures against heaving, the ground from the excavation bottom to a level 5m below it was improved (using point-contact circle execution) by the deep mixing soil stabilization method.

Figure 1 shows the standard section of the earth retaining structure, and Figure 2 shows the ground improvement plan.

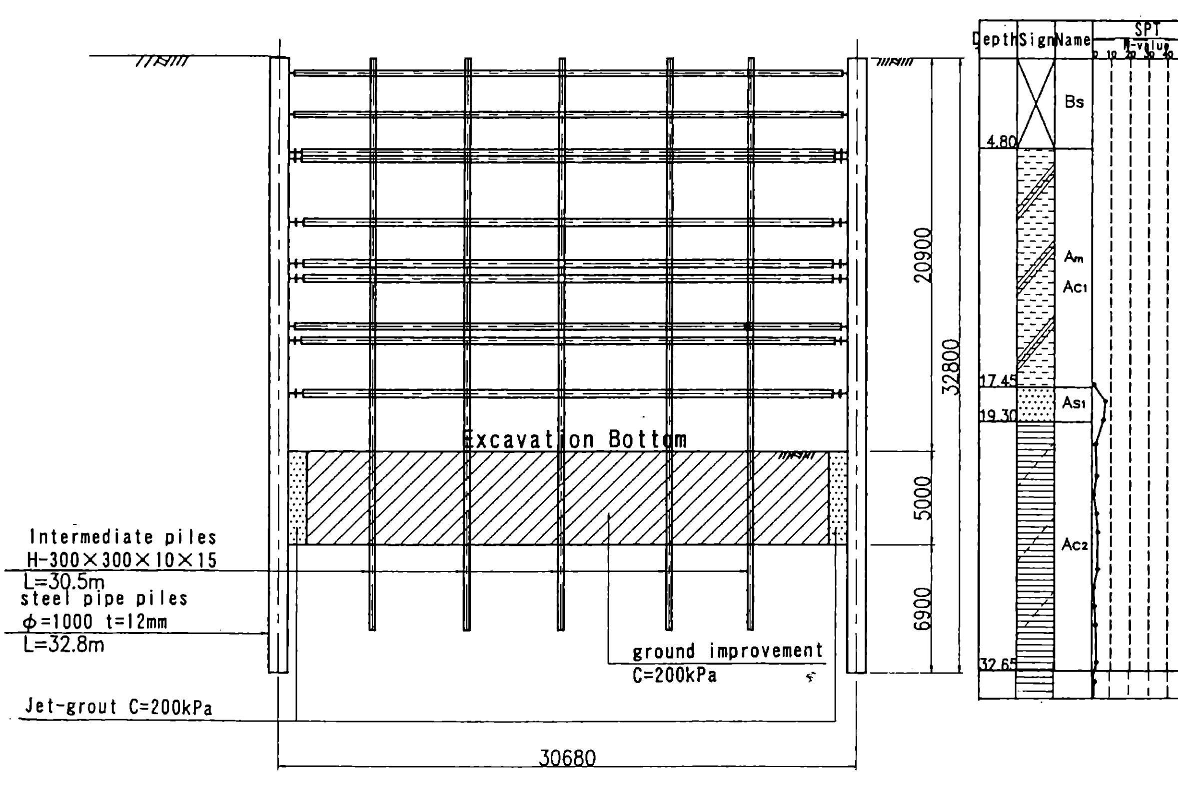

Figure 1. Standard section of the earth retaining structure.

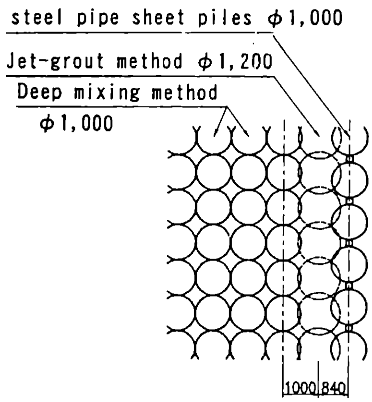

Figure 2. Ground improvement plan.

2 OUTLINE OF THE GROUND

This excavation site is reclaimed on soft soils existing to a depth of more than 40m below the surface.

These soils include the following from the ground surface downward:

1) Surplus soil from construction (Bs) is rarher loose sandy soil. The thickness of this soil is about 5m.
2) Dredged soils (Am and Ac1) are very soft silt to clayey soils with Wn = 40-180% and N-value = 0. The entire thickness is about 13m.
3) Alluvial sand (As1) is loose sandy soil with N-value = 0-9. The thickness is about 2m.
4) Alluvial clay (Ac2) is soft silt to clayey soil with Wn = 60-100% and N-value = 1-4. The thickness is 20m or more.

3 OUTLINE OF THE DESIGN

The earth retaining wall were steel-pipe sheet piles (φ1000, t= 12mm, L=32.8m) with struts arranged in seven stages.

The safety against heaving was checked according to Metropolitan Expressway Public Corporation's method and Peck's stability factor. As a result of the calculations, the safety factor of MEPC's method was 1.47 (>1.2:required safety factor), but the Peck's stability factor was 5.9 (>5). Therefore, soil improvement was performed at a depth of 5m below the excavation bottom.

On the other hand, the occurrences of heaving were reported in spite of soil improvement at the other sites in Tokyo Bay area. Accordingly the observational method was employed for excavation in this case.

4 OCCURRENCE OF HEAVING

Excavation work proceeded carefully and smoothly up to the sixth stage. The upward displacement of the excavation bottom due to the rebound by the removal of the excavation load was observed and the deformation of the earth retaining wall was suppressed in the bottom immprovement section as shown in Figures 3 - 4.

As the seventh stage of excavation proceeded, the upward displacement rate rose up and the bottom edge of the earth retaining wall was displaced to the excavation side. Then we stopped the excavation work temporarily, but the displacement did not slow down.

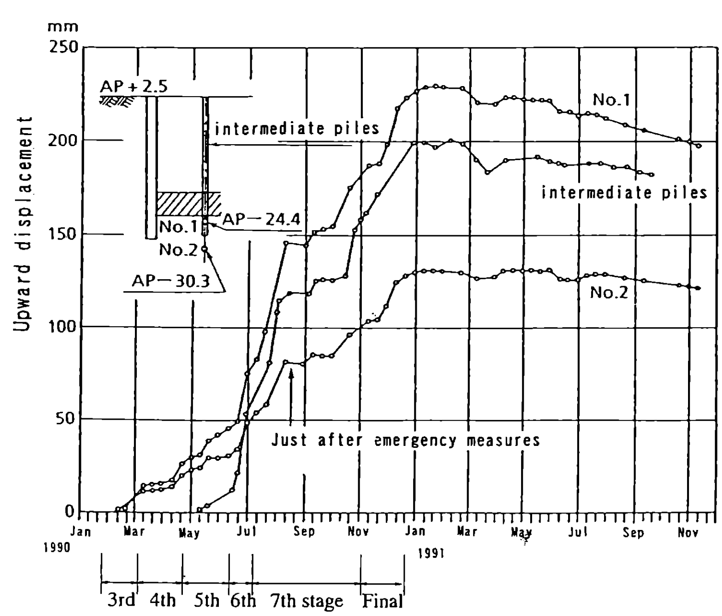

Figure 3. The upward displacement data.

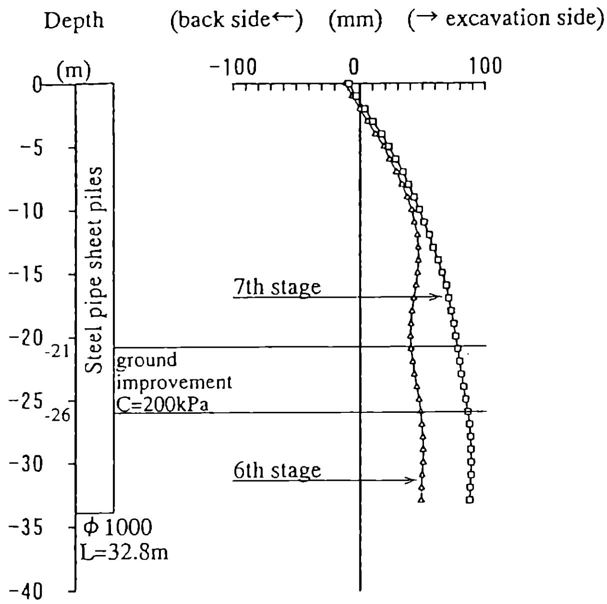

Figure 4. Deformation of Steel-pipe sheet pile.

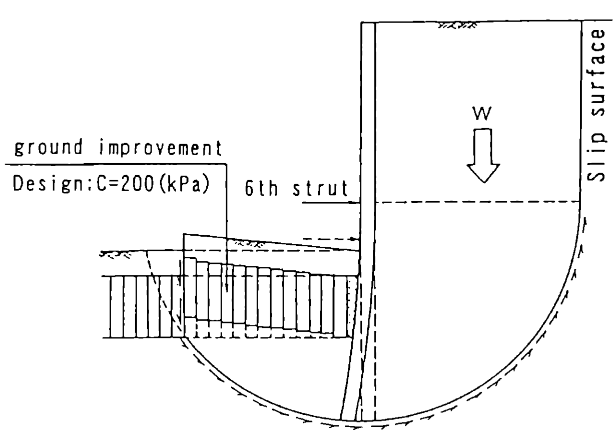

Figure 5. Slip surface by heaving.

We considered these problems to be symptom of heaving, and carried out removal of the soil from the back of the walls (up to GL-4m) and water injection into the excavated area (to a depth of 3.5m) as emergency measures. As a result, the bottom of the excavation ceased its upward displacement and the earth retaining wall stopped deforming.

5 CAUSE OF HEAVING

The results of unconfined compression test of a boring core sample revealed that the average strength of the improved ground was 400kPa (target strength: 255kPa) and the strength of the original ground at the same location before excavation was between 50 and 60kPa. Based on the back-analysis assuming a safety factor at the time of heaving to be 1.0, the apparent improved strength of the ground where the heaving occurred was estimated to be 100kPa (design value: 200kPa).

This decline in the apparent improved soil strength was assumed to be caused by the following factors.

1) When non-lapping circle ground improvement is performed, the improved bodies are only in contact at certain points. Therefore, slipping caused by heaving occurs in unimproved soil between improved bodies. The resistance against this slipping is only provided by the shear strength which is similar to that of the original ground (Fig.5).

2) For the ground improvement work, the deep mixing soil stabilization method was executed down to a depth of 26m. Due to the limited accuracy of execution, complete point-contact circle ground improvement was not achieved. In some places, the

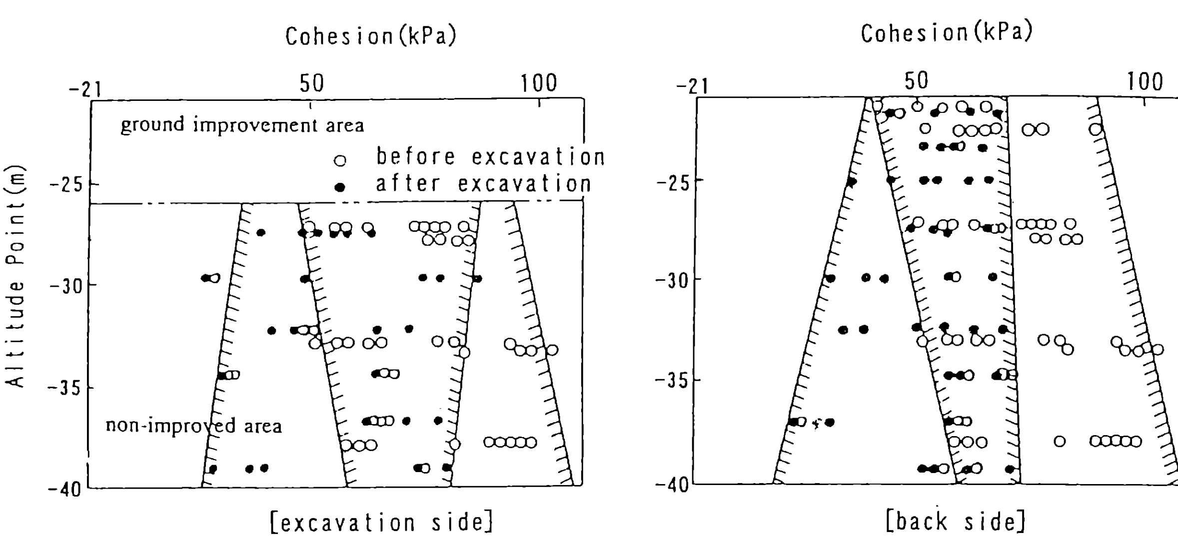

Figure 6. Comparison of soil strength between before and after excavation.

improved bodies were in contact with each other, whereas in other places they were separated. For these reasons, the resistance against slipping of the ground was lower than the design value.

On the other hand, the non-improved soil strength was also reduced to 50-80% of the original strength according to the results of the investigation executed after occurrence of heaving (Fig.6). We assume the strength decline in the excavation side to have been caused by reduction of effective stress due to removal of the excavation load and by swelling due to that. And the bigger decline of strength at the bottom edge of the wall was caused by shear deformation of the soil due to heaving. Then this strength decline furthered the occurrence of heaving.

6 COUNTER-MEASURES

We determined the final counter-measures based on the results of the investigation and the estimated apparent strength of the improved ground. The measures were as follows.

1) Removal of the soil behind the excavation up to GL-6m.
2) Additional deep well works (As1 layer) to reduce the axial force of the 5th and 6th-level struts.
3) Reinforcing the 5th, 6th and 7th-level struts.

7 PROBLEMS DUE TO CONFIGURATION OF THE SOIL IMPROVEMENT

We assumed this heaving phenomenon to be caused by point-contact circle ground improvement, the soil strength reduction due to rebound of the ground,the soil swelling and the shear deformation of soil.

When deep point-contact circle ground improvement up to 26m depth is performed as it was in this case, unimproved soil usually remains due to the limited precision of execution. It is assumed that the unimproved soil for slip layer could not resist the upward force by heaving. Even if perfect point-contact circle ground improvement is achieved, the improved soil bodies are only in contact with each other at certain points.

And when ground improvement is performed to increase the passive resistance of soil, the resistant force is sometimes lower than the expected value because of the strain increase due to stress concentration for point-contact and remaining of the unimproved soil.

Considering these facts, we believe that ground improvement undertaken to prevent heaving and increase the passive resistance should be conducted using the lapping execution.

8 CONCLUSIONS

For large-scale excavation in soft ground, the soil improvement at the excavation bottom is usually adopted in order to maintain safety for heaving and increase the passive resistance of soil. It is difficult to evaluate the strength, modulus of deformation, and other properties of the improved ground as composite ground. It is therefore necessary to conduct research to develop evaluation methods by accumulating data from future projects.

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