First Korea-Japan Joint Geotechnical Seminar
October 18-20, Seoul, Korea

BRACED EXCAVATION NEAR THE EXISTING STRUCTURES

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SUMMARY

This paper is an introduction of measured samples of a peripheral ground displacement resulting from excavation work, and the work carried out to minimize the displacement of the earth retaining wall and the adjacent structures.

INTRODUCTION

Building construction work is usually done in urban areas where the adjacent environmental conditions are difficult. This result is that excavation and earth retaining work is primarily carried out for the purpose of avoiding adverse effects to the adjacency.

In order to carry out excavation work near existing buildings safely, ground displacement and its features resulting from the work must be considered. Furthermore, it is most important to establish a working plan employing a method that does not disturb a stable ground conditions to some extent or eliminates the main cause. Then, it will be necessary to improve the ground to minimize the ground displacement, or establish a plan to protect the existing structures and other underground facilities from the effects of the displacement.

This paper first describes a measured example of gound displacement caused by the displacement of earth retaining wall, as well as the ground displacement caused by ground rebound resulting from an excavation. Then it describes two case histories of the work in which the effect on the adjacent structures was controlled within the allowable limit by minimizing the displacement of earth retaining wall.

GROUND DISPLACEMENT RESULTING FROM EXCAVATION WORK

Ground displacement factors

Ground displacement factors resulting from an excavation are referred as follows:

a) Retaining wall displacement resulting from an excavation.
b) Sediment outflow accompanied by a leak through the retaining wall or drainage.
c) Consolidation settlement of cohesive soil resulting from the low groundwater level caused by drainage.
d) Displacement resulting from the construction of a retaining wall.
e) Displacement resulting from a pulling out of the retaining wall.
f) Ground rebound resulting from an excavation.

Besides the above, heaving and boiling are also checked, but these are not included here since these phenomena can cause failure ^f the earth retaining structure. The ground displacement caused by these . .rs causes phenomena such as, settlement, rebound and horizontal displacement.

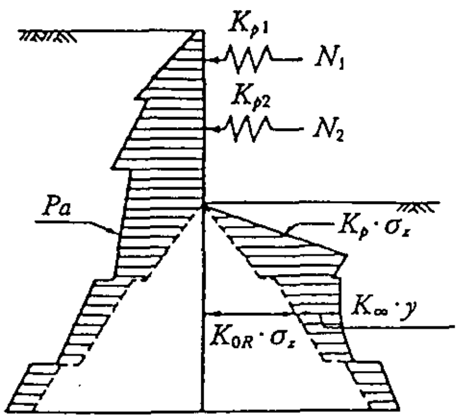
From among these factors, factors a),c) and f) can be estimated or studied quantitatively at the planning stage, but the other items must be handled with careful planning, construction and management with a full understanding of therelevant factors and phenomena.

As for factor c), a decrease in the groundwater level and a subsequent settlement of the ground may possibly be avoided by the use of cut-off walls. Therefore, we would like to introduce hereunder, some measured examples of a) and f) which are difficult to prevent during excavation work, and a simple method of predicting these phenomena.

Measured examples of ground displacement accompanying the earth retaining wall displacement.

The retaining wall displacement caused by excavation can be estimated with fair accuracy by the plasto-elastic method (Fig.1) in which the plasto-elastic characteristics of the ground and the displacement of the strut-supporting point are taken into consideration.

If the correlation between the displacement of the retaining wall and the backing ground is obtained, it may greatly aid the planning of excavation work, and the estimate of the ground and the adjacent structures displacement caused by the excavation.



Plastic region : $P_{p(z)} = K_p \cdot \sigma_z$ (1)

Elastic region : $P_{p(z)} = K_{0R} \cdot \sigma_z + K_\infty \cdot y$ (2)

Where, $P_{p(z)}$: Passive lateral pressure (tf/m^2)
$\sigma(z)$: Vertical stress in the excavation site (tf/m^2)
K_p : The coefficient limit of passive lateral pressure
K_{0R} : The coefficient of passive lateral pressure at rest during unloading
K_∞ : Coefficient of subgrade reaction with an infinite loading width (tf/m^3)
y : Earth retaining wall displacement (m)

Strut : $N_i = K_{pi}(y_i - y_{0i})$ (3)

Where, N_i : Axial load of the strut in step i (tf/m)
K_{pi} : Horizontal spring constant of the strut in step i (tf/m/m)
y_i : Earth retaining wall displacement at the strut in step i (m)
y_{0i} : Earth retaining wall displacement when installing the strut in step i (m)

Fig.1. : Computational Model for Retaining Structure

1) Retaining wall displacement and the settlement of the ground surface

Fig.2 shows the correlation between the retaining wall displacement and the settlement of ground surface based on the actual measurement [1]. The measurement is obtained from eight excavations performed in soft alluvial clay or a loose alluvial-sand layer with an N-value of less than 10. These measurements are obtained at a working site where the adjacent building has no underground exterior wall, and the decrease in the groundwater level of the surrounding area is negligible. The maximum value of the settlement of the adjacent area caused by factors a) and f) above are found to be less than the maximum displacement of the retaining wall.

Fig.2 shows broken lines enveloping the measured values of the settlement. If the retaining wall displacement can be calculated, the approximate maximum settlement of ground surface can be obtained by using Fig.2.

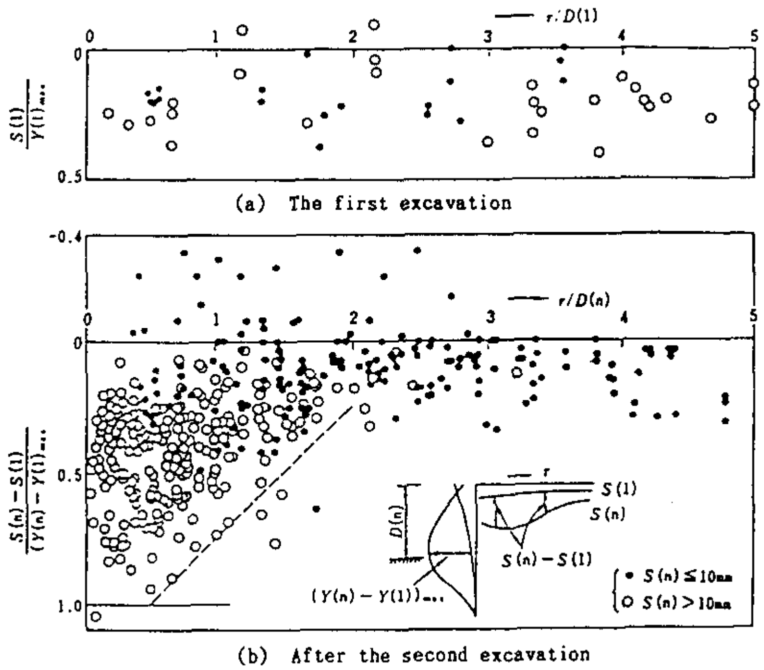


Fig.2. : Earth retaining wall displacement and settlement of the peripheral ground

2) the retaining wall displacement and the ground internal displacement

The following examples [2] show the measurement taken for the purpose of observing the adjacent ground displacement caused by the retaining-wall displacement.

Fig.3 shows the outline of the excavation and the ground. The approximate area of the excavation is 70m × 90m and the approximate depth is 13.75m. A soil cement pile wall (800ϕ) 24m in length is used as a retaining wall. Core materials using H-beam 588 × 300, are installed at 650mm @ (in the center). Steel strut supports are installed by the upside-down method. The site's soil layer consists of a backfilled layer from the surface to the 4m depth, a soft alluvium to the 32m depth, and a Tokyo gravel layer below that depth.

The measurements are taken for the displacement of the retaining wall, and for the horizontal and vertical displacement of the ground at points 2m, 5m, and 10m from the retaining wall. The vertical displacement was measured at a depth of GL-4m, GL-9m, and GL-16m.

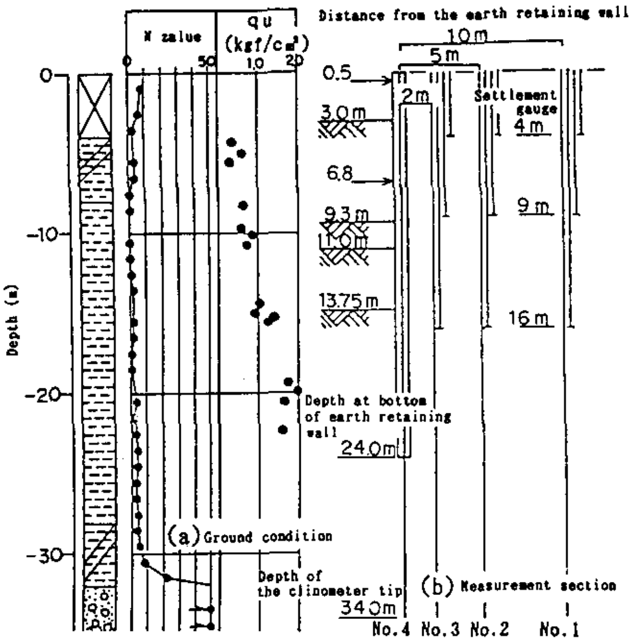


Fig.3. : Summary of ground and measurement

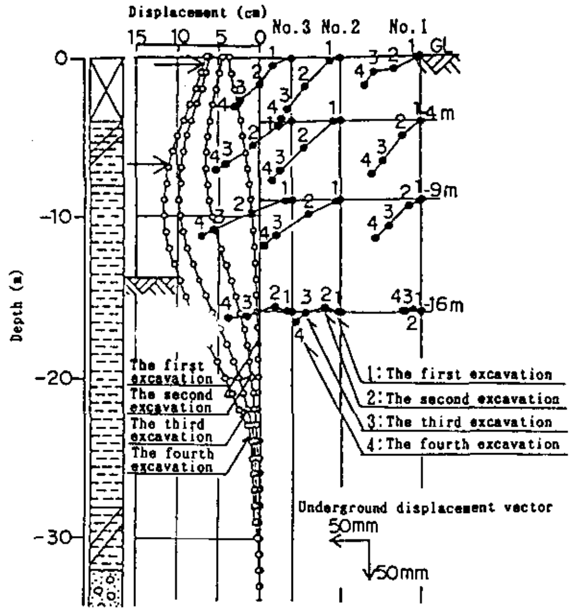


Fig.4. : Measured displacement of earth retaining wall and underground displacement vector

Fig.4 shows the horizontal displacement of the retaining wall and the displacement vector in the ground.

Since no leakage through the retaining wall was observed, the displacement of the adjacent ground was considered to be caused by the displacement of retaining wall and the rebound of the ground caused by the excavation. Therefore, we can assume that the measured displacement is represented by the following formula:

$$\delta H = \delta H1, \quad \delta V = \delta V1 + \delta V2 \tag{1}$$

δH: Horizontal displacement in the ground

$\delta H1$: Horizontal displacement resulting from the retaining wall displacement

δV: Vertical displacement in the ground

$\delta V1$: Vertical displacement resulting from the retaining wall displacement

$\delta V2$: Vertical displacement resulting from the rebound caused by the excavation

For the purpose of studying the characteristics of the ground displacement caused by only the retaining-wall displacement, the contours of the horizontal displacement in the ground were drawn as shown in Fig.5.

Fig.5 indicates the horizontal displacement in the ground after the first excavation, and the degree of the horizontal displacement after each excavation. The contours of the equal horizontal displacement after the first excavation show the features of a straight line, while the same features corresponding to the incremental displacement after the second excavation show a circular line.

If we assum that the internal friction angle is $\phi = 0$, and that the dilatancy angle is $\mu = 0$, for the cohesive-soil, the shape of the slip-line for displacement will be either a straight or a circular line.

Fig.6 indicates 4 types of slip-lines and the distribution of the contours of an equal horizontal displacement in the ground.

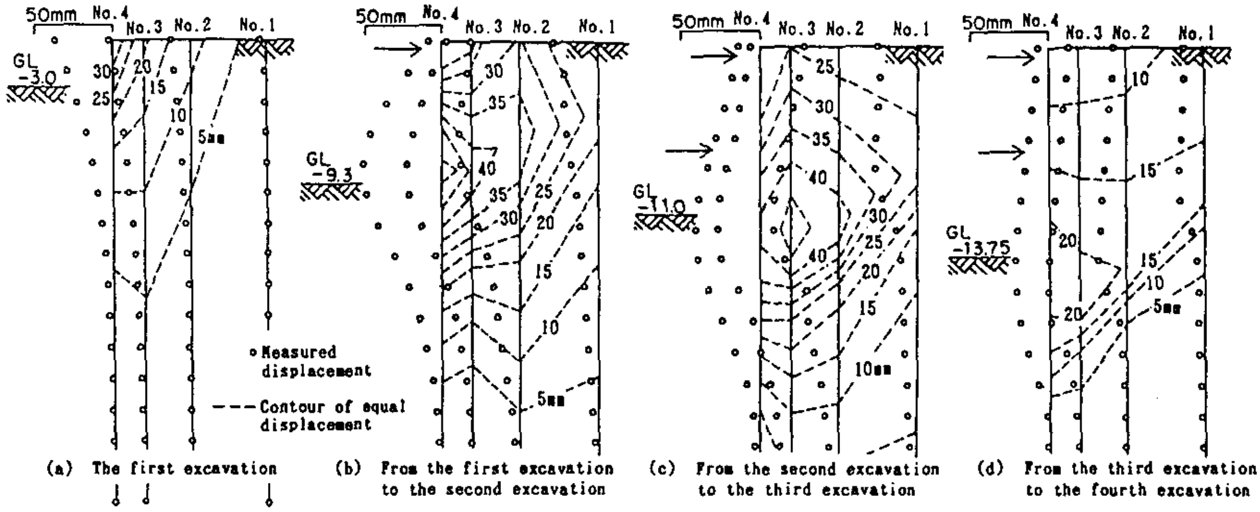


Fig.5. : Distribution of the equal horizontal displacement contour actually measured

By comparing the contours of the equal horizontal displacement between Fig.5 and Fig.6, we found that type A, after the first excavation, and type C or D, after the second excavation, exhibit a behavior close to the actual behavior.

Also, since the direction of the measured displacement vector (Fig.4) on the ground surface is nearly set at an angle of 45 degrees, after the second excavation, type D seems to be close to the actual behavior.

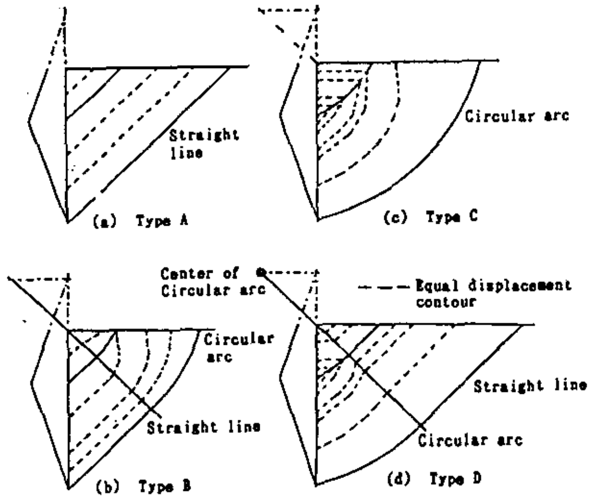


Fig.6. : Assumed slip-line and the distribution of contour of equal horizontal displacement

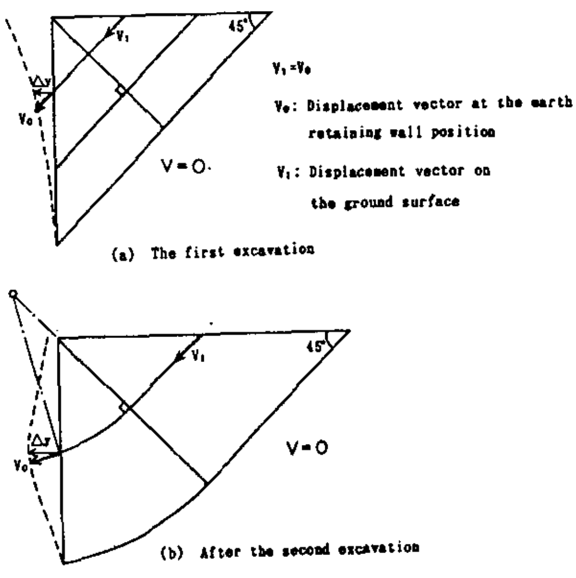


Fig. 7. : Method of finding the ground displacement

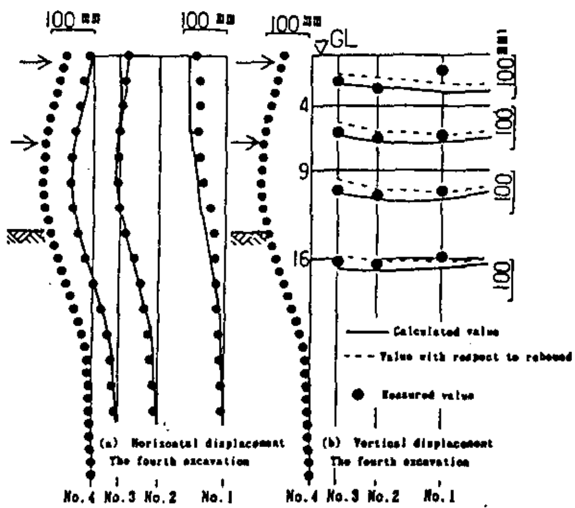


Fig. 8. : Comparison between the calculation based on the slip-line and the measurement

Therefore, by assuming the slip-lines as type A after the first excavation, and type D after the second excavation, we obtained the ground displacement from Fig.7, which is shown in Fig.8.

The calculated values agree considerably well with the measured values of both the horizontal and the vertical displacement.

The ground displacement caused by the retaining wall displacement can be obtained easily by Fig.10, the applicability of which is ensured by other measurements [3].

Ground rebound resulting from excavation

The ground, having its stress relieved by the load for the earth removed by excavation, will expand and cause rebound of the excavated ground surface, the adjacent ground, or the structures. The degree of rebound is generally the highest at the center of the excavated surface and it decreases with the distance from the center.

An example for such a ground rebound phenomena inside and outside the excavated area caused by excavation is shown as follows[4]:

Fig.9 shows the section of the excavation work and a summary of the ground.

The depth of the excavation is 12.6m, and the 17.0m long soil cement pile wall is used as a retaining wall. Two steps of support were installed by using ground anchors. The ground deeper than the bottom of the excavation is called the diluvium or the older stratum.

Fig.10 shows the excavation plan and the points of measurement. The vertical displacement was measured at 4 points inside, and at 4 points outside the excavated area.

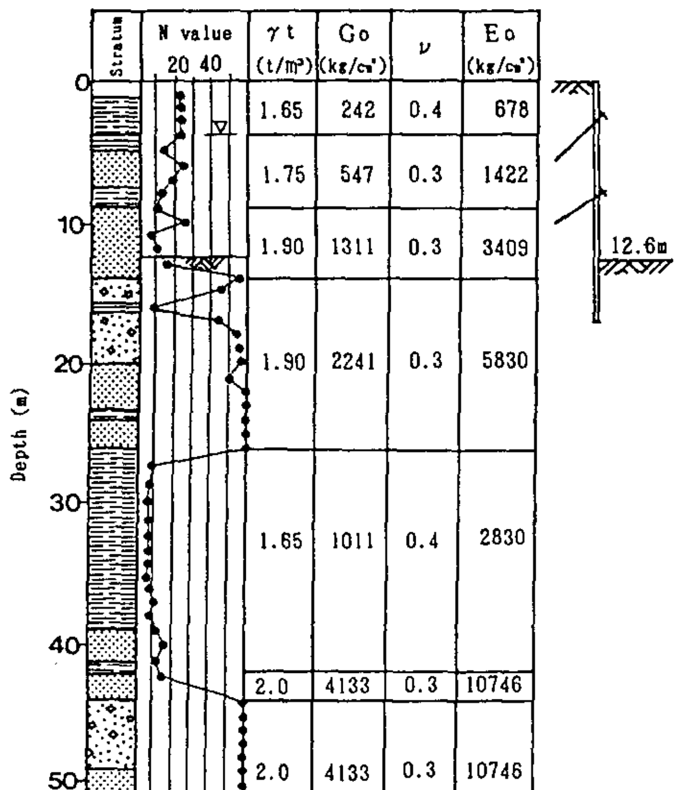


Fig. 9. : Ground condition and the excavation site

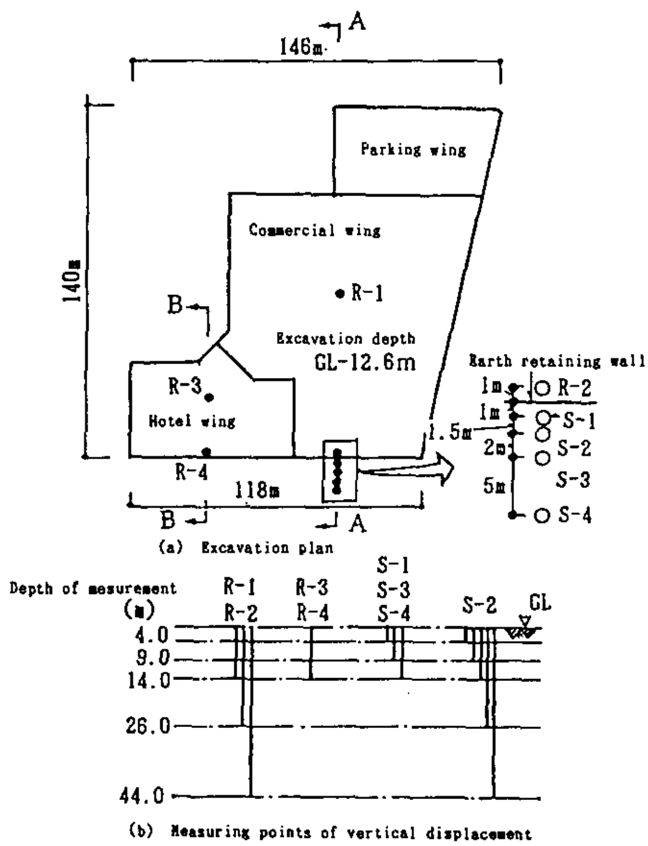


Fig.10. : Excavation plan and the measuring points

Fig.11 shows the measurements at each stage of the excavation and the depth of the excavation for each working area. The rebound amount after the last excavation at the bottom of excavation (GL-14m) is, approximately 50mm at the center (R-1), and 20mm in the vicinity of retaining wall inside the excavated area. This amount decreases with the distance from the retaining wall outside the excavated area.

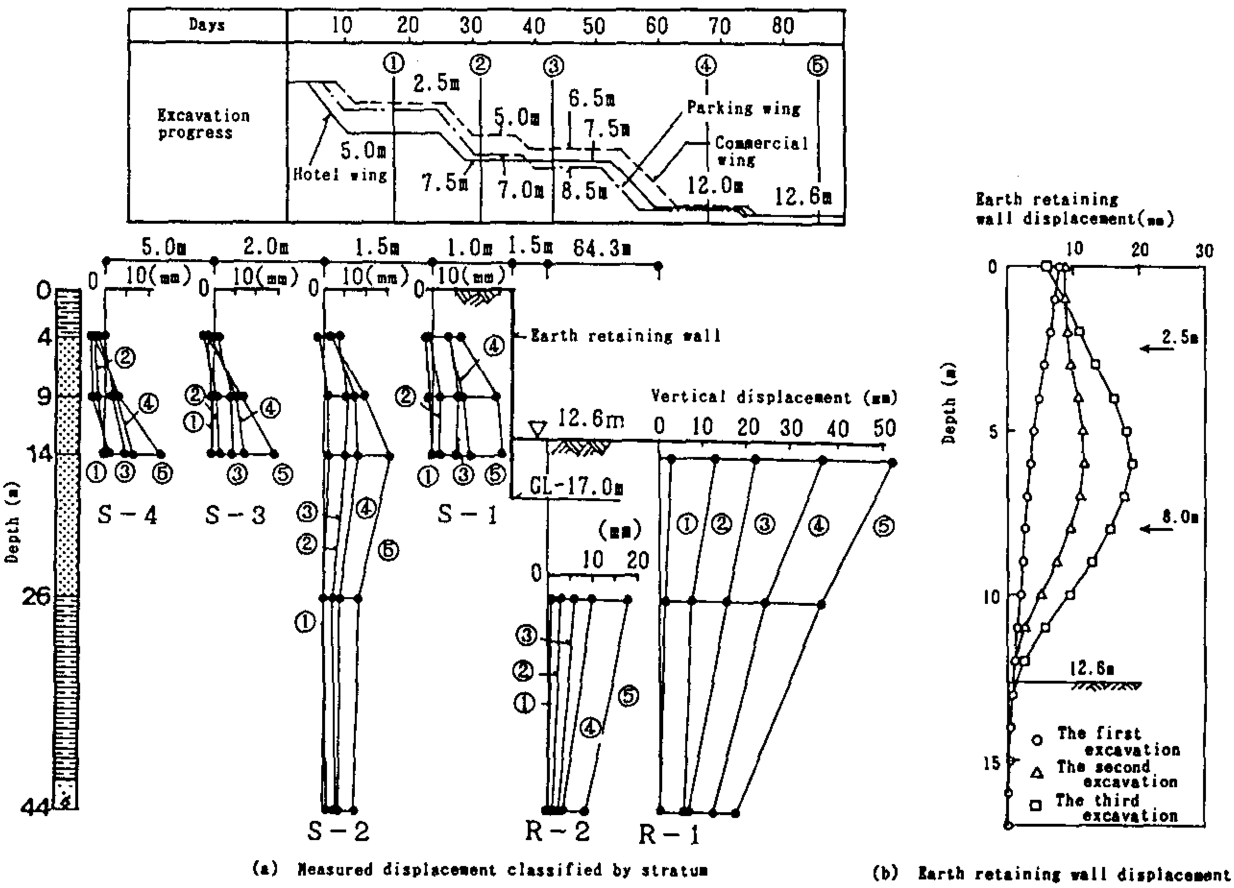
The rebound amount at a level higher than the bottom of excavation decreases as a result of the settlement caused by the retaining wall displacement, as well as the settlement caused by the decrease in the groundwater level near the surface resulting from the construction work. However, there is some amount of rebound near the retaining wall even after the last excavation.

Fig.12 indicates the plane distribution of the vertical displacement at the GL-14m and GL-26m levels after the last excavation. The calculated values in this figure were obtained from Eq.2 using Steinbrenner's approximate solution for a multi-layered ground [5].

$$\delta Zl = \Sigma (\delta Zu - \delta Zl) \qquad (2)$$

δZu, δZl: Vertical displacement at the top and at the bottom of the individual stratum (Fig.13).

The rigidity of the ground used for the calculation is selected by considering the effects of the mean principal stress σm and the shear strain γ. In a word, the effects of the mean principal stress resulting from the removed loan was evaluated by Eq.3, while the effect of the shear strain was evaluated by using the Ramberg-Osgood model in Eq.4 [4].



(a) Measured displacement classified by stratum

(b) Earth retaining wall displacement

Fig.11. : Result of measurement

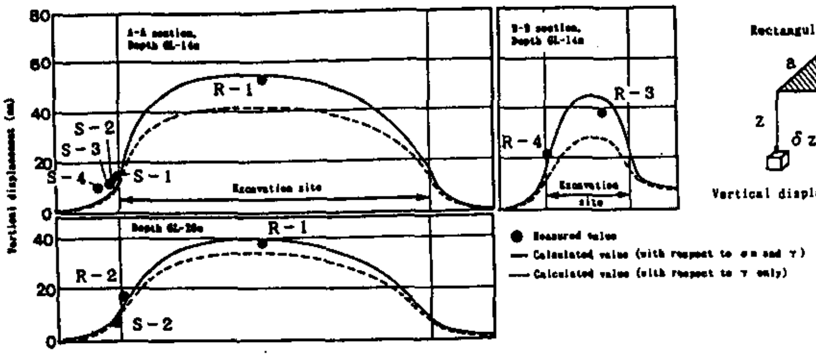


Fig. 12. : Plane distribution (Comparison between the measurement and the calculation)

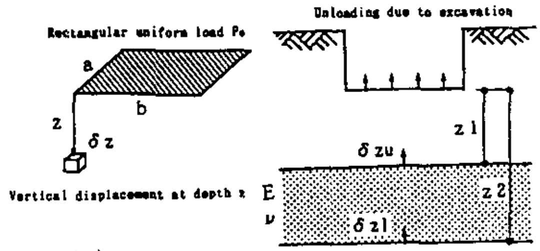


Fig. 13. : Solution of multi-layered ground

$$\frac{Go'}{Go} = \sqrt{\frac{1+\sqrt{\sigma Zo'/\sigma Z}}{2\cdot(\sigma Zo/\sigma Z)}} \qquad (3)$$

Go: Shear modulus before excavation (Set from the results of the PS logging)

Go': Shear modules after excavation

σZo: Vertical stress before excavation

$\sigma Zo'$: Vertical stress after excavation

$$\gamma = \frac{\tau}{Go'} + K\cdot\left(\frac{\tau}{Go'}\right)^{R} \qquad (4)$$

γ: Shear strain after excavation

τ: Shear stress after excavation

R, K: Constant

Cohesive soil:	R=1.8 K=570
Sandy soil:	R=2.1 K=1700

The amount of rebound caused by the excavation can practically be estimated fairly accurately, even by using a comparatively simple elasticity calculation, considering the non-linearity of the rigidity.

MEASURES FOR PREVENTING INFLUENCE TO THE PERIPHERY

A case history on the soft ground [6]

1) Summary of the work and ground

This is excavation work a soft alluvium soil in the section of 110m near the railway line which is constructed on 5m-high bank. Fig.14 shows the site conditions and the excavation section, while Fig.15 shows the site plan. The ground consists of, the backfilled soil from 2m to 4m from the surface, alluvium mainly containing sandy soil from 7m to 8m, alluvial silt and clay from 32m to 34m. Further below, it shows a gravel layer with an N valueof not less than 50. The cohesive soil layer to a depth of 25m, with an N-value of 0 ～ 1 and a natural water content exceeding the liquid limit by 20% to 40%, is very soft and sensitive.

2) Underground construction plan

Steel pipe sheet piles (ϕ914) were used for a section of the earth retaining wall near the high bank, after considering the deformation of the filled-up ground during the construction of the earth retaining wall, the cut off performance, the reliability of the wall material, and the period of construction. A soil cement-pile wall and steel sheet piles were used for the earth retaining wall, except for the north side corresponding to the condition of the site and the peripheries.

The upside-down method was used during the excavation to minimize the influence to the periphery, and in consideration of the ground condition and the scale of the excavation. In working areas A, B and C at the point in which they are adjacent to the filled-up ground, the southern section of 1st

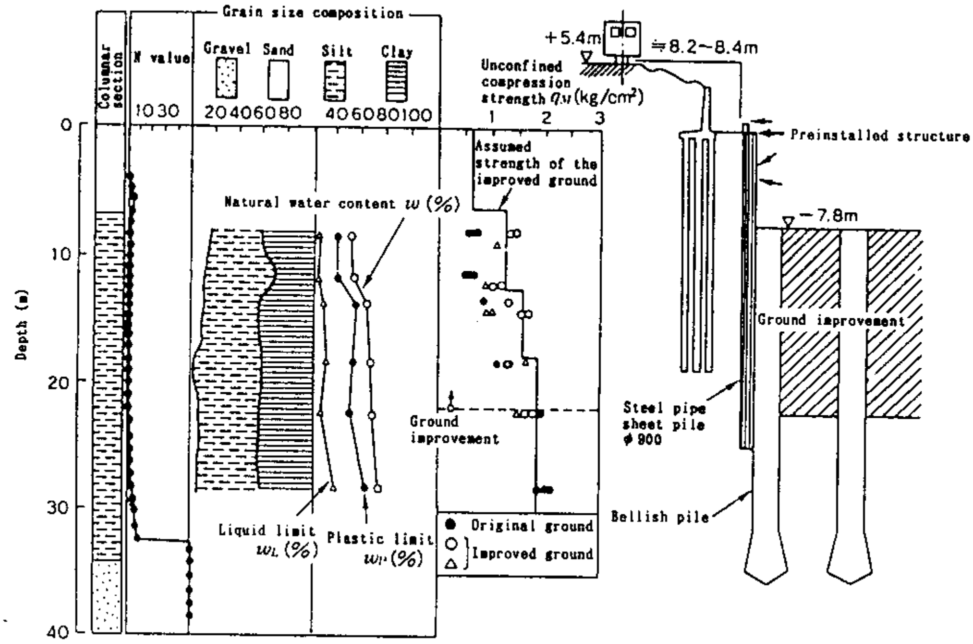


Fig.14. : Ground condition and the excavation site

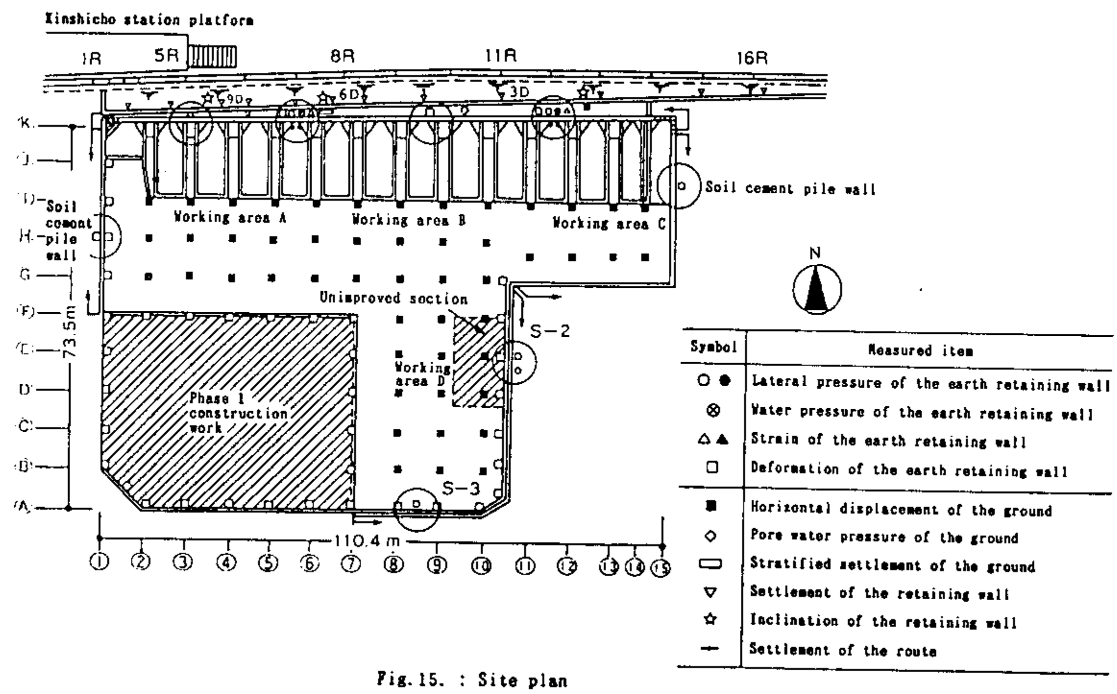


Fig.15. : Site plan

floor from column line I was constructed in advance to minimize the deformation of the earth retaining wall during the 1st excavation, and the excavation between column line I ~ K was performed by the Island method (Fig. 16).

Since the maximum displacement of the earth retaining wall was estimated to be about 120mm at the banking section even with the wall driven into the bearing stratum, the soil in the whole excavated area except in the D area was improved by the quicklime pile method for the purpose of stabilizing the excavated ground and preventing any adverse effects to the periphery. The quicklime piles were driven at the 1.3m pitch, to a depth of 25 ~ 19m in areas A, B and C, and to 13m at area D.

The driving pitch of the quicklime pile and the strength of soil after improvement were set based on the results of the unconfined compression strength of the improved soil through the use of the quicklime pile during the 1st phase of construction as shown in Fig.17 (a). Fig.17 (b) shows the calculated value of the earth retaining wall displacement on the bank side based on the abovementioned constant. This figure also shows the displacement calculated by the soil constant of the original ground, but the displacement was estimated to be limited at less than 1/2 through an improvement in the ground. Furthermore, a depth of 25m at the bottom of the earth retaining wall was believed to be suitable.

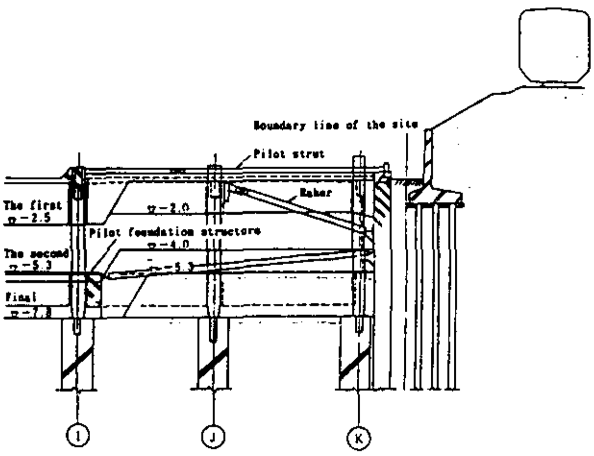


Fig.16. : Excavation method on the banking side

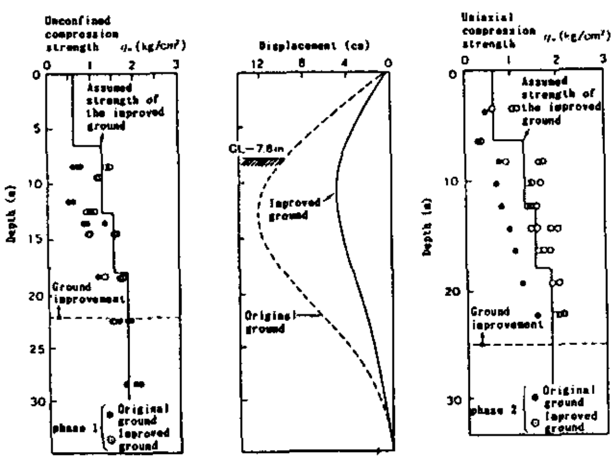


Fig.17. : Unconfined compression test results in the 1st phase of construction, and calculation of earth retaining wall displacement results in the 2nd phase of construction

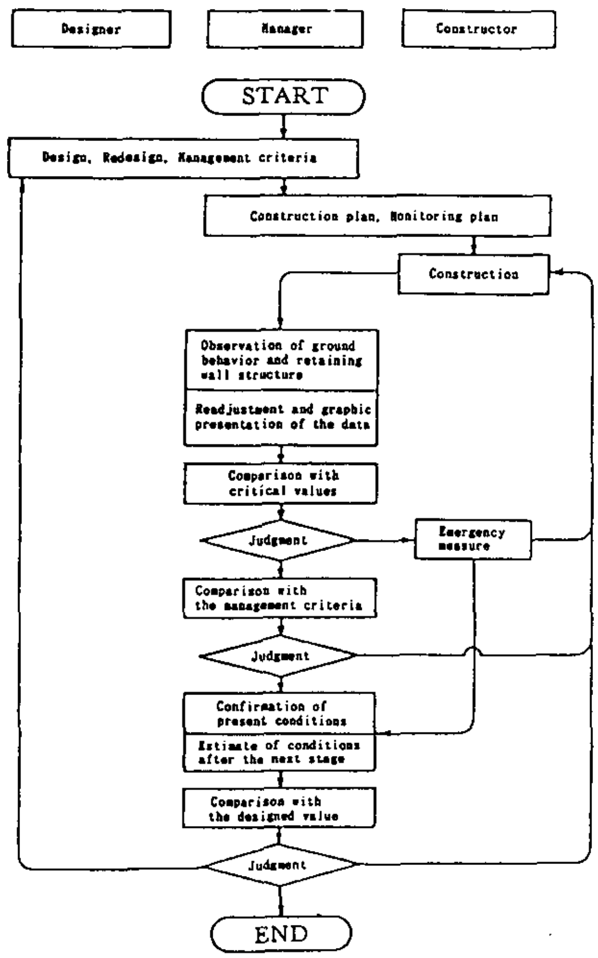


Fig.18. : Flow chart of Observational Construction Method

3) Monitoring plan

To minimize the influence on the bank, it is very important to discover the sign for the contingent occurrences as soon as possible during the work, in order to feed it back to the work, and prevent accidents before they happen. Therefore, one of the effective methods, we have employed is the observational construction method [7] (refer to Fig.18) which we used to clarify the difference between the plan and the results by a variety of monitoring, to find the cause of failures if any, and to continue the work after confirming the safety. Fig.15 shows the monitoring items and their points. With a view toward preventing the deformation of the route on the bank, in particular, more instruments and measuring points were located at the north side.

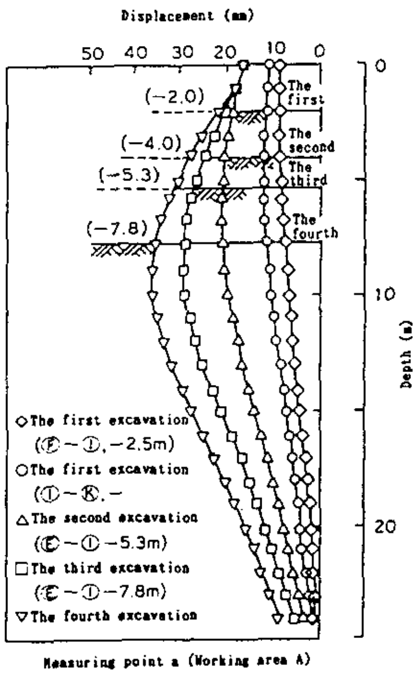
4) Measurement results

Fig.19 show the measured displacement of the earth retaining wall on the bank side for each phase of excavation. The displacement measurements were taken using the displacement just prior to the excavation asthe initial value.

The maximum displacement of the earth retaining wall after the final excavation is about 40mm, indicating a slightly smaller value than the calculated value for the improved ground shown in Fig.17. As the result, the Island method, together with the diagonal strut, may be admitted as having served its original purpose.

Fig. 20 shows a comparison of the measured displacement after the final excavation for the unimproved and the improved grounds in area D. Fig.15 shows that the measurement point are S-2 (the original ground) and S-3 (the improved ground). The maximum measured displacement is 65mm at S-2, and 20mm at S-3, indicating the clear effects of the ground improvement.

Fig.21 shows the behavior of the settlement related to the route on the bank and the retaining wall during the underground construction period. The amount of the aforementioned settlement is an accumulated value and the level of the actual route has been corrected. The foundation of the retaining wall is classified into 3 types, and Table.1 shows the foundation type and



Measuring point a (Working area A)

Fig.19. : Earth retaining wall displacement (JR side)

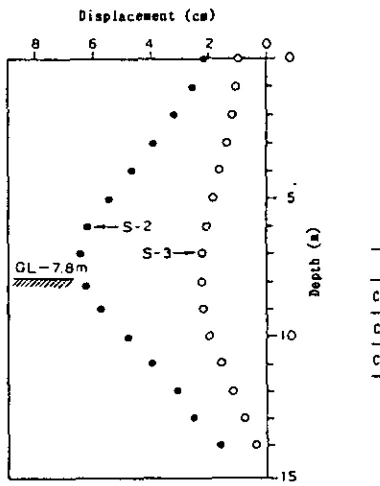


Fig.20. : Measured displacement of S-2 and S-3 earth retaining wall

Table 1 : Basic type of retaining wall

Section	Type of foundation
Column line ①~⑤	Sheet pile type Ⅳ. Tip depth GL-3.6m
Column line ⑤~⑨	Precast concrete pile. 350 φ. l = 18m
Column line ⑨	Cast-in-place concrete pile, 1000 φ. l = 32 ~ 34m

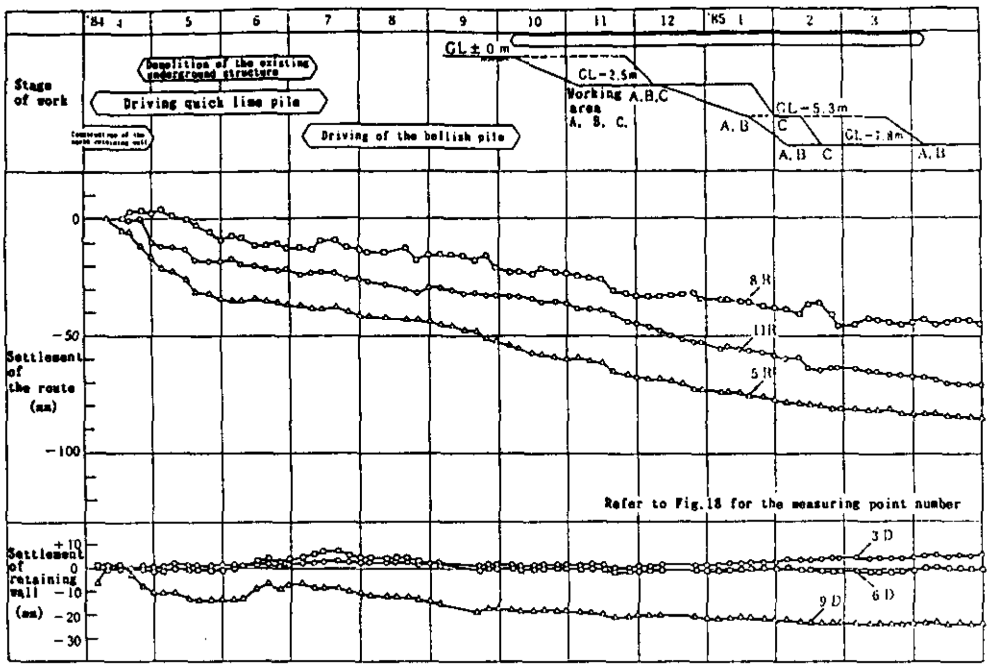


Fig. 21. : Construction progress and the behavior of high banking

placement section. Fig.21 shows the measured value at the measuring points (refer to Fig.15) corresponding to the type of individual foundation of the retaining wall.

The large rate of route settlement in the early period is considered to be mainly the result of dragging in the ground by driving the steel-pipe sheet pile used for the earth retaining wall. Furhtermore, the effect seems to differ depending on the type of the retaining wall foundation. In short, this effect is remarkable at 5R, the pile measuring point where it has the least penetration, corresponding to the results of the retaining wall measurement at measuring point 9D. The temporary floating of the retaining wall observed after the middle of June 1984 is the effect of the quicklime pile driven close to the retaining wall. However this effect is not visible on the route.

Incidentally, the settlement rate at measuring point 16R which is farthest from the excavation area and seems to have comparatively small effect on the work, although not shown in the figure, is 2mm/month. This value is considered to correspond approximately to the residual rate of settlement of the filling ground. Assuming these, the degree of settlement resulting from the excavation will be a maximum of 25mm, obtained by subtracting the amount of the residual settlement from the amount of the actual settlement.

Case history on diluvial deposit [8]

1). Summary of the construction and the ground

This building in this construction, as shown in Fig.22, has a plane area of 35 × 62m, 14 floors above ground and 3 floors below. The ground of the site, as shown in Fig.23, is fairly good. It consists of, from the surface, a clay, a Musashino gravel layer, an Upper Tokyo layer, a Tokyo gravel layer, and a lower Tokyo layer. The level of ground water is GL-9m. The work below the grade consists of a construction of a 27m long soil-cement pile wall around the outer border, and the excavation of the inside area by the upside-down method to a depth of GL-24.0m.

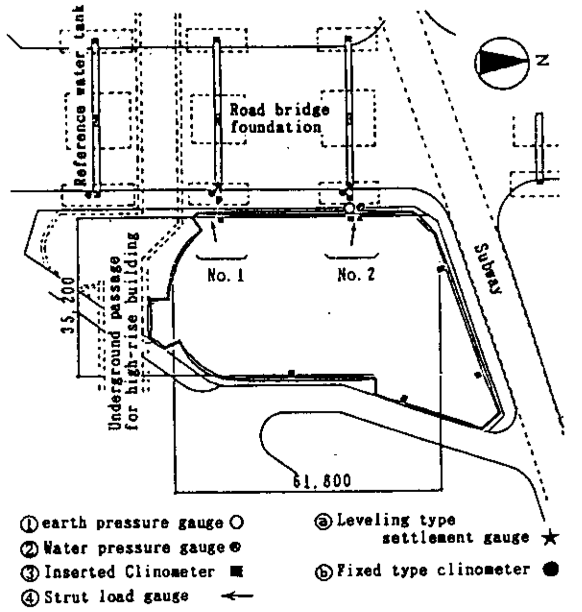


Fig. 22. : Summary of construction

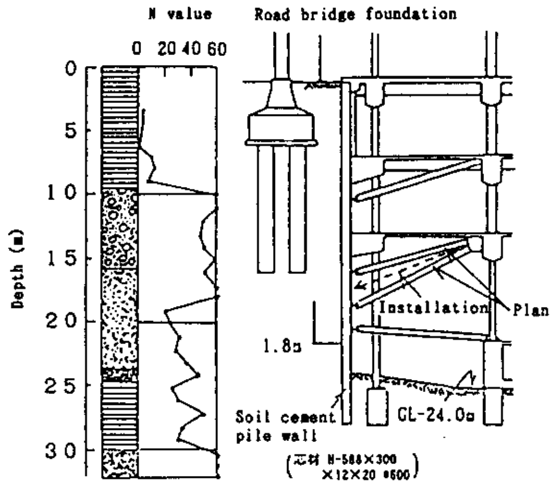
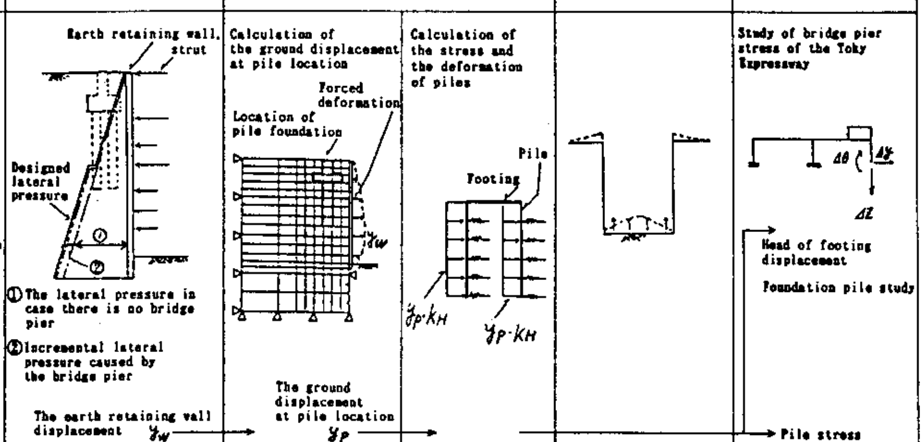


Fig. 23. : Summary of ground and earth retaining structure

2) Underground construction plan

This construction site has a very difficult peripheral environment including, the foundation of road bridges on the west side, an underground passage for a high-rise building on the south side, and a subway close to the north side. Among these, the adjoining conditions of the foundation of the road bridge is shown in Fig.23, where the distance between the foundation and the earth retaining wall is 1.8m. These conditions were so difficult that the excavation was performed at a 24m depth, very close to the bottom of the existing foundation piles located at GL-15m.

As a measure for preventing the displacement of the road bridge foun-



	Calculation of earth retaining wall displacement	Calculation of foundation displacement/stress caused by earth retaining wall displacement		Calculation of foundation diplacement caused by rebound	Study of structural stress of Expressway
Summary of calculation	Earth retaining wall, strut; Designed lateral pressure; ① The lateral pressure in case there is no bridge pier; ② Incremental lateral pressure caused by the bridge pier; The earth retaining wall displacement y_w	Calculation of the ground displacement at pile location; Forced deformation; Location of pile foundation; y_w; The ground displacement at pile location y_p	Calculation of the stress and the deformation of piles; Pile; Footing; $y_p \cdot k_H$		Study of bridge pier stress of the Toky Expressway; $\Delta\theta$; Δx; Δz; Head of footing displacement; Foundation pile study; Pile stress
Analysing method	Displacement and the stress of earth retaining wall were obtained by earth retaining analysis based on the plasto-elastic method. Incremental lateral pressure caused by the bridge pier was obtained by the foundation settlement analysis	Obtained by the finite element method	Obtained by the plane frame analysis	Steinbrenner's method of elasticity analysis	

Fig. 24. : Method of study

dation, two methods were considered. That is, chemical grouting under the foundation and controlling the displacement of the earth retaining wall. Since there is some doubt about the workability and the effect of the former method, the latter method was employed. As a method for limiting the earth retaining wall displacement, we used core materials with a high rigidity for the soil cement pile wall, by installing 4 steps of temporary steel-strut, introducing preload, in addition to 3 steps ofthe permanent frames (Fig.23).

When planning the construction work below the grade, we confirmed the safety of the foundation (Fig.24) by predicting the displacement of the bridge foundation resulting from both the earth retaining wall displacement and the rebound effect. This result became the control value for the work. The measurements were taken as shown in Fig.22, emphasizing the earth retaining wall displacement, the vertical displacement and the inclination of the road bridge foundations.

3) Observational construction method and the results of measurement

Fig.25 shows the measured displacement of the earth retaining wall after the fourth excavation compared to the predicted displacement. The measured displacement in sandy soil tended to be larger than the predicted displacement. The predicted lateral pressure was reviewed by reverse analysis to obtain the active side lateral pressure from the earth retaining wall displacement and the strut load. This result will hereafter be respected to as the confirmatory lateral pressure. Fig.25 shows this result after the fourth excavation. The value of confirmatory lateral pressure was 3 $\sim$ 5ft/m^2 less the predicted lateral pressure in sandy soil at GL-9.5 $\sim$ 25.0m, and was almost equivalent to the measured water pressure.

The earth retaining wall displacement for the following stages were estimated using the above results. As a result, the excavation work continued, because the retaining wall displacement for the following stages would probably come within the limit of the predicted value even with one step of the strut deleted. Fig.26 shows the maximum measured displacement of the earth retaining wall location at the road bridge foundation. This was approximately

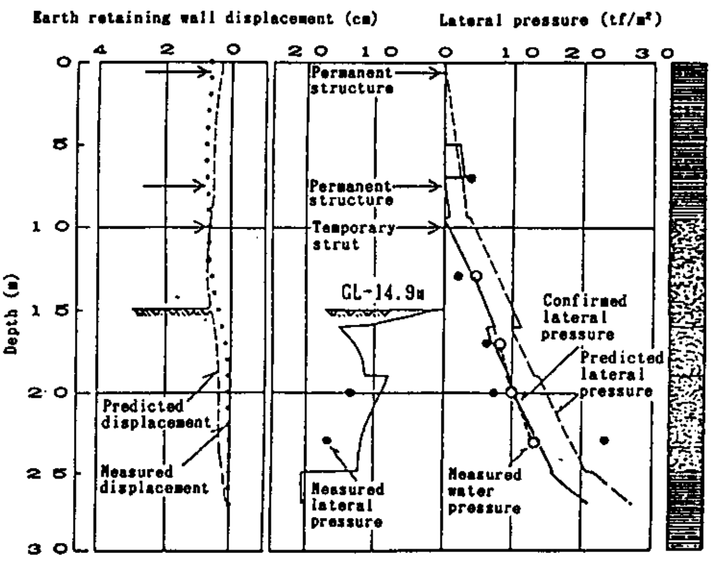


Fig.25. : Result of confirmation after the fourth excavation

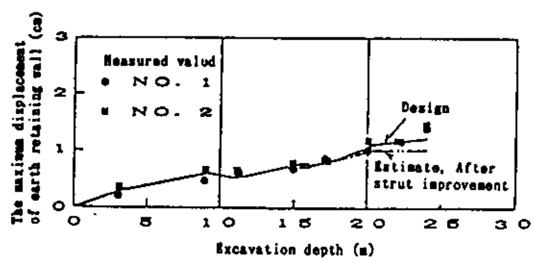


Fig.26. : Measurement result of earth retaining wall displacement

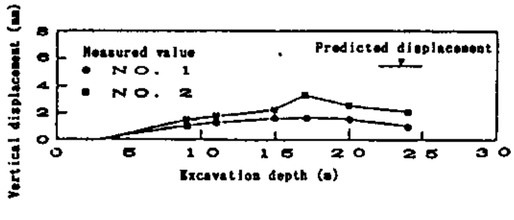


Fig.27. : Vertical displacement of road bridge foundation

the same as the predicted value yet more than the estimated. This is considered to be caused by contractions due to temperature fluctuations in the structural floor.

On the other hand, Fig.27 shows the correlation between the vertical displacement of the road bridge foundation and the excavation depth. Both road bridges (No.1 and No. 2) were subjected to the rebound effect, and the maximum vertical displacement was 4mm, a little less than the predicted value of 5.5mm.

CONCLUSION

This paper described about actual examples of countermeasures to minimize retaining wall displacement. Importance was placed on the peripheral ground displacenment due to the earth retaining wall displacement.

As described in paragraph 2., there are many factors influencing ground displacement, and their correlation is rather complicated. It is difficult at present to make accurate quantitative estimates of all the factors and phenomena.

Therefore, it is necessary to prepare an alternative plan for the construction work with quantitatively unknown factors, and work with a constant and monitor carefully the ground and structures either by instrumentation or observation.

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