Underground Construction in Soft Ground, Fujita & Kusakabe (eds) © 1995 Balkema, Rotterdam. ISBN 90 5410 536 4

Behavior of cantilever T-shaped diaphragm walls during excavations

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SYNOPSIS: This paper discribes the behavior of the cantilever type earth retaining walls with T-shaped diaphragm walls based on the field measurement. The excavation down to the depth of 17.1m was carried out with no brace supporting in the very soft ground in Tokyo, Japan. The results of the measurements and calculations showed the necessity of the equivalent flexural rigidity and equivalent bending capacity in the effective width of T-shaped walls and the flat walls upper of the T-shaped walls.

1. INTRODUCTION

In recent large scale excavation works, T-shaped reinforced concrete diaphragm walls are being used as part of cantilever type earth retaining walls. This construction method has two distinctive characteristics. The first relates to the big difference in flexural rigidities of T-shaped walls and flat walls. The other is the feasibility to excavate deeper than with the use of ordinary cantilever type earth retaining walls. However, the behavior of these earth retaining walls has not been investigated sufficiently, nor has their design method been formalized. This paper discusses the behavior of cantilever type earth retaining walls based on the results obtained from in-situ measurement of T-shaped continuous diaphragm walls for which excavation was made to a depth of 17.1 m.

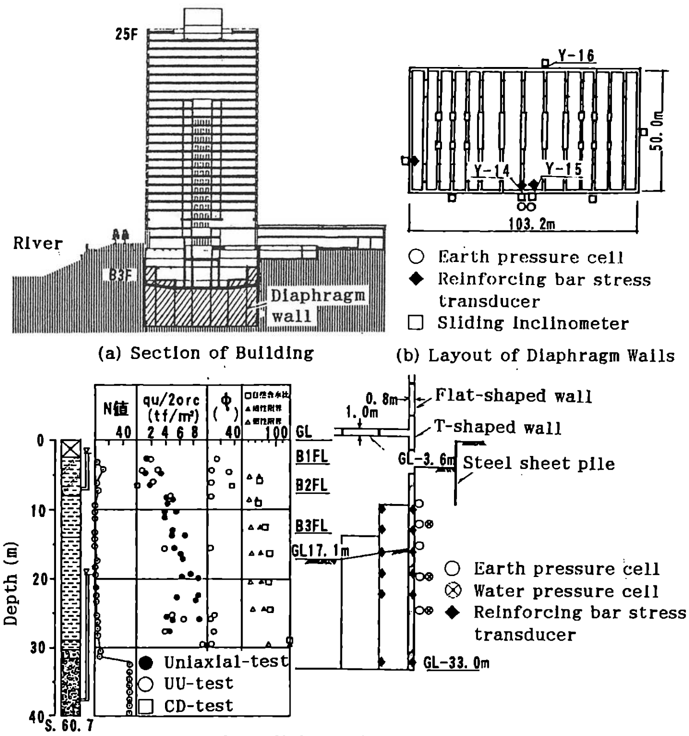
2. BUILDING AND SOIL CONDITIONS

A schematic of the building and a summary of the soil investigation are shown in Fig. 1. A 25-story office building with a total floor area of 137,200 m² and a 3-story basement, and the excavation area of about 100 m × 50 m at a depth of 17.1 m, are shown in Figs. 1(a) and 1(b).

The layout and section of the diaphragm walls are shown in Figs. 1(b) and 1(c). The diaphragm walls are built on perimeter of 100 m × 50 m rectangle and in interior foundation parallel to the shorter side. Above the excavation bottom, T-shaped and flat walls were placed alternately. The buttress length of T-shaped walls facing each other are larger at lower floor levels. The diaphragm walls form an extremely rigid cantilever as they are connected with the foundation walls below the excavation bottom.

From the ground surface to a depth of 29 m, the soil profile of the site, shown in Fig. 1(c), consists of a very soft silty clay (with a natural water content over its liquid limit), and a gravel sandy layer below it (the supporting stratum of the building).

The excavation was conducted without supporting braces



(a) Section of Building (b) Layout of Diaphragm Walls

(c) Ground Condition and Section of Diaphragm Walls

Fig.1 Schematic of the Building and Summary of the Soil Investigation

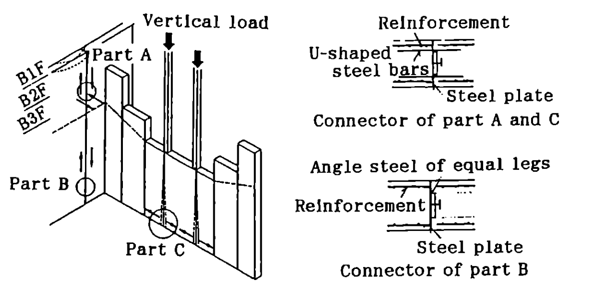


Fig.2 Detail of connectors

down to a depth of 17.1 m. The diaphragm walls were constructed after the first stage of excavation to a depth of 3.6 m inside of steel sheet piles buried around the outer perimeter.

Fig. 2 illustrates the connectors which are installed between individual units of the walls for the purpose of wall-to-wall integration. The efficacy of the connector as a stress transfer was confirmed by full scale strength tests.

Measurements were made of the lateral pressure and water pressure on the walls, the wall stress and displacement. The locations of the transducers are shown in Figs. 1(b) and 1(c).

3. OBSERVATIONS

Fig.3 shows the distribution of the lateral pressure and water pressure on the T-shaped diaphragm wall at each stage of excavation. A slight decrease in the lateral pressure was observed below a depth of 15 m, but otherwise no significant changes were seen. The equivalent coefficient of lateral pressure, Ka, from the ground surface to a depth of 24.5 m ranged from 0.35, at the first stage of excavation, to 0.33, at the last stage.

Fig.4 shows the displacement distribution of T-shaped walls, Y-14 and Y-16, and a flat wall, Y-15. As shown in Fig. 1(b), the excavation depth of Y-14 and Y-16 are same and the both walls are facing each other. A comparison of their displacements reveals the following facts. The displacement distribution of Y-16 shows an approximate straight line, while Y-14 tends to displace largely above the depth of 9.1 m. This may be the effect of overburden pressure of the soil behind the steel sheet pile adjacent to the diaphragm wall, since Y-14 is located closer to the steel sheet pile than Y-16. However, below the depth of 9.1 m, the displacement patterns of Y-14 and Y-16 were relatively similar.

A comparison of the displacement of Y-14 and Y-15 shows that the displacement of Y-14 was smaller below the depth of 9.1 m and above this depth there was a greater increase. On the contrary, the displacement distribution of Y-15 converged approximately to a straight-line without any large changes. Also, the difference in the displacements at the head of Y-14 and Y-15 walls was small.

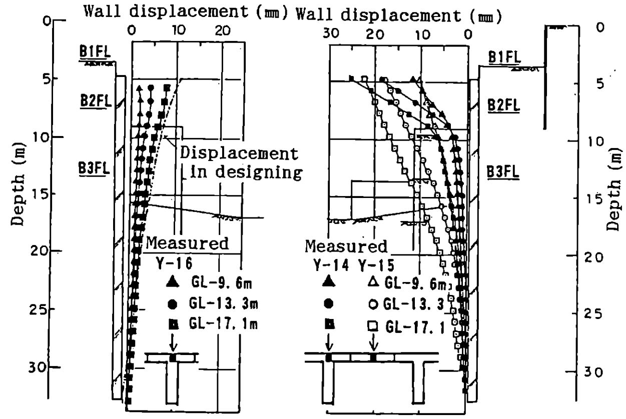


Fig.4 Distribution of Measured Wall Displacement

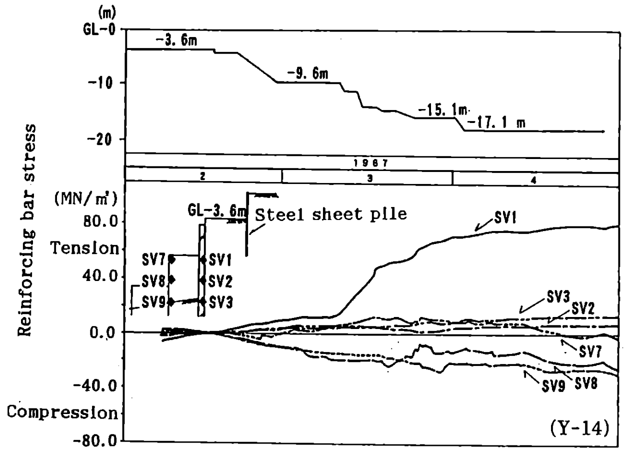


Fig.5 Development of Vertical Reinforcing Bar Stress

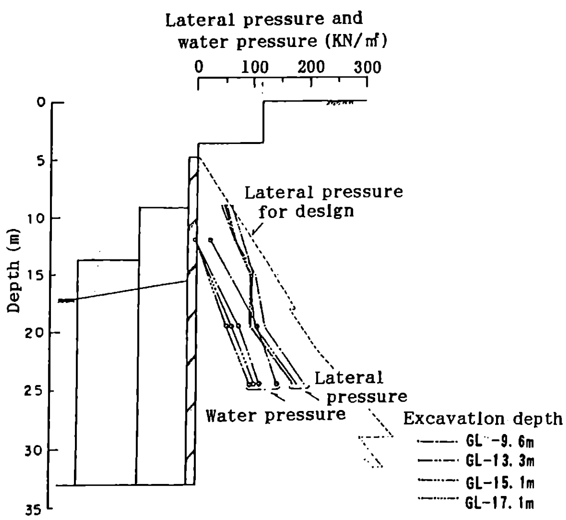


Fig.3 Distribution of Measured Lateral Pressure

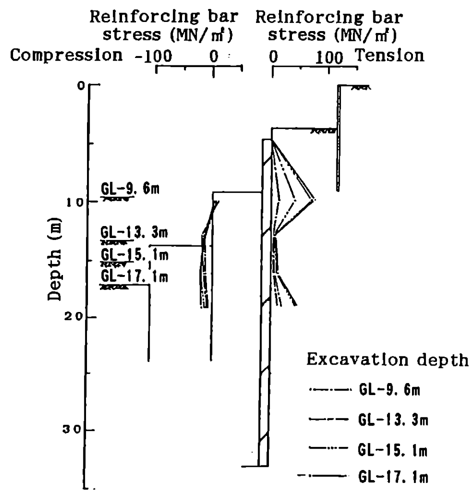


Fig.6 Distribution of Measured Vertical Reinforcing Bar Stress

The changes over time in the vertical reinforcing bar stress in Y-14 and its distribution are shown in Figs. 5 and 6, respectively. Tensile stresses were seen at SV-1,2,3 on the retained side; especially, at SV-1 at a depth of 9.85 m, below which T-shaped walls were used. A large stress was, also, observed during excavation at the depth of 9.6 m. Based on these it can be concluded that a crack developed in the concrete at the tensile side. The reinforcing bar stress of the T-shaped wall on the compressive side were noticeably large.

Fig.7 shows the changes over time in the lateral reinforcing bar stress on the T-shaped (Y-14) and flat (Y-15) diaphragm walls. Fig.8 shows their distribution at each stage of excavation. The T-shaped wall and flat wall showed an opposite behavior regarding compression and tension of the reinforcing bars. The effect of lateral stress transfer can be surmised from this behavior. This indicates that the flat diaphragm walls showed a behavior like a lagging between T-shaped walls against the lateral pressure on the retained side.

4. EVALUATION OF T-SHAPED DIAPHRAGM WALLS

In order to analyze the behavior of T-shaped diaphragm walls, an evaluation of the effective width is important in calculating the flexural properties. Considering the moment of inertia (I) of T-shaped walls to be approximately twice as big as that of buttress walls, the effective width of T-shaped walls is assumed to be B = 5.0 m while that of flat walls is assumed to be B = 9.6 m.

Fig.9 shows the relationship between flexural rigidity (EI) and resisting moment (M) of flat and T-shaped walls. For both walls the flexural rigidity (EI) decreases sharply and the bending capacity reaches its peak just before the formation of tension cracks in the concrete. This behavior is found to be more remarkable in T-shaped walls. Amount of EI and M of T-shaped walls are found to be quite different from those of flat walls.

The displacement of the earth retaining walls were calculated using the model of an elasto- plastic beam on spring, AIJ(1988). Passive lateral pressure on the excavated ground was taken as equal to the soil pressure down to the depth of 17.1 m. Below the depth of 17.1 m, the foundation walls were located perpendicular to the earth retaining walls. The compressive rigidity of the concrete was evaluated by Eq.(1); and Eq.(2) was used to evaluate its flexural rigidity.

$$\overline{Kc}=Ec/Lc\cdot Bc/Bo+Ks\cdot(Bo-Bc)/Bo \qquad (1)$$

$$\overline{EI}=EI(B)/Bo \qquad (2)$$

where,

Bc : width of diaphragm walls crossing perpendicularly (m^2),
Ec : Young's modulus of the concrete (N/m^2),
Lc : efficient length (0.5 × excavated width) (m)
Bo : distance between T-shaped diaphragm walls (9.6m) (m)
Ks : coefficient of subgrade reaction of the ground
$\overline{Kc}$: equivalent coefficient of subgrade reaction (N/m^3)
EI(B) : EI of efficient width (B) ($N\cdot m^2$)
$\overline{EI}$: equivalent EI ($N\cdot m^2/m$)

Fig. 4 shows the calculated values and they agree rather well with the measured values of Y-16. However, the measured values of Y-14 showed a larger curvature at the depth of buttress wall head. The difference between the calculated and measured values may be the result of tension cracks in the concrete on the tensile side.

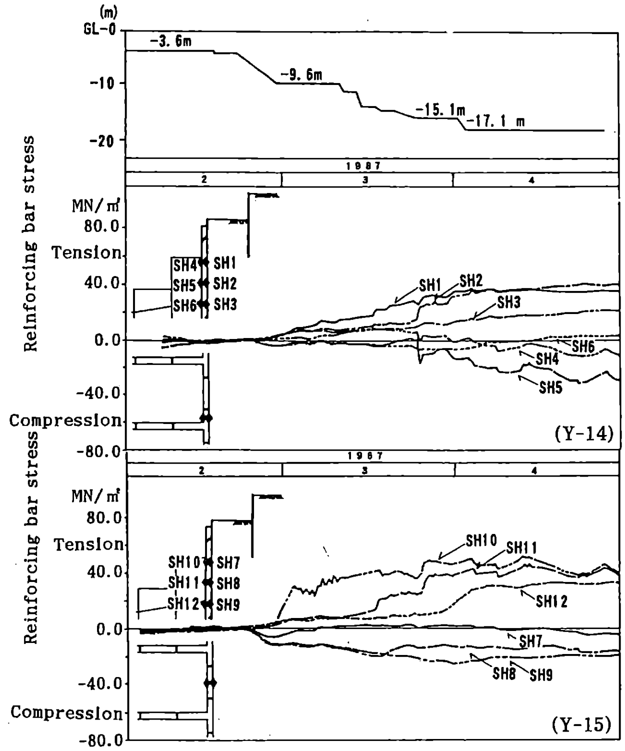


Fig.7 Development of Horizontal Reinforcing Bar Stress

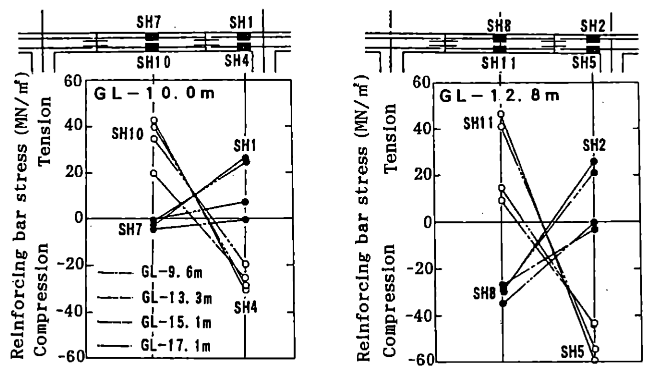
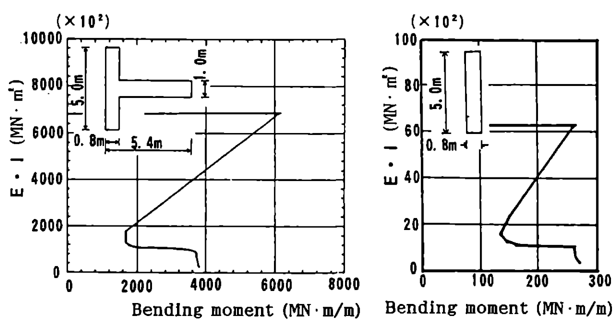


Fig.8 Distribution of Measured Horizontal Bar Stress



Concrete strength : Fc=30MN/m²
Tensile strength=0.15Fc
Reinforcing bar strength : ft=fc=300MN/m²
(Deformed bar dia., D29 @200)

Fig.9 Relationship Between Bending Moment and Flexural Rigidity

In the case of cantilever type earth retaining walls, the bending moment above the excavation bottom is determined by the lateral pressure from ground surface to the given depth. The lateral pressure is assumed to have a trapezoidal distribution and its gradient is taken to be the same as the value used in the design. The top of the lateral pressure was estimated from the bending moment which produced the tension crack on the flat walls, shown in Fig. 9. The estimated lateral pressure, shown in Fig. 10 (a) was about 1.2 times as large as the value used in the design. The result shows that the lateral pressure of the flat walls worked as a lagging on the flat walls upper of the T-shaped walls, thereby increasing the equivalent lateral pressure.

The measured lateral pressure did not increase as much but the displacement at the head of Y-14 wall showed an increase at each stage of excavation (see Figs. 3 and 4). The lateral load was most likely transferred horizontally through the flat walls upper of the T-shaped walls. As a result, the rate of load transfer increased as excavation proceeded. The measured displacement at each excavation stage and the analytical values calculated with various concrete rigidities are compared in Fig. 10(b). The calculated values with EI_2 disagree with the measured displacement but by decreasing the equivalent rigidity in accordance with excavation, a better match can be obtained.

Fig.11 shows the relationship between the excavated depth at each excavation stage and the equivalent rigidity of the flat walls. The values on the vertical axis denote the dimensionless equivalent rigidity ratio, EI2(B)/EI2(Bo). This shows a decrease in its effective width of flat wall. Most likely the flat wall between flat walls upper of T-shaped wall behave like a lagging becoming stronger as excavation proceeds.

5. CONCLUDING REMARKS

The behavior of the cantilever type earth retaining walls as based on the results obtained from in-situ measurement of a T-shaped diaphragm walls, are summarized below.

1) T-shaped diaphragm walls have a large flexural rigidity and its use makes it possible to excavate to a depth of 17.1 m without supporting braces even in very soft ground.

2) The equivalent flexural rigidity and equivalent bending capacity should be evaluated using an effective width for T-shaped walls and for flat walls upper of T-shaped walls.

ACKNOWLEDGMENT

The authors are very grateful to Mr. Yuko Ikuta, Takenaka Corporation, for his valuable suggestions.

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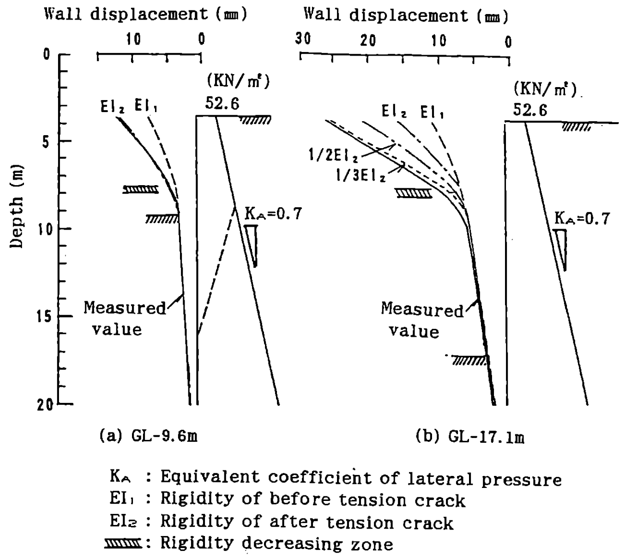

Fig.10 Comparison Between Calculated and Measured Values of Wall Displacement

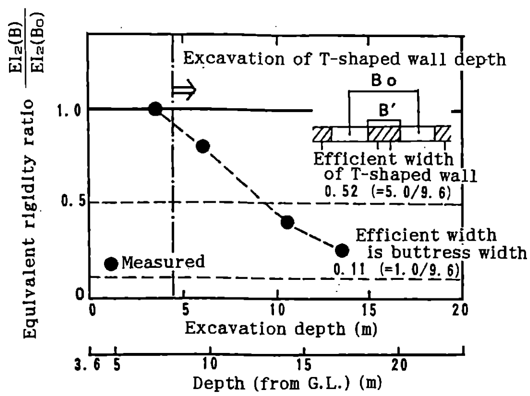

Fig.11 Relationship Between Excavation Depth and Equivalent Rigidity

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