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Long-term measurements of lateral pressures acting on braced walls in soft clay

S.Fukui
Japan Sewage Works Agency, Tokyo, Japan

T.Tamano & H.Suzuki
The City of Osaka, Japan

SYNOPSIS: The mechanical behavior of earth and water pressures acting on braced walls in soft clay grounds, which must be determined more exactly than other factors in designing the excavation work, is more complex than the behavior of these pressures under other conditions, since the pressures change as coupled phenomena. In this paper, the mechanical behavior of earth and water pressures in soft clay layer is discussed in detail based on longterm measurements.

1 INTRODUCTION

The earth and water pressures acting on braced walls have been collectively evaluated as the lateral pressure, or the sum of earth and water pressures, because it is difficult to evaluate these values separately, except on a sandy ground with a high degree of permeability. However, setting the design external force at this summed-up lateral pressure is not based on correct understanding of the earth and water pressure characteristics, and may lead to a significant error. Especially, the mechanical behavior of earth and water pressures in soft clay grounds, which must be determined more exactly than other factors in designing the excavation work, is more complex than the behavior of these pressures under other conditions, since the pressures change as coupled phenomena. Therefore, measurement cases at which the behavior is accurately measured are rare.

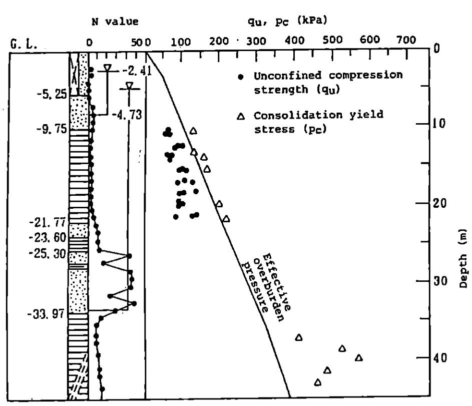

Fig. 1 Ground Condition

This paper discusses the problem involved in the excavation work using the diaphragm wall in the soft ground, which consists mostly of soft clay layer. In particular, the mechanical behavior of earth and water pressures in the soft clay ground is discussed in detail based on the longterm measurements.

2 MEASUREMENT CASE

The measurement case described in this paper concerns the construction work for a large-scale sewage pumping station (85.5 m long, 61.8 m wide, 20.8 m deep) in the coastal area of Osaka. Fig. 1 shows the ground condition and Fig. 2 shows the braced wall section.

The clay layer, located between G.L. -9.8 m and -21.8 m, comprises normally consolidated clay with the natural water content 40 ~ 50%, the liquid limit of 50 ~ 70%, the plastic limit of 20 ~ 27%, and the unconfined compression strength 58 ~ 146 kPa. The diaphragm wall with wall thickness of 1.0 m and depth of 38.25 m was used as braced wall.

The reversed construction method was used in installing beams and floors in the first to fourth stages of excavation (G.L. -12.25 m), employing high rigidity SRC (Steel Reinforced Concretes) beams, whereas the ground anchor method was used in the fifth to seventh (final) stages of excavation (G.L. -20.8 m).
Accordingly, it is probable that the behaviors of earth and water pressures acting on the braced wall in the first to fourth stages of excavation were different from those in the fifth to seventh stages of excavation. In the following, the behaviors in the two periods are discussed separately.

3 EARTH AND WATER PRESSURES UNTIL IMMEDIATELY BEFORE EXCAVATION

Fig. 3 shows the change of water and lateral

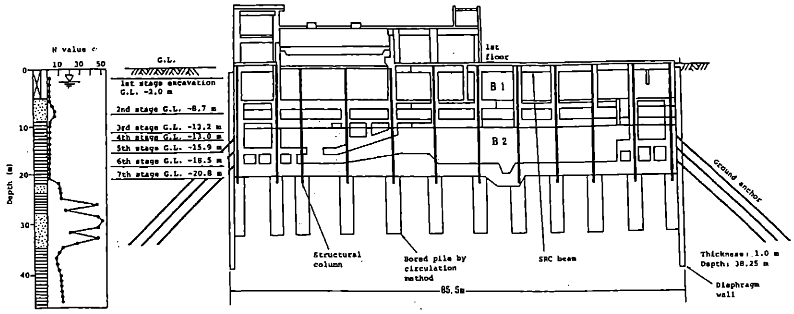

Fig. 2 Braced Wall Section

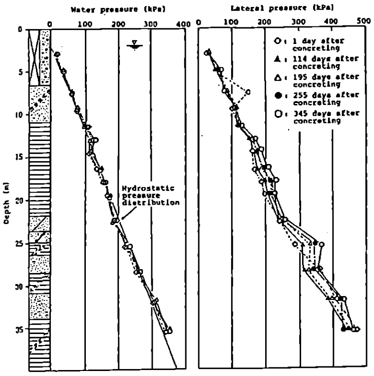

Fig. 3 Water and Lateral Pressures Measured at the Time Immediately Before Excavation (Measured at Point 1 on the back side)

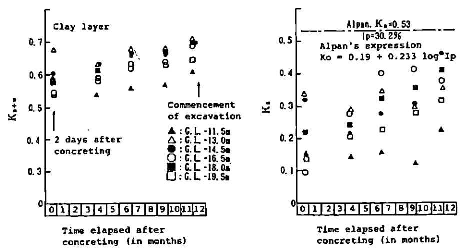

Fig. 4 Time-Related Change of Coefficient of Lateral Pressure Ks+w and Coefficient of Earth Pressure Ks up to Immediately Before Excavation (Measured at Point 1 on the back side)

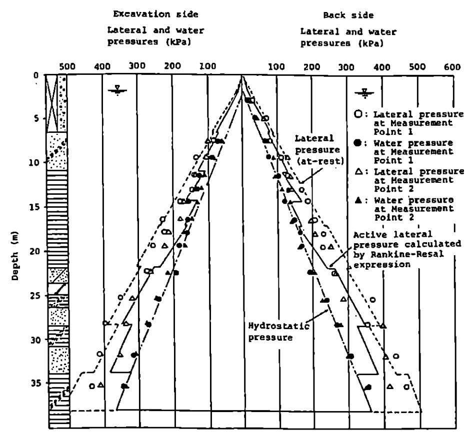

Fig. 5 Lateral and Water Pressure Distributions Immediately Before Excavation

pressures for a period of approximately 12 months, starting from 52 hours after the concreting of the slurry trench and ending immediately before excavation.

The earth pressure cell was calibrated by using clay actually taken from the clay layer.

As shown in Fig. 3 the change in water pressure during this period was minimal, with hydrostatic pressure distribution at the beginning of the period roughly corresponding with that at the time immediately before excavation.

Fig. 4 shows the time-related changes of the coefficient of lateral pressure K_{s+w} (= $\sigma h/\sigma v$) and the coefficient of earth pressure K_s (= $\sigma h'/\sigma v'$) starting from the concreting of the slurry trench and ending immediately before excavation.

As stated above, "earth pressure" refers to the earth pressure against the wall, or horizontal earth pressure, which is calculated by subtracting the water pressure measured by a water pressure cell from the lateral pressure measured by an earth pressure cell.

As shown in Fig. 4, both K_{s+w} and K_s in the clay layer showed a linear increase until the time immediately before excavation; however, the earth pressure did not return, to the at rest condition (Jaky, 1948, Alpan, 1967) by this time.

As shown in Fig. 5, measured water pressures on the back side roughly corresponded to the hydrostatic pressure distribution. The water pressure corresponded to 70 to 80% of the lateral pressure. This indicates that the change in water pressure at excavation greatly affected the lateral pressure at rest. The measured lateral pressure was between the active lateral pressure and the lateral pressure at rest. This indicates that the earth pressure, which became active state at slurry trench excavation, did not return to the at rest condition 12 months after construction of the diaphragm wall was completed (Tamano, et al., 1984).

4 EARTH AND WATER PRESSURES ON THE BACK SIDE

(1) First to fourth stages of excavation

Fig. 6 shows earth, water and lateral pressures in the period starting immediately before excavation and ending in the fourth stage of excavation, and Fig. 7 shows the deformation of the wall.

In the sand layer and the gravel layer, the earth pressure on the back side decreased with the progress of excavation. Due to the wall displacement, the earth pressure entered an active phase. However, the earth pressure increased in the clay layer.

Fig. 8 shows the relationship between wall displacement and earth pressure in the clay layer (Fukui, et al., 1991). The earth pressure decreased in the first stage and lasted up to the second stage of excavation, during which the wall displacement ranged from 15 mm to 30 mm. The earth pressure began to increase as displacement further increased, eventually reaching a level higher than that prior to excavation.

The water pressure distribution in the upper layer, the loose silty sand layer, roughly corresponded with the hydrostatic pressure distribution. In the clay layer, the water pressure which corresponded with the hydrostatic pressure before excavation, gradually decreased as excavation progressed with a maximum decrement of 90 kPa at the completion of the fourth stage of excavation.

Fig. 9 shows the relationship between wall displacement and water pressure in the clay layer. The water pressure decreased with the increase in wall displacement. In particular, wall displacement and water pressure changed in linear proportion to each other.

(2) Fifth to seventh stages of excavation

Fig. 10 shows the distributions of earth, water and lateral pressures. The wall displacement in the fifth to seventh stages of excavation was smaller than that in the first to fourth stages of excavation, indicating the effect of the preloading of ground anchors. The water pressure decreased in the fifth and sixth stages of excavation in the sand layer and the gravel layer, which were artesian aquifers. This decrease was due to holing for the installation of ground anchors in these stages. At the final stage of excavation, by which the installation of ground anchors had been completed, the hydrostatic pressure distribution before excavation recurred due to the recurrence of the artesian aquifer in the layers. In the clay layer, the water pressure increased due to the pressure of water originating from holding for the installation of ground anchors, and water confined in the sand layer and the gravel layer.

The earth pressure showed a complex behavior, alternately increasing due to the preloading of ground anchors and decreasing due to the wall displacement. The lateral pressure, like the water pressure, increased due to the increase of the water pressure.

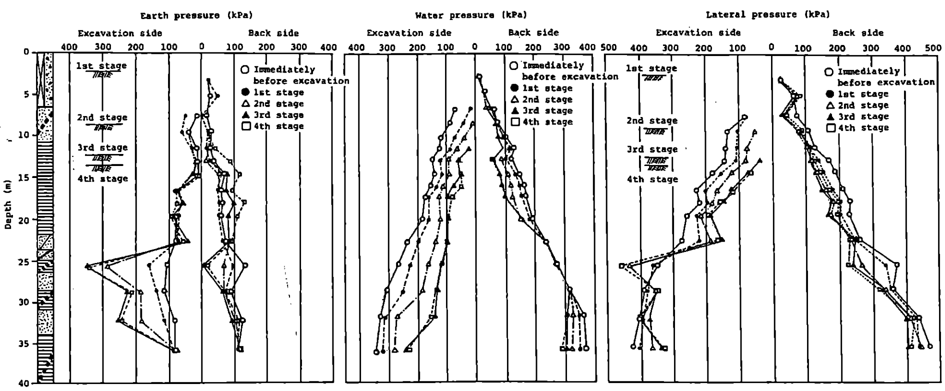

Fig. 6 Distribution of Earth, Water and Lateral Pressures (Measured at Point 1, 1st to 4th Stage of Excavation)

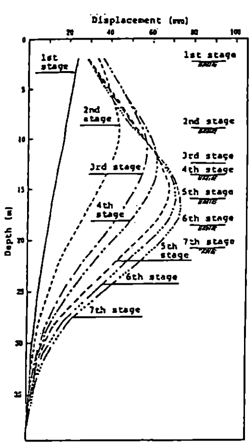

Fig. 7 Deformation of Braced Wall

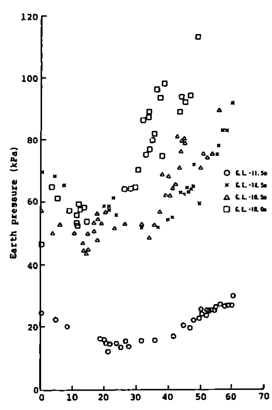

Fig. 8 Wall Displacement vs. Earth Pressure (Measured at Point 1)

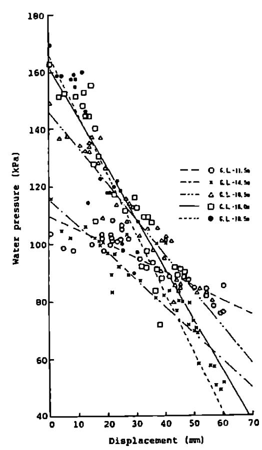

Fig. 9 Wall Displacement vs. Water Pressure (Measured at Point 1)

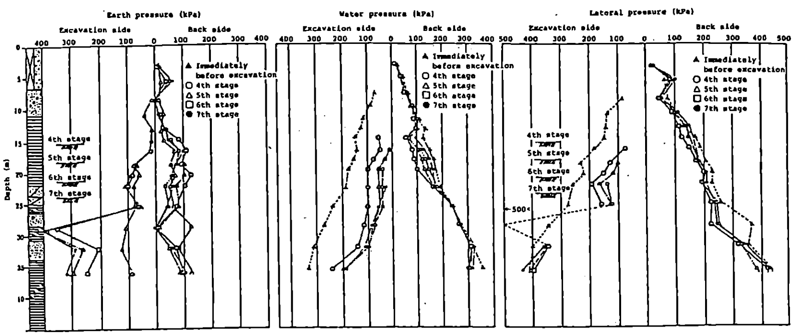

Fig. 10 Earth, Water and Lateral Pressure Distributions (Measured at Point 1, 1st to 4th stages of excavation)

5 EARTH AND WATER PRESSURES ON THE EXCAVATION SIDE

Figs. 6 and 10 show the distributions of earth, water and lateral pressures on the excavation side.

In the clay layer, the earth pressure scarcely changed despite the decrease in effective over-burden-pressure due to excavation; this is attributed to the effect of the passive resistance. In the gravel layer, the passive resistance became perceptible in the first to second stages of excavation, and sharply increased in the subsequent stages as excavation progressed and as wall displacement increased. Since the clay layer was soft and the braced wall was rigid, the wall was deformed to a considerable depth at the early stage of excavation, with the gravel layer working as the support.

Fig. 11 shows the relationship between the water, earth and lateral pressures and the wall displacement on the excavation side at the time immediately before excavation and forth stage of excavation.

In the sand layer and the gravel layer, the water pressure decreased in proportion to water level, which decreased due to deep well operation. In the clay layer, however, the water pressure did not decrease immediately after water level lowered; consequently, the pore water pressure remained at a high value even after the lowering of the water level. The slow rate of decrease of the pore water pressure together with the excess hydrostatic pressure due to the wall displacement contributed greatly to the occurrence of the passive resistance. And in the gravel layer, the water pressure roughly corresponds to the hydrostatic pressure distribution.

In the gravel layer, though the wall displacement was small as below 20 mm, the large passive resistance occurred, while in the clay layer, in spite of the wall displacement 40 to 60 mm, the passive resistance was small, and did not exactly correspond with the lateral pressure determined by the Rankine-Resal expression.

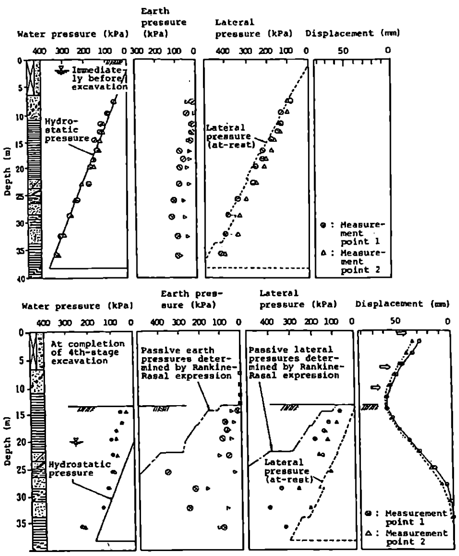

Fig. 11 Earth, Water and Lateral Pressures and Wall Displacement on the Excavation Side

6 CONCLUSIONS

The conclusions obtained from this paper are summarized as follows:

① The earth pressure on the back side in the clay layer, which becomes active state at slurry trench excavation, does not return to the at rest condition 12 months after construction of the diaphragm wall was completed.

② The wall displacement causes the water pressure on the back side in the clay layer to decrease. The quantity of decrease and wall displacement show a linear proportional relation.

③ The earth pressure on the back side in the clay layer first drops to the active earth pressure due to the wall displacement up to 15 to 30 mm. After the range is exceeded, the earth pressure increases with the wall displacement.

④ The lateral pressure on the excavation side in the clay layer is still small in the case of wall displacement 40 to 60 mm and does not achieve the passive earth pressure determined by the Rankine-Resal expression.

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