Geotechnical Aspects of Underground Construction in Soft Ground, Kusakabe, Fujita & Miyazaki (eds)
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Ground settlement around a braced excavation work

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ABSTRACT: When a braced excavation is carried out near a structure, it is neither the extension of the area affected by the settlement of the ground being retained nor the maximum settlement thereof, but the change in gradient of the ground that must be taken into account to keep adverse effects on such structure at bay. This study was conducted to determine how the distribution of settlement at ground surface changes behind a retaining wall as the work progresses through its various stages. Differential settlement was measured there at 5m interval starting from the retaining wall to work out the gradient. From the results, a quantitative relationship was established between change in gradient of the ground arising from its differential settlement and the resulting adverse effects on wooden buildings in affected area at different distances from the retaining wall and also at various stage of work.

1 INTRODUCTION

Works involving such essential facilities as water supply, sewerage and drainage usually entail a small-scale braced excavation to a depth from 5m to 10m. In these works sheet pile retaining walls are often used for economy and good workability. Even with such retaining walls an excavation work generally results in a settlement of the nearby ground as it progresses. The settlement behind the retaining wall attains a considerable extent, particularly when the sheet piles are pulled out, bringing about a number of problems by giving rise to adverse effects on nearby structures.

In spite of the fact that the ground settlement characteristics behind a retaining wall as employed in a braced excavation work has much to do with the extent of damages on structures in near-by area, few studies appear to have been conducted to quantitatively determine the effect of the former on the latter.

The current practice to select an appropriate method for a braced excavation is to preliminarily determine the possible pattern of ground settlement behind a retaining wall, which may give rise to damages on structures in affected area, by using such techniques as the active collapse angle and Peck(1969) methods, on a case by case basis. To improve the situation, however, it is deemed necessary to quantitatively identify the characteristics of ground settlement behind a retaining wall and its incidence on damages on structures in affected area.

In this study, settlement was measured of the ground behind the retaining wall at various stages, including excavation, back filling, sheet pile removal, composing a braced work conducted on a soft ground with a view to determining, in a quantitative manner, the relationship between the pattern of settlement of the ground behind the retaining wall and possible damages on wooden structures in affected area arising from gradient settlement. Based on the results, gradient was identified of the ground in terms of distance from the retaining wall and its incidence was discussed on possible damages on wooden structures in affected area. Further studies were proposed to solve a number of problems related to planning and executing a braced excavation work close to structures that may suffer possible damages from such work.

2 DETAILS OF SOIL AND WORK

2.1 *The soil*

Shown in Figure 1 is the cross-sectional view of the ground at each of the three positions of the work site.

Included therein are the boring logs, the N-values of the soils determined through a standard penetration test, the levels to which excavation was carried out, as well as the depths to which sheet piles were driven. It can be seen that the soil was composed, from surface to downwards, of a layer of back-fill(B), an alluvial clay stratum (Ac_1), an alluvial sand stratum (As_1), and an alluvial silt/alluvial clay stratum (Ac_2, Ac_3). The top and the second layers are of soft soils with an N-value about 1 to 6 while the third layer, about 7 to 12m thick, consists of medium grain homogeneous loose sand having an N-value between 2 and 18. The lowermost stratum is composed of soft silt and clay with an N-value of 1 to 4 .

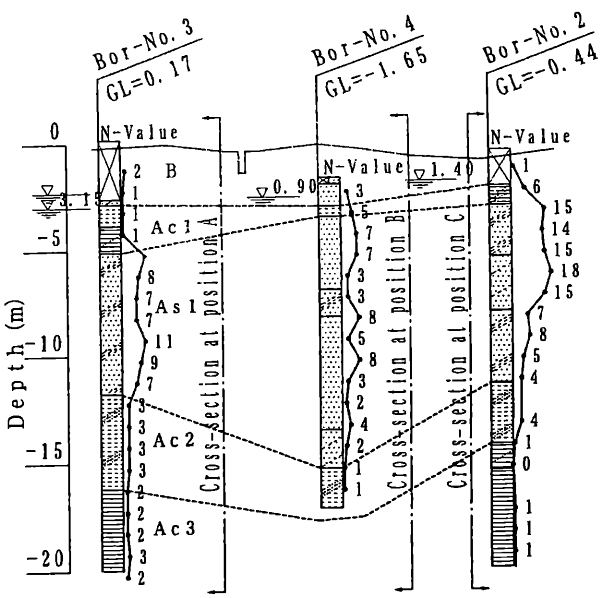

Figure 1. Cross-section views of the site.

2.2 *The work*

The work herein referred to was a braced excavation to lay a 1500m-long twin drainage water pile-line (SP ϕ=1600mm ×2). The site was divided into three sectors at which work was conducted simultaneously.

Illustrated in Figure 2 are three diagrams showing the typical details of the work conducted at each sector. At every sector, retaining walls were built with steel sheet-piles (Type IV, 13-15m in length) driven with a hydraulic pile driver. Two braces with no pre-load were used to hold the retaining walls in place. The sheet piles were driven to the clay stratum (Ac_2) which was thought to be impermeable so as to keep further consolidation settlement from developing in neighbouring areas due to possible lowering of underground water level. The bottom of the excavation was back filled to a thickness of 30cm by spreading a high-grade soil, which was subsequently compacted by rolling. The sheet-piles were pulled out by using the hydraulic pile driver. Voids created by sheet pile removal were not back filled. The work was

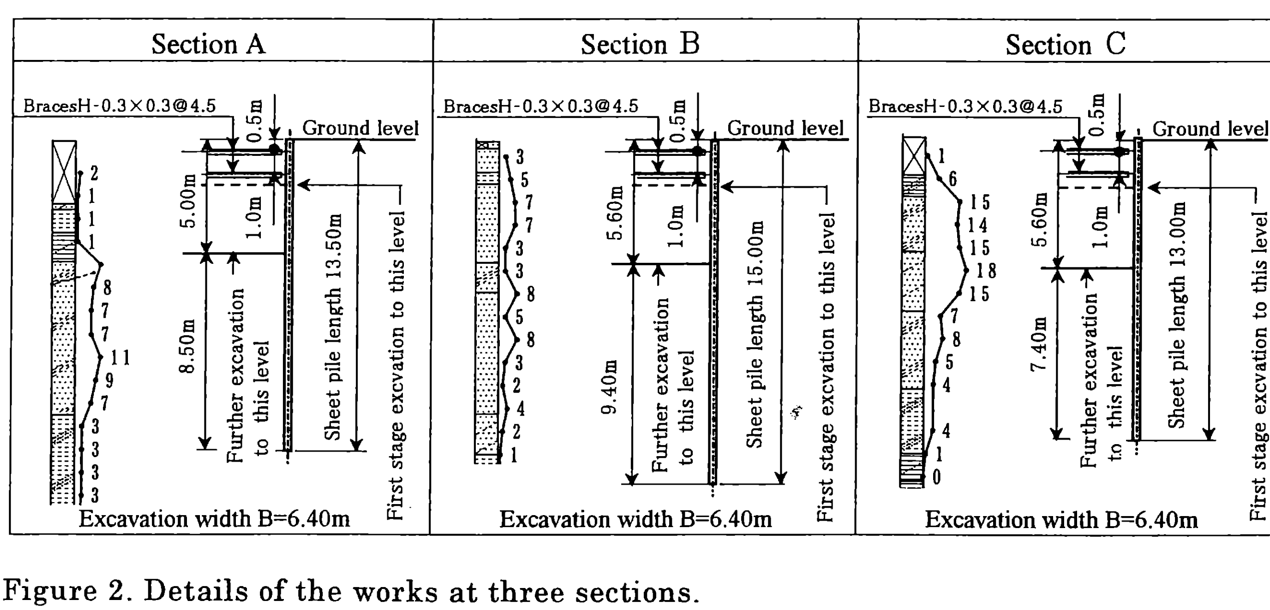

Figure 2. Details of the works at three sections.

conducted in dry condition by pumping out water from a sump.

3 DATA GATHERING AND ARRANGM-ENT

Settlements were measured of the ground behind the retaining wall by determining with a theodolite the levels of a number of test piles driven along a line normal to the retaining wall. Figure 3 shows the test pile arrangement. Data were taken at various stage of work. The distance between test piles was not uniform nor was the measurement conducted simultaneously or at fixed intervals at every section, because test conditions varied from place to place along the length of the work extending to 1,500m and also with time.

The data thus taken were collated into the following three groups:

– Settlements as registered from the time excavation was commenced until the pipe-line was laid down.

– Settlements observed during back filling including the removal of the braces.

– Settlements arising from the removal of sheet piles as recorded from the time they were pulled out until measurements were completed.

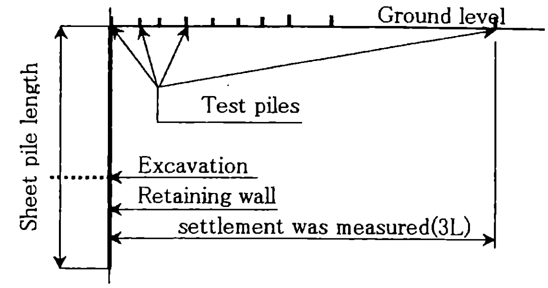

Figure 3. Test pile arrangement.

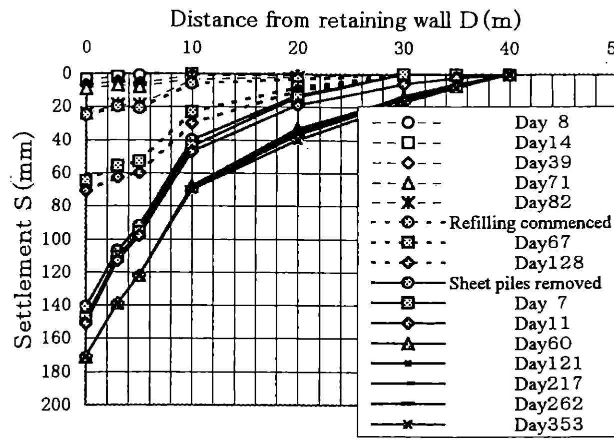

Figure 4 (a). Variation of settlement with distance (at Section C).

4 SETTLEMTNT DISTRIBUTION

Plotted in Figure 4(a) are the settlements behind the retaining wall against distance from the wall at section C. Number of days, as counted from the date on which work was started, is used as parameter to indicate the variation in settlements with time and at different stages of the work. The same data were rearranged in Figure 4(b) to indicate the variation in settlements with time with the distance from the retaining wall as parameter. Figures 4(a) and 4(b) provide an overall picture of how the ground settlement and the range of affected area behind the retaining wall progressed with time as the work advanced. From these figures it can be seen that :

– the maximum settlements observed during back filling and sheet pile removal stages were 3.5 times and 7 times as large as the maximum settlement recorded during the excavation stage which was about 10mm. within the range 5m from the retaining wall.

– the settlement developed even during the back filling stage in spite of the pressure exerted by the back refill into the soil. Progress was particularly large when the sheet piles were removed resulting in a larger settlement than that recorded during excavation stage.

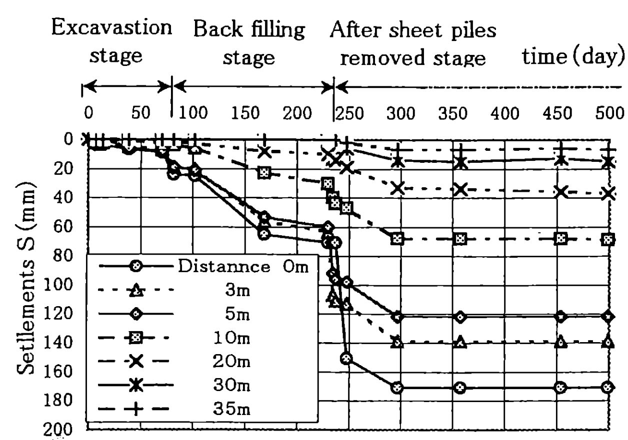

Figure 4 (b). Progress of settlement with time (at Section C).

—the area affected by the settlement extended to 30m from the retaining wall during excavation and back refilling stages while it reached as far as 40m as the sheet-piles were pulled out.

Figure 5 shows the variation in settlement behind the retaining wall with time at each of the sections A, B and C. Indicated above the figure is the time interval corresponding to each stage of work. Data are shown of those taken on both right and left sides of the excavation at section B and indicated with the letters R and respectively with reference to the diagrams shown in Figure 2. No appreciable difference was noted between the data recorded on either side, though the settlements at section B were measured over a relatively short period of 30 days.

Table 1 is a comprehensive list showing the maximum settlements at section A, B and C and at different stages of work. Shown in bracket is the ratio between the settlement as recorded during each stage of work at each section and the total settlement.

From the data shown in Figure 5 and Table 1, it is seen that settlements arising from sheet pile removal are by far the largest as compared with those developed during excavation or refilling, the former being as large as 60 to 90% of the total settlements. This trend was the same at all the sections A, B and C. Although its progress was not recorded throughout the period until it stabilized, the settlement arising from sheet pile removal was found to be particularly substantial at section B. This phenomenon can be ascribed to the fact that the sheet piles used at section B were longer than those at sections A and C,

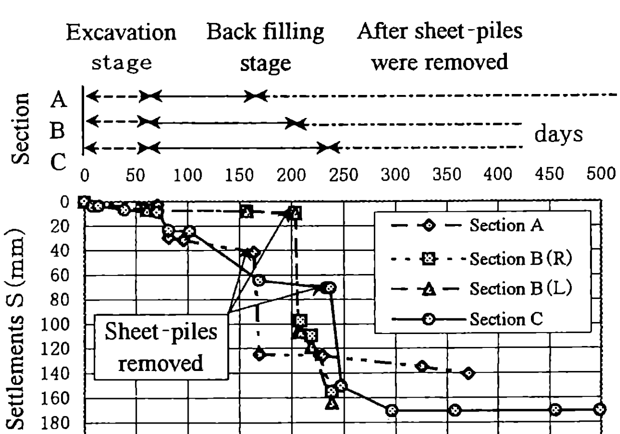

Figure 5. Progress of settlement with time.

Table 1. Maximum settlements (mm).

Section	Excavation Stage	Refilling Stage	When Sheet-piles were Removed	Total settlement
A	32(21)	10(6)	113(73)	155(100)
B	7(4)	2(1)	155(91)	171(100)
C	25(15)	46(27)	100(58)	171(100)

Note: ( )%

and also the soil there contained a larger amount of soft silt than at the other sections; because of this, a larger volume of soil was removed with the piles as these were pulled out, creating a larger void in the ground and this in turn gave rise to a larger settlement due to the larger amount of soil replacing the void.

Attention should be paid to the fact that the settlements behind the retaining wall due to back refilling and sheet pile removal were particularly large as was discussed in reference to their progress with time through various stages of the work.

5 GROUND SURFACE GRADIENT AND ADVERSE EFFECTS ON WOODEN BUILDINGS

Despite the fact that, when a braced excavation is carried out, it is the gradient ground settlements behind a retaining wall that has much to do with adverse effects on structures in the area, few studies seem to have been conducted to quantitatively determine the incidence of the former on the latter.

To make up for the deficiency, distribution was determined of such settlements by defining the gradient or relative settlement as shown in Figure 6, so as to clarify the incidence of the former on possible damages on wooden buildings in near-by area.

Shown in Figure 7 are the variation in ground gradient with distance from the retaining wall at each of the different stages of work. The gradient was worked out in the manner shown in Figure 6 and using the settlement data measured at 5m interval along a line normal to the wall.

Also indicated in Figure 7, are allowable values of gradient at which a wooden building may suffer damages to the different degrees of severity as given in Table 2(AIJ:1988). Data shown in Figure 7 and Table 2 provide a quantitative idea of how the gradient of ground behind a retaining wall arising from its non uniform settlement varied with distance from the wall, and how the magnitude of such gradient is related to the severity of damages on wooden buildings.

From Figure 7 and Table 2 it can be observed that:

- While excavation was in progress, the maximum range over which the gradient exceeded 1/1000 at which a wooden building might suffer damages was 10m from the retaining wall.
- During back filling work the gradient increased from 3/1000 to 5/1000 within the range of 15m from the retaining wall, safe area for wooden buildings where gradient was smaller than 1/1000 being farther than 25 m away from the wall,
- When sheet piles were pulled out, the gradient within the range of 10m from the wall further increased to 10/1000, a value large enough to cause structural damages on wooden buildings. Safe area in which a gradient smaller than 1/1000 was registered was in the range farther than 35m away from the wall.

From the above, it now became clear that the settlement of the ground behind a retaining wall and the range of area

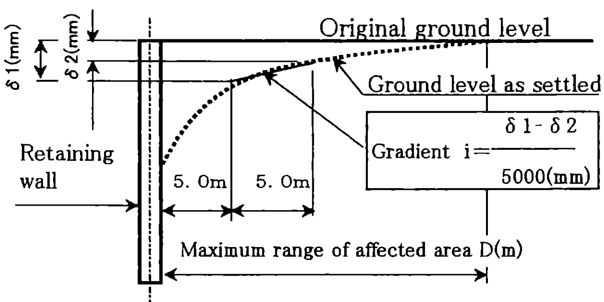

Figure 6. Settlements and gradient.

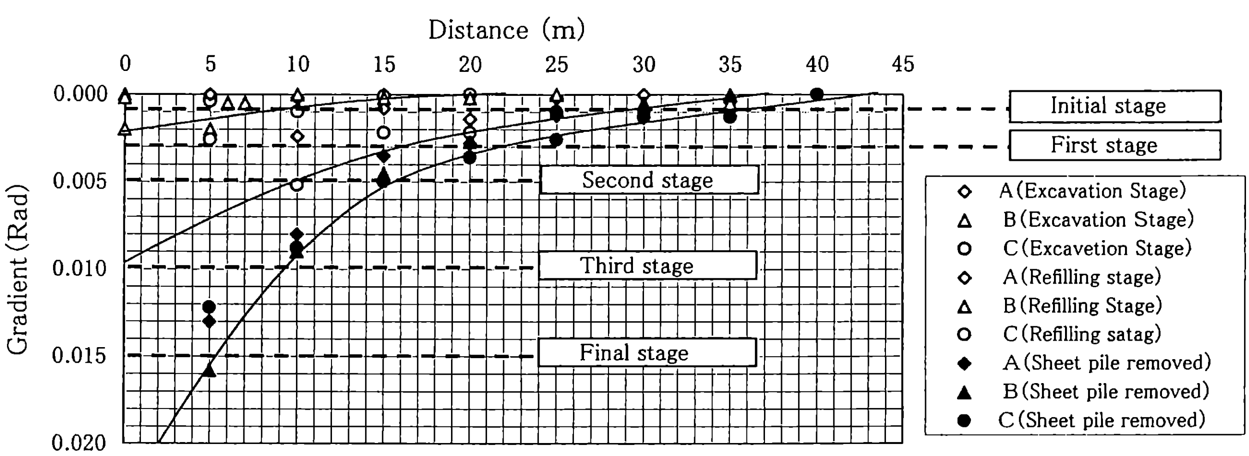

Figure 7 . Variation in Gradient with Distance Various Stage of work.

Table 2. Differential settlement damages wooden buildings and inclination angle.

Stage	State of damages due to differential settlement	Limit gradient
Initial stage	Cracks start forming on mortar walls or outside concrete paved walks.	1/1000*1
First stage	Cracks on concrete basement and floors inside a building.	3/1000*2
Second stage	Cracks on walls and tiles on walls. Gaps appear between doors, windows and their casings. Damages on outside structures including concrete block walls and paved walks.	5/1000*2
Third stage	Tilted columns, windows and doors including those on build in furniture hard to open and shut, and also slanted floors causing difficulties.	10/1000*
Final stage	Further inclination of columns leading to possible collapse of a building. Large inclination of floors causing difficulties.	15/1000*2

*1 : M. Makata 1980 *2 : T. Haga 1987

affected by such settlement increase by back filling work even when sheet-piles composing the wall are left there.

The removal of sheet piles further adds to the growth of the range of affected area. Accordingly, when planing a braced retaining wall design including its rigidity and bracing arrangement, as well as the method to execute and control such work.

CONCLUSIONS

By using measured data on ground settlement arising from a braced excavation conducted on a soft soil, relationship was examined in an quantitative manner between gradient of the ground behind the retaining wall and damages on wooden buildings due to differential settlement. Results of the study are as follows:

1. Distribution was determined of the settlement of ground over a range of distance behind the retaining wall during a braced excavation work and progress was identified of such settlement as the work advances. Subsequently, ratio was determined of the settlement arising from each of the work stages comprising excavation, back filling and removal of sheet-piles composing the retaining wall, over the total settlement.
2. Incidence was identified of the change in gradient of the ground behind a retaining wall on the severity of damages that may be incurred by a wooden building in area affected by differential settlement.

Further studies are suggested:

1. To verify the consistency of the results from this study with actual damages wooden buildings have suffered in the past due to such differential settlement, and
2. To establish appropriate methods for design and execute a braced excavation adjacent to wooden buildings or structures, to incorporating certain measures of assessment of risks including damage reparation.

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