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Evaluation of lateral pressure on braced walls in diluvial sandy soil

E. Sato, M. Aoki & M. Maruoka
Research & Development Institute, Takenaka Corporation, Tokyo, Japan

SYNOPSIS: This paper describes the characteristics of the lateral pressure on the earth retaining walls in diluvial sandy soil (i.e. sandy soil deposited in Pleistocene) and the evaluation method of the lateral pressure, based on the laboratory test results on the undisturbed specimens and the field measurement results of lateral pressure and pore water pressure. The lateral pressure in diluvial sandy soil could be evaluated by the Rankine-Resal's equation, which takes into account the real cohesion due to the binding effect of fine fraction between sand particles.

1 INTRODUCTION

It is necessary to evaluate the resultant of earth pressure and pore water pressure on earth retaining walls for earth retaining structure design (In this paper the resultant is called "lateral pressure"). In sandy soil the proportion of pore water pressure to lateral pressure on walls is large. And as the density of soil increases, the earth pressure decreases to the point where pore water pressure nearly equals lateral pressure. And the many instances, in which the measured lateral pressure was less than the pressure derived from the Rankine-Resal's equation on assumption of c=0, were observed in lots of excavation works. This phenomenon is especially noticeable in diluvial deposits.

This paper describes the properties of lateral pressure and the the evaluation method taking into account cohesion of diluvial sand, based on the laboratory test results on the undisturbed specimens and field measurements of lateral pressure and pore water pressure.

The sandy soils which have fine fraction content (i.e., the ratio of particles finer than 75μm by weight) of 20% or less, are investigated in this paper.

2 PROPERTIES OF LATERAL PRESSURE IN DILUVIAL SANDY SOIL

The lateral pressure is affected by such factors as the type of earth retaining wall and the excavation method. The earth retaining walls investigated in this paper were limited to the reinforced concrete diaphragm walls. In addition, the values of the lateral pressure and the pore water pressure measured with earth pressure cells and pore water pressure cells were utilized. Table 1 and 2 provide outline of the excavation works and the ground conditions of the constructions.

An example of the lateral pressure measured in site A is shown in Fig.1. In this site, layers below the depth of 4.0m are diluvial soils. The lateral pressures measured at the depth of 12.3m and 17.3m were less than the value derived from the Rankine-Resal's equation (Eq.(1)) for c=0. It can be seen that the lateral pressure was mostly comprised of pore water pressure, i.e. the earth pressure was small.

$$Pa=\sigma z' \cdot \tan^2(45° - \frac{\phi}{2}) - 2C \cdot \tan(45° - \frac{\phi}{2}) + Pw \qquad (1)$$

where, Pa=lateral pressure, σ z'=effective overburden pressure. Pw=pore water pressure, ϕ =internal friction

Table 1 Construction sites and excavation works

Construction site	Excavation: area (m²)	depth (m)	wall *1	timbering *2
Site A (Tokyo)	4, 172	16. 9	RC-800	S-4
Site B (Tokyo)	5, 000	20. 3	RC-800	RC-3
Site C (Nagoya)	1, 330	25. 5	RC-900	RC-3 & S-1
Site D (Osaka)	5, 315	18. 7	RC-700	RC-6
Site E (Osaka)	10, 000	22. 0	RC-700	RC-4 & S-2
Site F (Osaka)	5, 000	33. 2	RC-1200	RC-3 & anchor-4
Site G (Osaka)	7, 200	26. 8	RC-800	RC-6
Site H (Okayama)	760	13. 3	RC-600	RC-6
Site I (Fukuoka)	4, 100	17. 3	RC-600	RC-4
Site J (Tokyo)*3	3, 000	31. 9	RC-1200	S-7 & RC-5
Site K (Tokyo)*3	5, 700	29. 6	RC-1000	RC-2 & S-6
Site L (Tokyo)*3	700	14. 1	RC-600	S-4

*1 "RC-800" stands for "Reinforced Concrete diaphragm wall of 800 mm in thickness
*2 "S-4" stands for "Steel struts of 4 levels
*3 Measured date from references

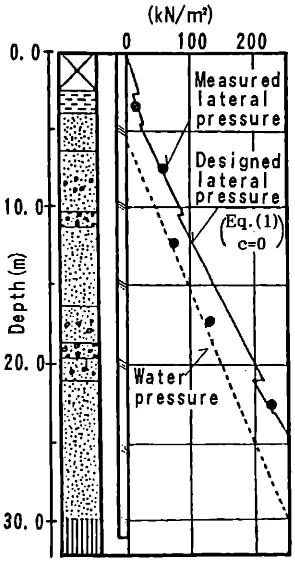


Fig. 1 Example of active lateral pressure

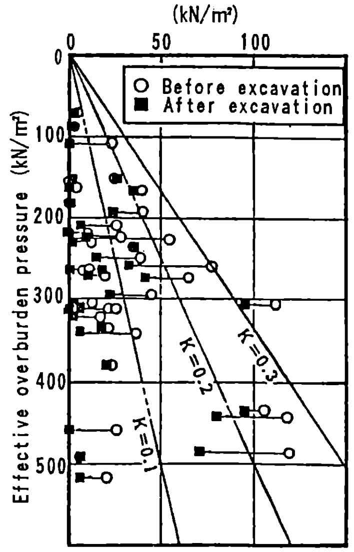
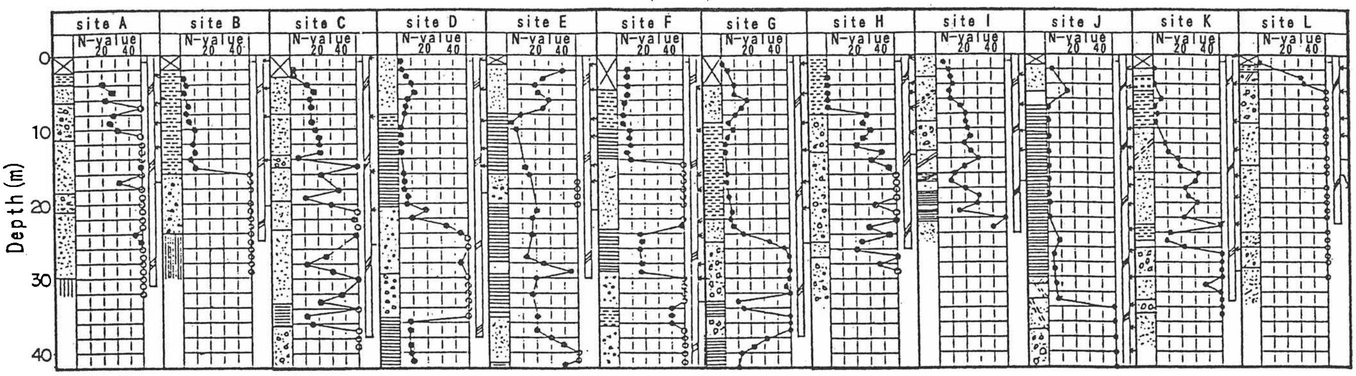


Fig. 2 Earth pressure and effective overburden pressure

Table 2 Ground conditions and excavation works at the investigated sites



angle, and C=cohesion. And Pa, σ z', Pw and C are in kN/m²

The relationship between the earth pressure of the diluvial sandy soil (derived from the lateral pressure and pore water pressure measured before and after excavation), and the effective overburden pressure, is shown in Fig.2. The value of the coefficient of the earth pressure at rest K_o =0.3, obtained from the Jaky's equation ($K_o = 1 - \sin\phi$) taking ϕ as 45°, is shown by the solid line. Most the ratios of earth pressure to overburden pressure before excavation were 0.3 or less. Although the earth pressure at rest in overconsolidated diluvial soils had previously been thought to exhibit larger values than normal consolidated soil, the measurement results showed that the ratios were 0.3 or less. It is thought that due to displacement of ground occurred during the trench excavations for the diaphragm walls, the ground was already approaching an active state before excavation.

Nearly all the earth pressure coefficients after excavations were smaller than 0.2, which is obtained from the Rankine-Resal equation for C=0 and ϕ =45. Moreover, about half of these values are extremely small, i.e., 0.1 or less.

The relationship between the decrease of earth pressure and the rotation angle of the diaphragm wall, at the depth where the earth pressure was measured, is shown in Fig.3. When the angle of wall rotation is approximately 0.5×10^{-3} or more, the rate of pressure decrease begins to decrease gradually. It is thought that an active plastic state is entered at this degree of rotation angle.

The reasons that the measured lateral pressures are smaller than the values obtained from the Rankine-Resal's equation for C = 0, includes: ① discrepancy in evaluating the strength parameter, ② effect of friction on the diaphragm wall surface, ③ effect of the redistribution of the earth pressure. In this paper the discrepancy in evaluating strength parameter of ①, especially the effect of cohesion, was investigated. In the active earth pressure, the influence of the wall surface friction (②) was small, accounting for only 10% or less of the earth pressure coefficient. In regards to ③, it is believed that it would be difficult for the redistribution of the earth pressure to occur since the maximum displacement of the retaining wall and the relative displacement in the direction of the depth are small in the diluvial soil.

Fig.4 shows the laboratory test results on the undisturbed sand sampled from the three sites A, C, and J. It compares the cohesions derived from the consolidated drained triaxial test (hereafter called the CD test) with the ones which are back-calculated from the measured lateral pressure and pore water pressure with Eq.(1). Each arrow in the figure means the progress of the excavation. In the calculation the internal friction angle derived from

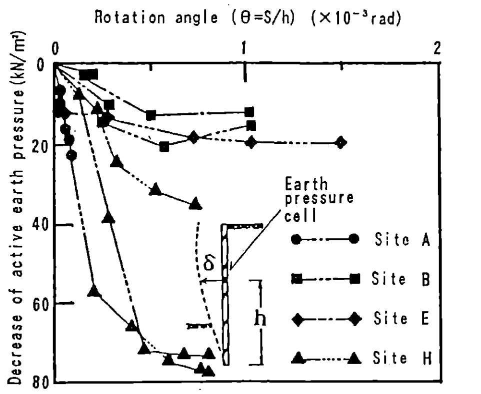


Fig. 3 Lateral pressure and rotation angle of wall

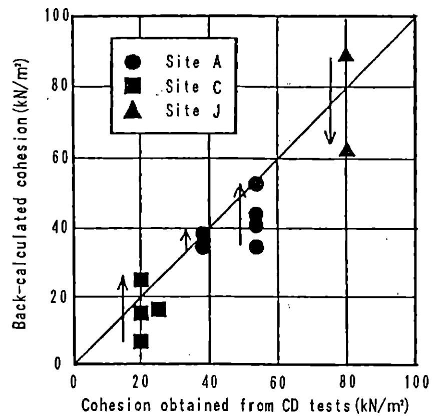


Fig. 4 Comparison of the cohesions

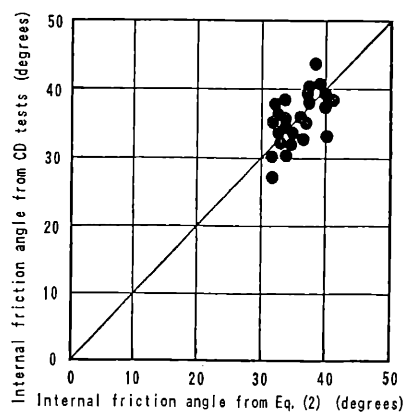


Fig. 5 Comparison of internal friction angles

the CD test was used.

In Fig.4 the cohesion obtained from the CD test coincide with the maximum cohesions obtained during excavation. Therefore it was determined that the cohesion of the sandy soil was a main reason of small earth pressure. And it was thought that lateral pressure in diluvial sandy soil could be evaluated by Eq.(1) using the internal friction angle and cohesion derived from CD tests on undisturbed soils.

3. EVALUATION OF COHESION

The cohesion in diluvial sandy soil is caused by the binding effect of fine particles between the larger grains of sand. It is thought that the factors, affecting the degree of cohesion might include ① amount of fine particles in sandy soil, ② relative density, ③ aging effect of sediment, ④ degree of oxidation, and ⑤ types of substances which comprise the fine particles. Of these factors, ① and ② were selected for this investigation. As for index of ① the fine fraction content, obtained from the grain size analysis conducted on soils from the standard penetration test, were used. As for ②, N-values were substituted for relative density. Finally, most of the measured values were taken from the strata dating the late Pleistocene.

In few cases the undisturbed samples are obtained from sandy soils. Therefore the cohesion was calculated from measured earth pressure and pore water pressure using Eq.(1) (hereafter called the back-calculated cohesion). In the calculation, it was necessary to determine the internal friction angle. In many proposed relations for the angle, the following Eq.(2) by Aoki et al.(1985) was used.

$$\phi = 1.85 \left(\frac{100N}{\sigma z' + 70} \right)^{0.6} + 26 \qquad (2)$$

Where, N = N-value, $\sigma z'$ = effective overburden pressure at the depth where the N-value was obtained.

In Fig.5 the ϕ derived from Eq.(2) and the ϕd values obtained from the CD tests on samples from construction sites are compared. There is a good correspondence between the calculated ϕ and measured ϕd.

Fig.6 shows the relationship between the N-value and back-calculated cohesion from the measured values during the excavations. In Fig.6, the soils of fine fraction content of 10% or more are designated by black dots, while the soils of less than 10% are represented by white dots. When N-values are the same, the greater the fine fraction content is, the greater the degree of cohesion is.

Tohno(1979) proposed the relation between the N-value and cohesion (C) divided by fine fraction content (pf). Fig.7 shows the relationship between the N-value and the back-calculated cohesion (C) divided by the (pf). Although there are dispersion, a correlation is seen between the N-value and the (C/Pf) (correlation coefficient r=0.81). The regressed equation is as follows:

$$\frac{C}{Pf} = 0.08 \cdot (N + 10) \qquad (kN/m^2/\%) \qquad (3)$$

The relationship (Eq.(4)) derived from Tohno's proposed relationship is shown by the broken line in Fig.7.

$$\frac{C}{Pf} = 0.073 \cdot (N + 10) \cdot \tan(45^\circ - \frac{\phi}{2}) \qquad (kN/m^2/\%) \ (4)$$

The value of Eq.(3) is nearly twice that of Eq. (4). One possible explanation for this difference is that Eq.(4) is based on values obtained from laboratory tests, in which some specimens were disturbed by such things as the relief of stress, while the calculated values for cohesion were derived from in-site measurements.

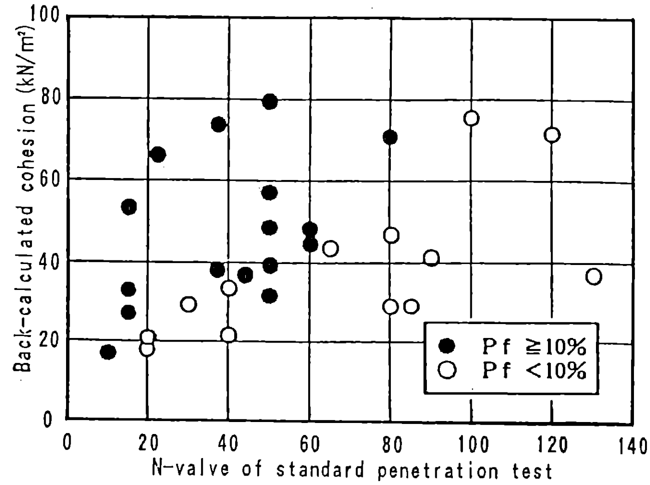


Fig. 6 Relationship between N-value and back-calculated cohesion

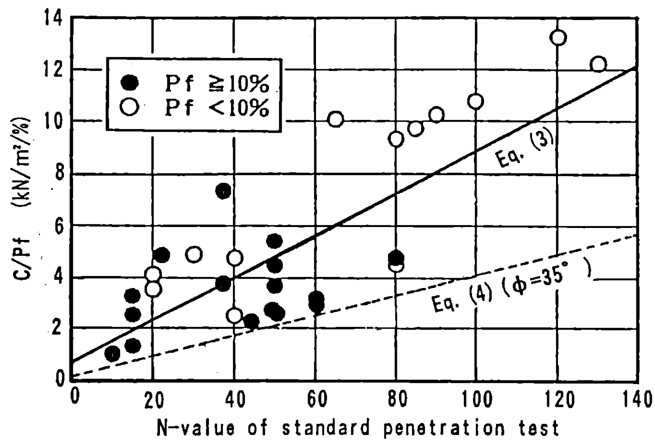


Fig. 7 Relationship between C/Pf and N-value

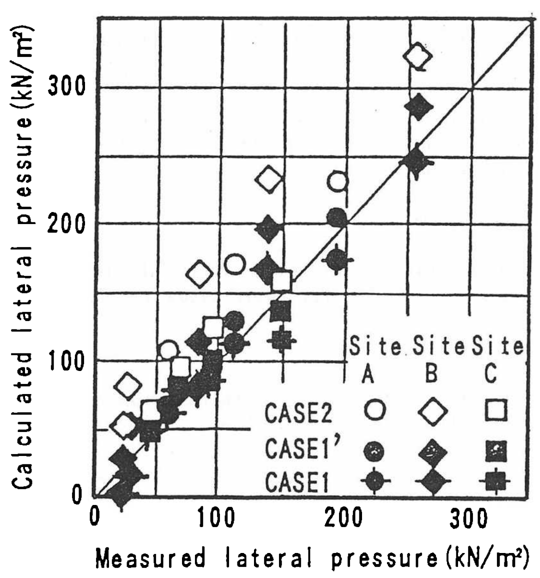


Fig. 8 Calculated and measured values of lateral pressure

4. TRIAL CALCULATIONS OF THE EARTH RETAINING WALL IN CONSIDERATION OF COHESION

In order to understand how the cohesion affects on the stress and displacement of earth retaining walls, trial calculations were made concerning the sites A, C, and H. In CASE 1 and CASE 1', cohesion was taken into account with Eq.3 and Eq.4, respectively. In CASE 2 cohesion of sandy soils was ignored. The internal friction angle was derived from Eq.(2). Analysis was performed with using the earth retaining structure analysis program incorporating elasto-plastic soil behavior .

Fig.8 compare the calculated and measured active lateral pressure on the earth retaining wall. The lateral pressure of the earth retaining wall were close to measured values when cohesion was included in the calculation. On the other hand they were much greater than measured values when cohesion was ignored.

Fig.9 shows the soil strength parameter(CASE1 and CASE1') used in calculating stress and displacement of the walls, and earth retaining structure conditions of sites A and H respectively. And Fig.10 and Fig.11 shows the distribution of calculated and measured values relating to the lateral pressure, the retaining wall displacement, and the bending moment.

When the cohesion of diluvial sandy soil was considered into the analysis (CASE 1, CASE 1'), the lateral pressure, the displacement, and the bending moment are closely correlated with the measured values. The distribution curve for wall displacement in site H did not accurately reflect the measured values due to the influence of alluvial layer. However, the displacement of retaining wall in diluvial soils is considerably smaller when cohesion is taken into account than when it is not. And there is a good correspondence between the measured wall displacement and calculated wall displacement when the cohesion is included. The bending moment of wall is smaller than when it is not. Therefore the efficient retaining structure design is possible with considering the cohesion.

5. CONCLUSION

Lateral pressure of retained side in diluvial sandy soil could be evaluated by the Rankine-Resal's equation which takes into account the cohesion due to binding effect of sand particles. Also, the trial calculation for the lateral pressure which considers the cohesion, shows out that the cohesion greatly affected the stress and displacement of earth retaining walls.

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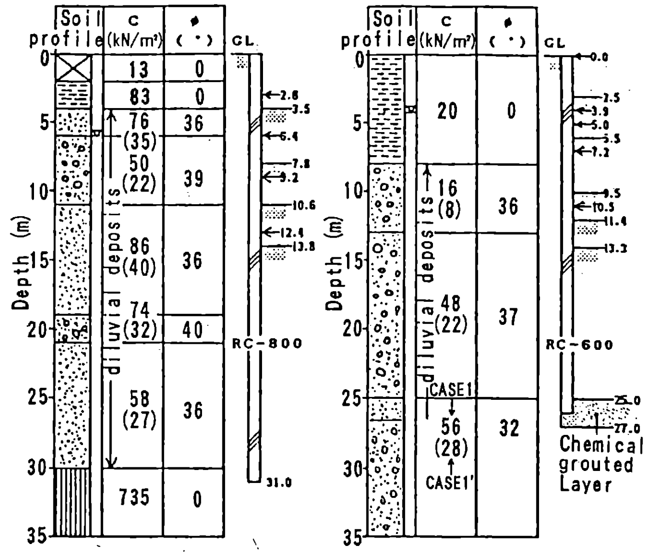

(a) Site A (b) Site H

Fig. 9 Soil constants and structural conditions

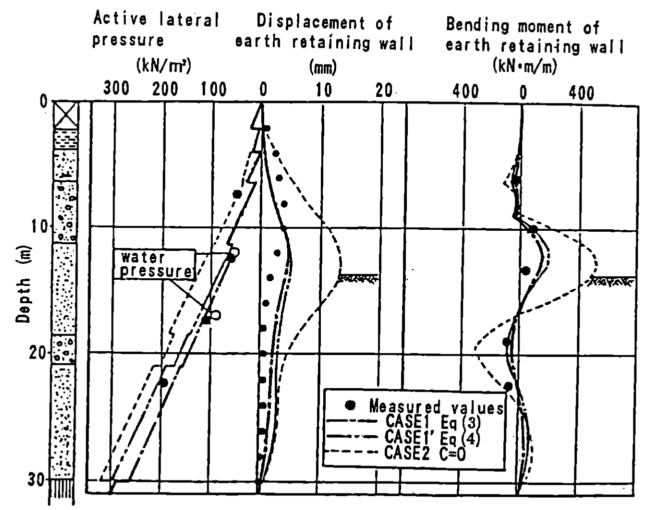

Fig. 10 Comparison of calculated and measured values at Site A

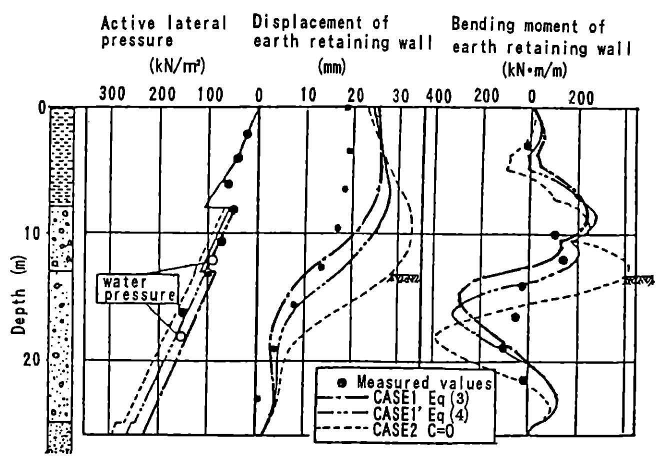

Fig. 11 Comparison of calculated and measured values at Site H