Geotechnical Aspects of Underground Construction in Soft Ground – Ng, Huang & Liu (eds)

Measurements of ground deformations behind braced excavations

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ABSTRACT: The deformation behavior of earth retaining wall and backside ground due to braced excavation were measured at the construction sites of Osaka Subway Line No. 8. It was observed that backside ground moved to excavation & down side along a circular slip following the wall deflection, and its influence spread to the ground surface. The backside ground surface settlement near the wall was suppressed due to the friction between wall and surrounding ground, and maximum settlement occurred at some distance from wall in the 45–60 degree area from the bottom of the wall. The backside ground deformation area decreased exponentially with the distance from the wall. As a result each observed data from monitoring sites was analyzed statistically according to the soil characteristic, wall deflection and surface settlement in prominent soft clay layer were larger than those in prominent sand and gravel layer. The relation between the wall deflection area A_δ and backside ground settlement area A_s was that $A_s \cong (0.2–0.3) \times A_\delta$ in prominent soft and sensitive clayey layer. The backside ground settlement of this observed data converged smaller than past data.

1 INTRODUCTION

There are many neighboring constructions in recent subway works. In order to guarantee the construction safety and control the influence on the surrounding environment to the minimum, it is necessary to use the observational method and prediction results effectively. For example, in the case of cut and cover method, which is usually used to construct the subway station, it is necessary to evaluate the backside ground deformation of earth retaining wall and groundwater level fluctuation, to carefully monitor some particular concern points, and of course to estimate the safety of timbering of a cut and the excavation bottom.

In this paper, earth retaining wall deflection and backside ground deformation due to braced excavation were evaluated circumstantially in open cut construction sites, which main excavation soil was the alluvial soft clay, in Osaka Subway Line No. 8. All observed data in 11 monitoring sites were got together and analyzed with the same idea. The evaluated results were described for each soil characteristic. Some behaviors of ground deformation due to braced excavation based on these monitoring results were considered.

2 CONSTRUCTION SUMMARY

Osaka Subway Line No. 8 was constructed at the east side of Osaka city as north–south rail route in underground. Every station was built by open cut method. In order to control the settlement at the ground surface and the influence on the neighboring ground environment, seepage control method was adopted in all of the station construction sites with extending earth retaining walls, where the most were Soil Mixing Walls, to the Pleistocene clayey layer under the artesian aquifer.

It is possible to classify three areas roughly based on the difference of soil characteristic as Figure 1 shows. This new rail route located at the East side of Uemachi-plateau, and this area was an inland sea in ancient times.

(1) North Area

This area interleaved the Yodo-river, and constitutes the alluvial layer, upper and lower Pleistocene. Alluvial layer is composed of a fine sandy layer having low uniformity coefficient Uc, and soft and sensitive clayey layer having unconfined compressive strength $q_u = 40–100\,kN/m^2$. Tenma-gravel layer accumulated

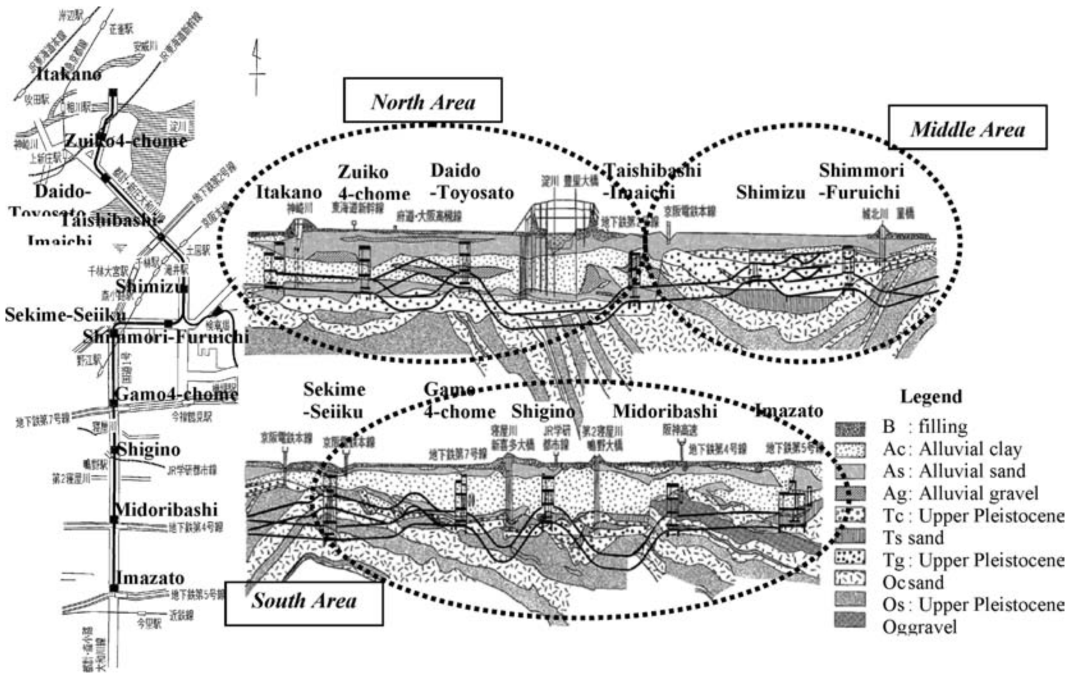

Figure 1. Plain view and soil crossing view of Osaka Subway Line No. 8 (Unei *et al.*, 2002).

continuously with just about uniform thickness as upper Pleistocene layer with high permeability. Lower Pleistocene layer Osaka Group is laminated ground with stiff clayey layer of cohesion $c = 300–600$ kN/m^2, and dense sandy layer of Standard Penetration Test N-value is more than 60. Each Osaka Group dips in the south and east direction neighbor the Yodo-river.

(2) Middle Area
This area is constituted of the thin alluvial layer, upper and lower Pleistocene. Upper Pleistocene layer is constituted with stiff clayey layer (N-value = 5–10) and very dense sand and gravel layer with high permeability. Lower Pleistocene layer Osaka Group is laminated ground with stiff clayey layer ($c = 200–400$ kN/m^2) and dense sandy layer (N-value > 60). The ground of this area is harder than other areas comparatively.

(3) South Area
This area located in Neyagawa-lowland and it is different from the rest area for that the very soft and sensitive alluvial clayey layer (N-value = about zero, $q_u = 40–100$ kN/m^2, liquid limit I_L = about 1.0) deposited within about 15 meters. Under the Alluvial layer, upper Pleistocene layer (N-value = 22–60) with high permeability and lower Pleistocene layer Osaka Group, with stiff clayey layer ($c = 200–400$ kN/m^2) and dense and slightly cohesive sandy layer (N-value = 30 – and above 60). Each Osaka Group dips in the south and east direction parallel to Uemachi-plateau.

3 BEHAVIOR OF BACK GROUND DEFORMATION DUE TO BRACED EXCAVATION

Here, some monitoring results of the earth retaining wall deflection and backside ground deformation due to braced excavation at the A-site are represented and the dispersed behavior in backside ground from wall to ground surface is described as Figure 2 shows (Ito *et al.*, 2006).

Alluvial layer and upper & lower Pleistocene layer are formatted from the ground surface near the A-site. Alluvial layer is composed of a fine sandy layer (1st aquifer) with 2 m thickness having low *Uc* and N-value equals to about 2, and a soft and sensitive clayey layer with N-value = 0–3, $I_L = 0.4–1.0$, $c = 20–100$ kN/m^2. This Alluvial clay layer is a typical soft layer in this construction site. On the other hand, upper Pleistocene sandy and gravel layer Tsg (2nd aquifer) with partially scattered gravel, lower Pleistocene clayey layer Oc3 (c = about 400 kN/m^2) and lower Pleistocene sandy layer Os3 (3rd aquifer, N-value >60) existed continuously under the Alluvial layer.

Seepage control method was adopted in this construction site with extending the wall to the low

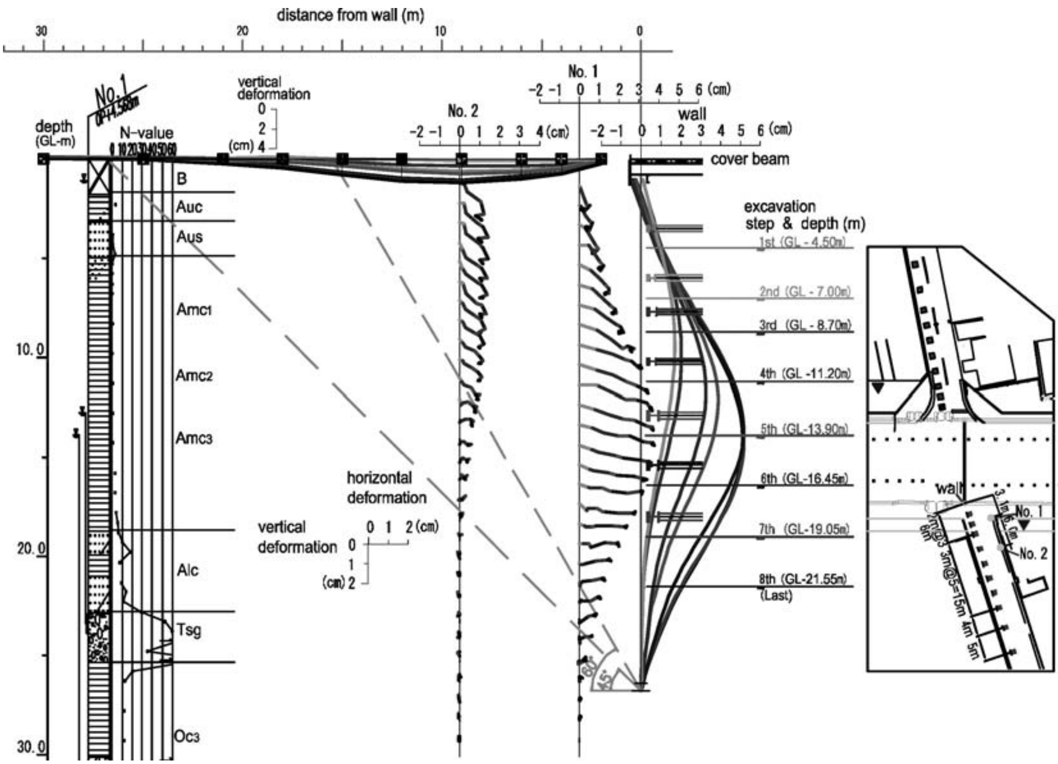

Figure 2. Earth retaining wall deflection, backside ground deformation vector and distribution of backside ground surface settlement at the A-site.

permeable layer Oc3 (GL-26.3 m). The excavation width was 16.2 m, and the final excavation depth was GL-21.5 m, in short, the wall penetration depth is 4.8 m. Because the soil improvement work was carried out near the monitoring site after GL-1.5 m excavation depth to protect the deficient part of wall, initial value of each observed data was set the value after 1st excavation to GL-4.5 m.

The maximum wall deflection occurred at a slightly deeper depth from the excavation bottom due to the braced excavation till the 6th excavation step, and this influences reached the backside ground and surface. For example, the maximum wall deflection was 38 mm at the excavation bottom, which was the middle of Amc layer (GL-12.5 m), in the 5th step. According to this influences, the maximum horizontal ground deformation of the No. 1 was about 29 mm at the slightly above the maximum deformation depth of wall. The maximum horizontal ground deformation of the No. 2 was about 12 mm in Auc layer and Aus layer. It was known that the wall deflection caused the back side ground deformation like the circular slip and this influence reached the ground surface.

On the other hands, the maximum surface settlement at the No. 2 was 6 mm, and the settlement distribution was convex downward with 0 mm settlement at the point, 20 m outside from the wall. It was thought that the friction between the wall and surrounding ground supported the surface settlement. These ground movements happened in the 45–60 degree area from the bottom of the wall.

The maximum wall deflection increased to 51 mm at just above from the excavation bottom, which is the lower of Amc layer (GL-14 m), in the 6th step. Since the 6th step, wall deflection did not increase any more. It was believed that the cause of this inhabitation phenomenon was from the subgrade reaction in the Tsg and Oc3 layer was large and the effects of pre-load on the wall.

Figure 3 shows the definition of symbols used in this paper. The relation between the excavation depth to the maximum wall deflection ratio δ_{max}/Z_e and the maximum deformation ratio S_{max}/δ_{max} are shown in Figure 4.

East and west wall deflection became large due to the braced excavation in the middle of Amc layer till the 4th step, and S_{max}/δ_{max} was tend to decrease. However, the wall deflection was decreased gradually, and S_{max}/δ_{max} was tend to increase adversely.

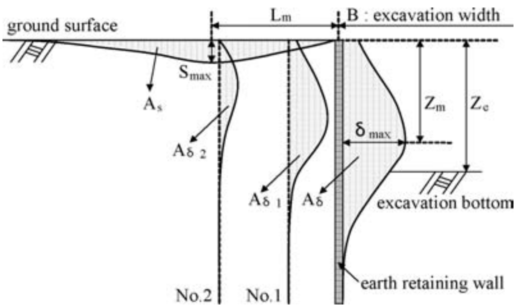

Figure 3. Definition of each symbol.

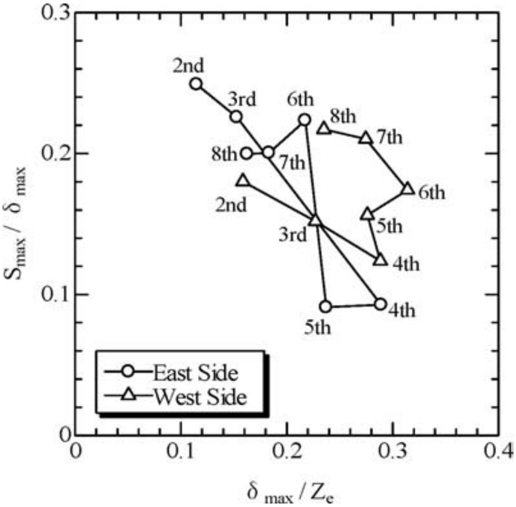

Figure 4. Relation between δ_{max}/Z_e and S_{max}/δ_{max}.

The relation between the excavation depth to width ratio Z_e/B, the maximum deformation ratio S_{max}/δ_{max} and the deformation area ratio are shown in Figure 5. Z_e/B is the non-dimensional value for excavation size and increase due to the braced excavation.

As the increase ratio of the wall deflection and surface settlement is small till the 4th step due to the braced excavation in the middle of Amc layer, S_{max}/δ_{max} was tend to decrease. However, S_{max}/δ_{max} was increased conversely due to the braced excavation after the 4th step. This tendency occurred in the same way with the relation of A_s/A_δ.

Figure 6 shows the relation between the wall deflection area A_δ and the backside ground surface settlement area A_s at the beginning of the excavation and after removing all struts. More or less A_δ and A_s tend to increase from the start to the end. Both side wall deflections have $A_s \cong 0.2 \times A_\delta$ relationship in the 8th step, and shifted to $A_s \cong 0.3 \times A_\delta$ relationship due to removal of struts. Unalterably, the west side wall deflection was larger than the east one.

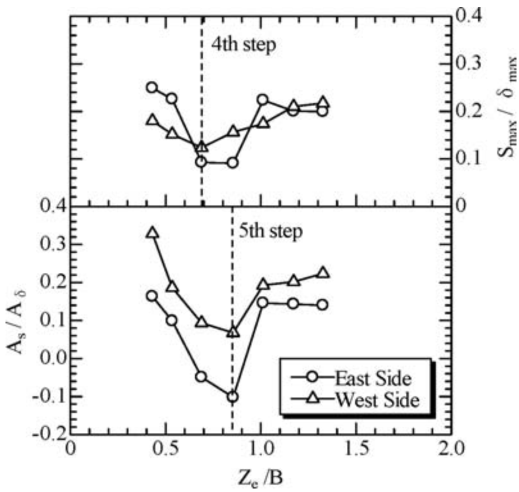

Figure 5. Relation between Z_e/B, S_{max}/δ_{max} and A_s/A_δ.

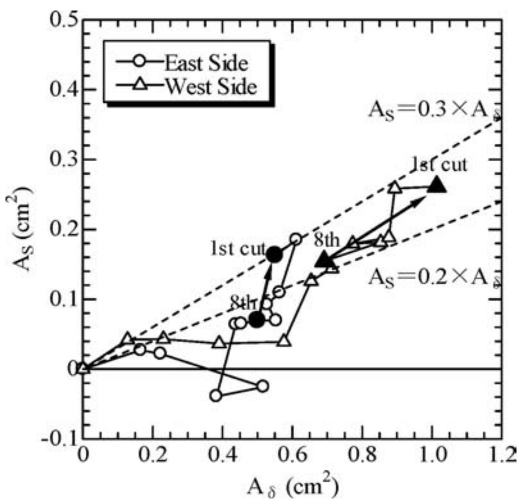

Figure 6. Relation between A_δ and A_s.

The relation between the distance from the wall to backside, wall deflection area A_δ and backside ground deformation $A_{\delta 1}$ & $A_{\delta 2}$ are shown in Figure 7. Broken line is the approximate curve based on the calculation result by least-square method with three measurement data in each excavation stage.

The ground deformation area attenuated gradually as getting away from the wall position till the 6th step. On the other hand, as the increase of the wall deflection became small, each deformation area changed little. The attenuation rate of the backside ground deformation area on wall deflection area was just about steady, about 70% at the No. 1 and about 25% at the No. 2.

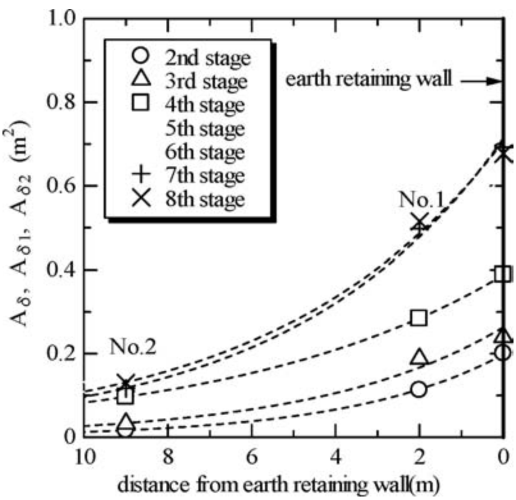

Figure 7. Influence propagation aspect to backside ground due to braced excavation.

4 STATISTICAL COMPARISON BETWEEN WALL DEFLECTION AND BACK GROUND SURFACE SETTLEMENT

Figures 8 and 9 show the relation between the wall deflection area A_δ and backside ground surface settlement area A_s at the beginning of the excavation and after removing all struts of all monitoring site for excavation soil characteristic. The broken line shows the observed data from final excavation stage to all struts removal stage.

The case of soft and sensitive clayey layer is shown in Figure 8. For example there were different tendencies between east and west wall deflection behavior, however, $A_s \cong (0.2–0.3) \times A_\delta$ relationship was given. Additionally, the wall deformation and surface settlement increased due to the removal of struts. A_δ and A_s were larger than one in the other different grounds. The case of alluvial sandy layer is struts. A_δ and A_s were larger than one in the other different grounds. The case of alluvial sandy layer is shown in Figure 9. There are great variances in this reference, however,

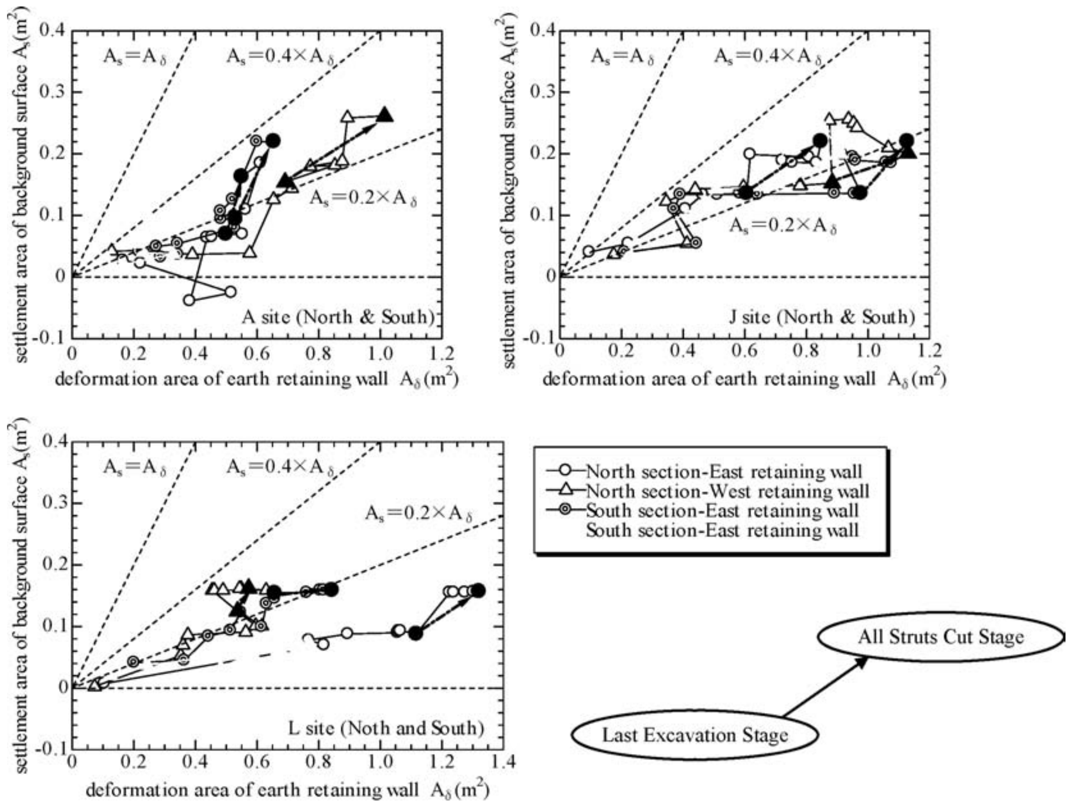

Figure 8. Relation between A_δ and A_s in the case of soft and sensitive clayey layer.

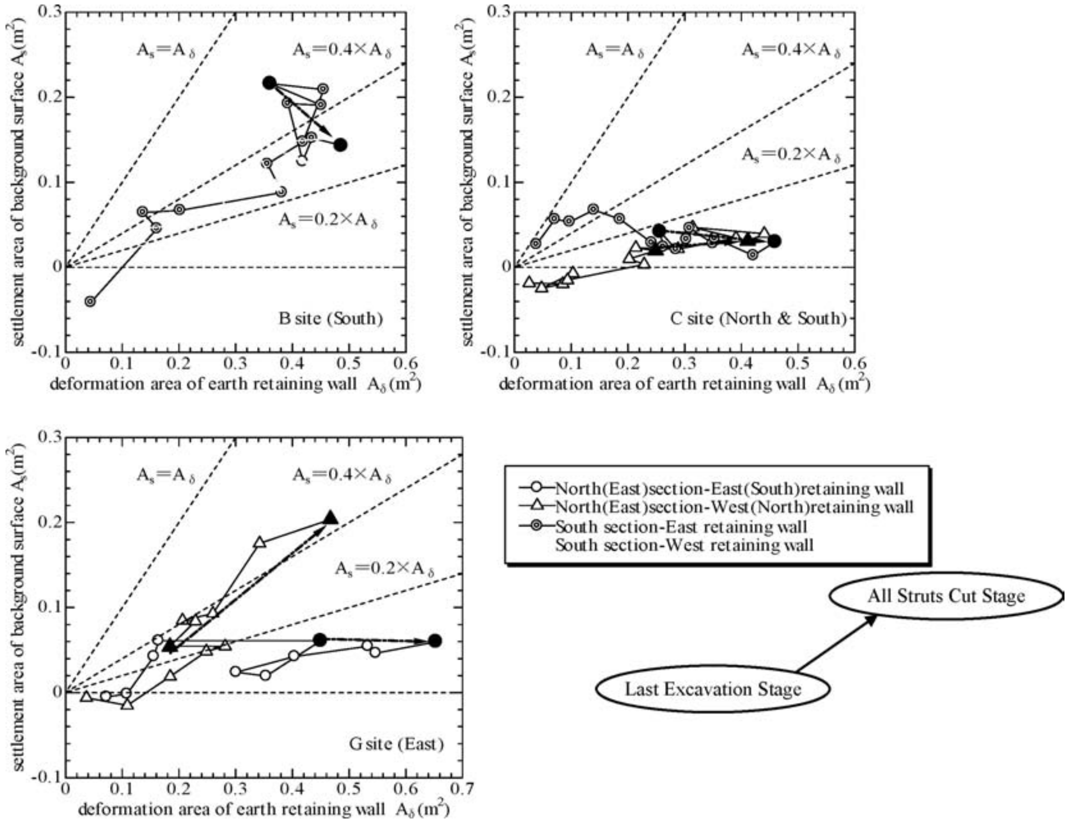

Figure 9. Relation between A_δ and A_s in the case of alluvial sandy layer.

$A_s \cong (0.1–0.4) \times A_\delta$ relationship was given. The deformation area of wall and surface increased due to removal of struts the same as the behavior of the soft and sensitive clayey layer case. But the amount of deformation was relatively small.

Figure 10 shows the predictive method of backside ground surface settlement based on the relation between A_δ and A_s due to the braced excavation. $A_\delta = A_s$ means that the influence of the wall deflection passes to the surface settlement directly without volume change (volume loss = 0%).

In the case of including the consolidation settlement, A_s was larger than A_δ according to the literature. On the other hand, A_s was smaller than A_δ in other cases (JSCE, 1993). Some observed data in the case of alluvial soft clay ground were added to past examples shown as Figure 10. Because the seepage control method was adopted in No. 8 Line construction, and actually the change of ground water level was small, it is possible to estimate the small amount of degradation for the consolidation settlement caused by the groundwater level. However past observed data were distributed along the $A_\delta = A_s$ relation, some monitoring data in No. 8 Line construction were located along the $A_s \cong (0.2–0.3) \times A_\delta$ relation and under the $A_s \cong 0.4 \times A_\delta$ relation. The backside ground settlement of this observed data converged smaller than the past data and the volume loss from A_δ to A_s was 70–80%. One of the reasons for this phenomenon is thought to be the support to the neighboring ground based on the arching effect developed in backside ground.

5 CONCLUSIONS

The conclusions are drawn as follows:

1. It was found that the earth retaining wall deflection caused the back side ground deformation like the circular slip and spread influences to the ground surface in A-site.
2. The distribution of backside ground surface settlement occurred as convex downward with the maximum value at some distance from the wall. It was thought that the friction between the wall and around ground supported the surface settlement.

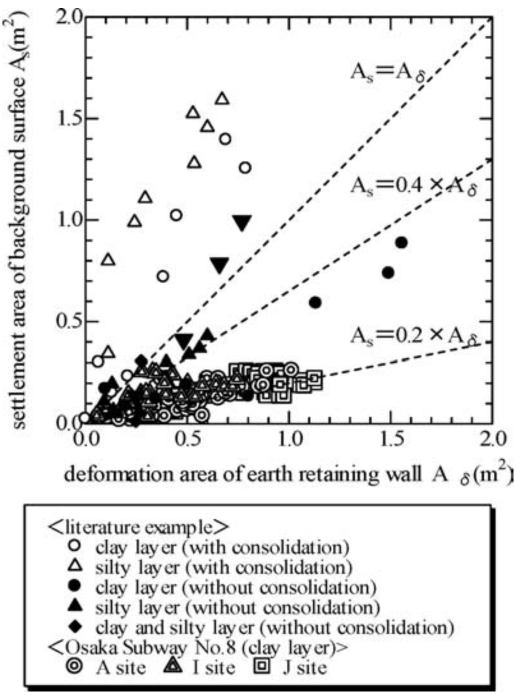

Figure 10. Relation between A_δ and A_s.

These ground movements happened in the 45–60 degree area from the bottom of the wall.

3. The attenuation rate of the backside ground deformation area on wall deflection area was just about steady, about 70% at 2 m distance and about 25% at 9 m distance from the wall.
4. The relation between the wall deflection area A_δ and backside ground settlement area A_s was that $A_s \cong (0.2–0.3) \times A_\delta$ in prominent soft and sensitive clayey layer, and $A_s \cong (0.1–0.4) \times A_\delta$ in prominent Alluvial sandy layer depended on the construction condition.
5. Some monitoring data in No. 8 Line construction were located under the $A_s \cong 0.4 \times A_\delta$ relation. The backside ground settlement of this observed data converged smaller than past data, and the volume loss from A_δ to A_s was 70–80%. One of the reasons for this phenomenon is thought to be the support to the neighboring ground based on the arching effect developed in backside ground.

It is necessary to carry out the evaluation preliminary in detail and use the observational method to void some kinds of risk. It is believed that this study will become useful for predicting the influences of neighboring construction in future.

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