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

Long-term field measurement of earth pressures acting on braced walls

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SYNOPSIS: This paper reports field measurements of lateral earth pressures acting on braced walls. The measurements have been observed for 10 years (4 years during excavation and 6 years after completion). The lateral earth pressures were decreased considerably during construction as a result of wall deformation, and gradually recovered after completion with cyclic seasonal pressure changes.

1. INTRODUCTION

The dimensions of the underground structure (an underground transformer substation) are approximately 45m×80m, and at a depth of 36.6m below ground level (Figs. 1,2,3). Reinforced concrete diaphragm walls having a thickness of 1m were constructed prior to excavation, and the structure was constructed using the "Sakauchi Method".

Earth and water pressure sensors were installed on the diaphragm walls (Fig.2). The measurements were utilized as a part of observational procedures during construction, and the observed earth and water pressures after completion are a contribution to the design of walls in deep ground (Table 1).

In Japan, many data concerning the earth pressure on a diaphragm wall during construction are

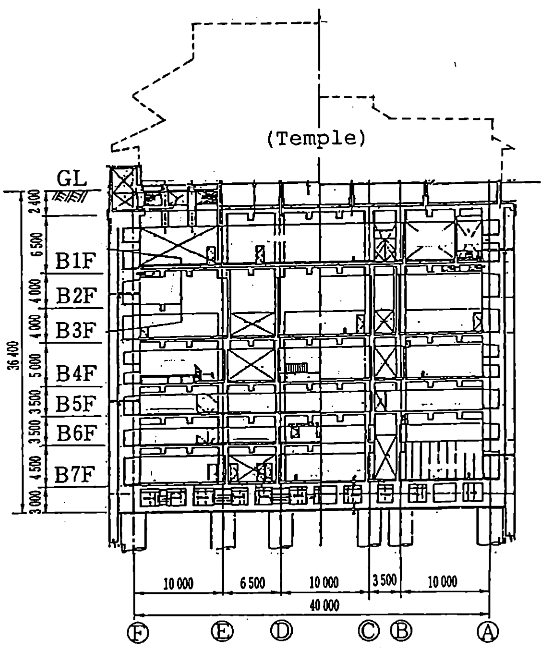

Figure 1. Section of structure (1-1)

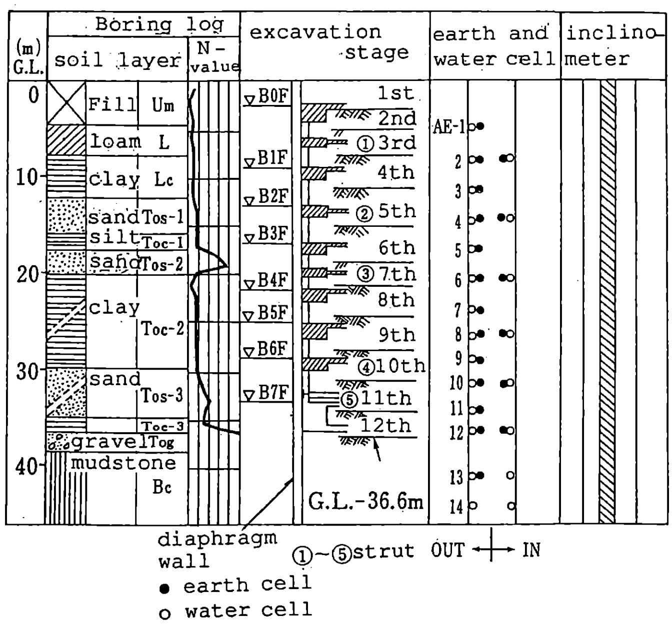

Figure 2. Ground condition, excavation stage and sensor arrangement

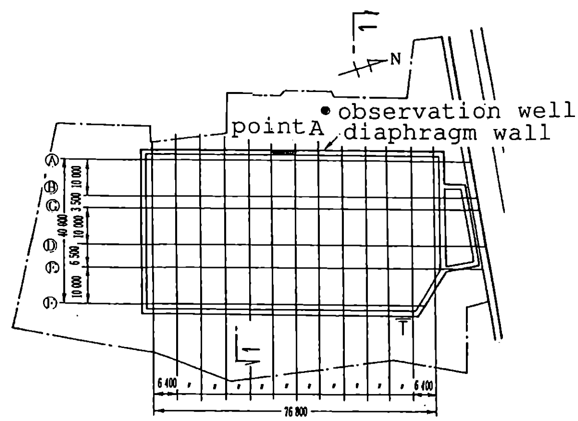

Figure 3. Plan and measurement point

Table 1. Schedule of construction and measurement

Schedule \ Year	'83	'84	'85	'86	'87	'88	'89	'90	'92
Diaphragm wall	—								
Cast-in-place pile		—							
Excavation		—	—	—					
Concrete		—	—	—	----	----	--		
Monitoring	—	—	—	—					
Long-term measurement					—	—	—	—	—

already available, and the coefficient of lateral pressure for several soil types are proposed in some design manuals. However there are only few measured data of the earth pressure at rest acting on a retaining wall. In this paper, the Authors study the earth pressure at rest based on the results of long-term measurements.

2. GROUND CONDITIONS AND OUTLINE OF MEASUREMENT WORKS

2.1 Ground conditions

The construction site is located at the edge of a plateau, 27.7m above sea level, and 6km south-south·west from Tokyo Station. The ground consists of diluvial deposits. Upper layers consist of loam (L) and clay (Lc), and lower layers consist of sand (Tos) and clay (Toc). At excavation level there is a gravel layer, and mudstone (Bc) exists below foundation level (Fig.2).

2.2 Outline of measurement works

Monitoring of earth retaining walls is carried out for the purpose of construction safety management, using earth and water pressure cells, reinforcing bar stress transducers and inclinometers. Usually, the monitoring starts at the time of construction of diaphragm walls and ends when the underground structure is completed. However in this case, measurements were continued after completion for the purpose of earth pressure observation. The sensors were carefully selected for long-term field measurements. Pressure cells are differential transformers of the second diaphragm type (Table 2). Special mold cables were used for waterproofing. Earth and water pressure cells were installed using a hydraulic jack when the diaphragm wall was constructed. It was judged that the cells were properly installed from the results of measurements in slurry and those at the time of concrete placing.
An automatic measuring system with a personal computer was adopted, and measured data were checked carefully everyday. The measurements were carried out twice a day during excavation, and once a day after completion.

3. LATERAL PRESSURE

The variations of lateral earth pressures on the outside of the retaing wall at point A from October 1983 to December 1992 are shown in Figs. 4 and 5. AE-1 is an earth pressure cell installed

Table 2. Specification of sensors

Pressure cell	PD-150 made of stainless steel
	measurement range 200~600kN/m^2 nonlinearity F.S±0.5%
Water cell	PD-150P made of stainless steel
	measurement range 200~600kN/m^2 nonlinearity F.S±0.5%

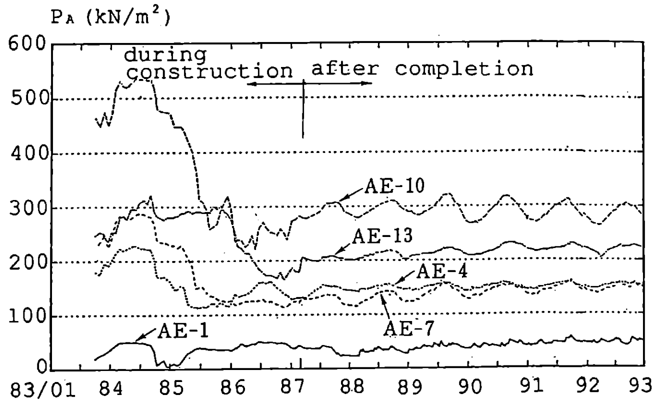

Figure 4. Variation of lateral earth pressure (P_A)

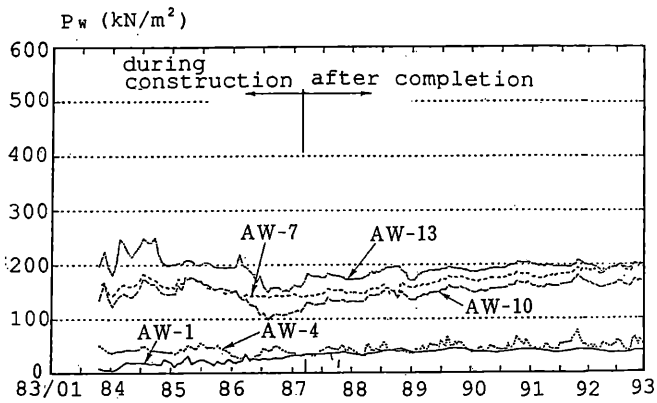

Figure 5. Variation of water pressure (P_W)

at a depth of 4.9m in the loam layer. AE-4 is at 14.5m in the sand layer (Tos-1), AE-7 is at 24.1m in the clay layer (Toc-2), AE-10 is at 31.6m in the sand layer (Tos-3), AE-13 is at 41m in the mudstone layer (Bc). The cells AE-4, AE-10,AE-13 are in permeable layers. The lateral pressures at each construction stage shown in Fig.4 changed as follows.

1. The pressures increased when the construction of cast-in-place piles started, and became stable except for AE-13.
2. The lateral pressures reduced during excavation as a result of wall deformation (Fig.6). Some had become stable before excavation finished. The remainder continued reducing until

excavation finished.

3 The lateral earth pressures gradually increased after completion with cyclic seasonal changes. In particular AE-10 changed within a larger range than the others.

Regarding the variation of water pressure, Fig. 5 shows that the water pressures change according to the lateral earth pressures at each stage. The range of variation of the water pressures is less than that of the lateral earth pressures, but the changes are in the same sense. The variation of earth pressures is shown in Fig. 7. The earth pressure is calculated using the following formula ;

$$P_A = P_E + P_W$$

where

P_A: lateral earth pressure (kN/m²)

P_E: earth pressure (kN/m²)

P_W: water pressure (kN/m²)

P_A and P_W are measured values.

From Figs.4,5,7:

•The lateral earth pressure at AE-1 in the loam layer decreased to zero at the time of excavation,and after completion most of the decrease was recovered by the water pressure.

•The lateral earth pressure at AE-4 in the Tos-1 layer decreased to the same extent as the earth pressure at the time of excavation. The water pressure corresponded to the water level of an observational well shown in Fig.3. Water pressure had a tendency to increase slightly after conpletion.

•The lateral earth pressure at AE-7 in the Toc-2 layer decreased at the time of excavation. After completion, the water pressure had a tendency to increase, and the lateral earth pressure had the same tendency, but the earth pressure decreased.

•The lateral earth pressure at AE-10 in the Tos-3 layer decreased considerably at the time of excavation. After completion, the water pressure increased sligtly, the lateral earth pressure remained constant, and the earth pressure decreased slightly. The lateral earth pressure and the earth pressure showed seasonal change, but the water pressure changed little.

•The earth pressure cell AE-13 in the mudstone layer is installed below excavation level. The lateral earth pressure decreased at the time of excavation. Following excavation the water pressure and the lateral earth pressure increased, but the earth pressure remained constant.

The following can be concluded from Figs. 4,5,7.

1. All the lateral earth pressures have a tendency to reduce during excavation. Most of the reduction is due to the earth pressures, and the water pressures change little.
2. The ground water of each layer is independent and has an independent ground water pressure.
3. All the water pressures gradually increase after completion. This increase is about equal to the increase of lateral earth pressures.
4. Earth pressures at AE-4,7,10,13 change seasonally . The maximum range is 50kN/m² at AE-10. The principal pressure that contribute to the seasonal change is the earth pressure.

4. DISCUSSION

4.1 Relationship between lateral earth pressure and deformation of braced wall during construction .

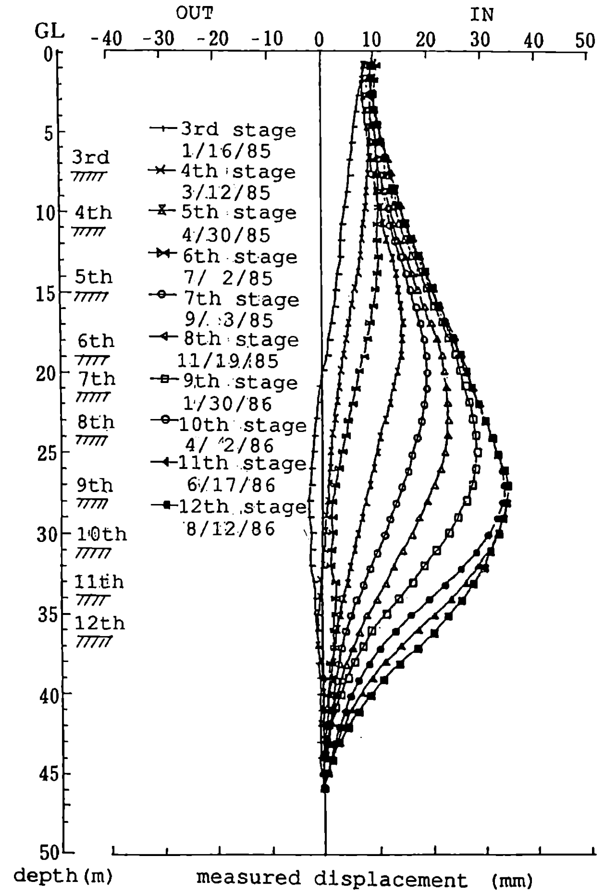

Figure 6. Deformation of braced wall at each excavation stage (point A)

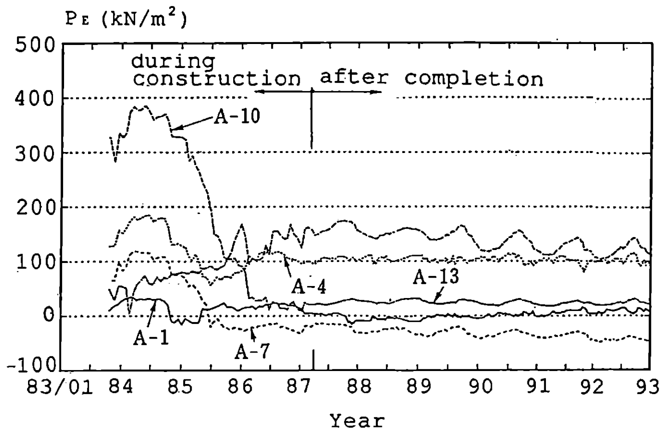

Figure 7. Variation of earth pressure (P_E)

The measured values were compared with computed values by the finite element method. Soil properties for the analysis are shown in Table 3. Forced deformation corresponding to the measured displacements of the braced wall at each excavation stage (Fig.6) were used in the analysis to obtain the lateral earth pressures.

Table 3. Soil properties

Soil		γ (kN/m³)	Cu (kN/m²)	E (kN/m²)	ν*	φ (°)
Um	Fill	14.5	40	10,000	0.49	5
L	loam	14.5	50	10,000	0.40	10
Lc	clay	14.5	50	10,000	0.49	5
Tos-1	sand	18.0	10	20,000	0.33	25
Toc-1	clay	17.0	100	20,000	0.49	5
Tos-2	sand	18.0	10	30,000	0.33	35
Toc-2	clay	17.5	100	20,000	0.35	5
Tos-3	sand	19.5	100	30,000	0.33	5
Toc-3	clay	19.0	120	25,000	0.49	5
Tog	gravel	20.0	0	140,000	0.33	45
Bc	mudstone	19.0	130	140,000	0.33	15

* Assumed value

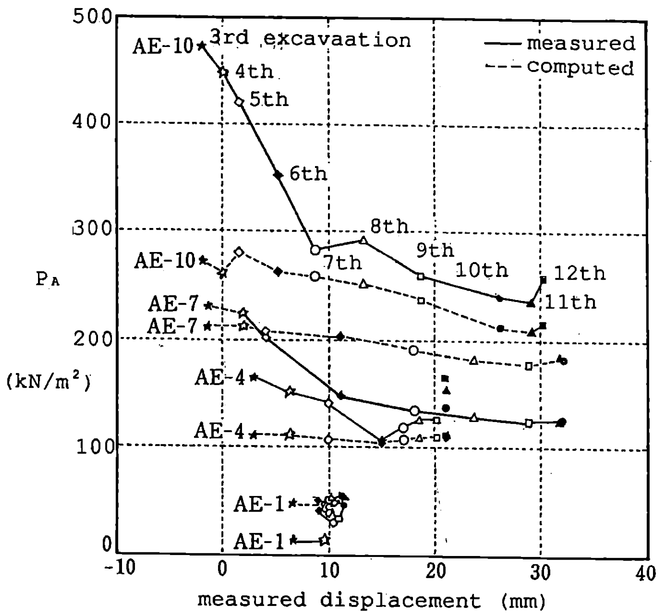

Figure 8. Relationship between the lateral earth pressure and defomation of braced wall during construction

The results of the analysis agree well with the measured values. It is clarified that the reduction of lateral earth pressure corresponds with braced wall deformation (Fig.8).

4.2 Lateral earth pressure after completion

As shown in Fig. 4, lateral earth pressures after completion have a tendency to gradually increase due to the increase of water pressures. It is expected that the lateral earth pressures will correspond to the water pressures in the future. If the final measured lateral earth pressures are compared with design lateral earth pressures for deep underground structures, they are almost equal at AE-1,4, and the measured pressures are a little less than the design pressures at AE-7,10 (Fig.9). Therefore the design lateral earth

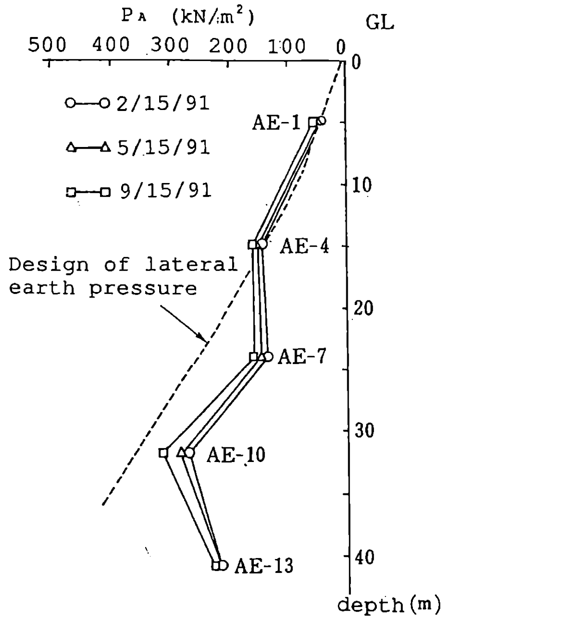

Figure 9. Lateral earth pressure (P_A) after completion

pressures are shown to be appropriate for long-term conditions. The seasonal change of the lateral earth pressures seems due to expansion and shrinkage of reinforced concrete caused by the seasonal temperature change. However, the reason is not totally clear.

5. CONCLUSIONS

The lateral earth pressures acting on the outside of braced walls were observed over 10 years. The results are summarized as follows :

1. The lateral earth pressures acting on braced walls decrease considerably during construction as a result of wall deformation. Most of the decrease is due to that of earth pressures. Water pressures change little.
2. The lateral earth pressures after completion have a tendency to increase due to the increase of water pressures, and reach a balanced state. They change seasonally, but the reason for this is not clear.
3. The temporal and long-term design lateral earth pressures for braced walls are found to be appropriate for a large underground construction
4. The sensors and the automatic-measuring system used in this study were proved to be effective for long-term filed measurement with maintenance and support.

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