Settlement Behavior of Peat Under Embankment Loading - monitoring in Full-scale Test Embankment and its Prediction

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ABSTRACT: This paper describes the applicability of a method proposed by Noto to the prediction of peaty ground settlement from an engineering viewpoint. The settlement of peaty ground cannot be fully explained by Terzaghi's theory. Noto proposed a method for predicting settlement behavior in peaty ground on the basis of statistical analyses of numerous oedometer test results. For the purpose of verifying the applicability of the Noto method, data on the settlement of full-scale test embankments built in Hokkaido, Japan, were compared with predictions obtained by this method. The comparisons show that predictions are mostly in agreement with field observations.

1 INTRODUCTION

Peat is very soft, and the settlement of structures constructed over peat has posed a serious problem. Several previous studies based on laboratory tests have discussed that the consolidation behavior of peat is significantly different from that of clay (e.g., Oikawa, 1987; Noto, 1987). So, it is difficult to accurately predict the settlement of peaty ground, particularly in terms of temporal changes, by Terzaghi's theory (den Haan, 1994; Kogure, 1998).

In Noto (1991), more than 2,000 oedometer test results on peat were statistically analyzed, and a novel method for predicting the settlement of peaty ground (i.e., the Noto method) was proposed. As peat is heterogeneously deposited and use of a theoretical approach is difficult, thus the Noto method is useful as a realistic means of settlement prediction.

This paper shows data on the settlement of full-scale test embankments built on peaty ground in Hokkaido, Japan and values calculated by the Noto method are compared with the measured values in the test embankments in order to verify the applicability of the Noto method.

2 NOTO METHOD FOR PREDICTING SETTLEMENT OF PEATY GROUND

In this paper, only the study results relevant to the Noto method are shown below. The process for developing the Noto method and the test data used in that process are shown in Noto (1987) and Noto (1991).

The Noto method assumes the temporal changes in the settlement of peaty ground as shown in Fig.1

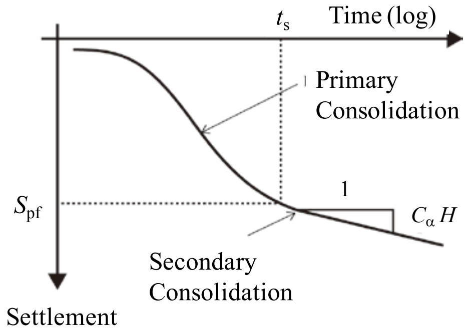


Fig. 1 Concept of peat settlement curve (Noto method)

the primary consolidation process is represented with the curve (i.e., Eq. (1)) in Fig.1, and it ceases at the time t_s, which is calculated by Eq. (2). Following the completion of primary consolidation (i.e., after the time t_s), secondary consolidation, having a linear relationship to the logarithm of time as expressed by Eq. (3), takes place.

Settlement in the primary consolidation, S_p (cm):

$$S_p = (\varepsilon_f /(1+C_p \times t^{-0.62})) \times H \qquad (1)$$

where, ε_f is the final strain in primary consolidation, C_p is the coefficient of the primary consolidation rate, t is the given time (days), and H is the initial thickness of the peat layer (cm).

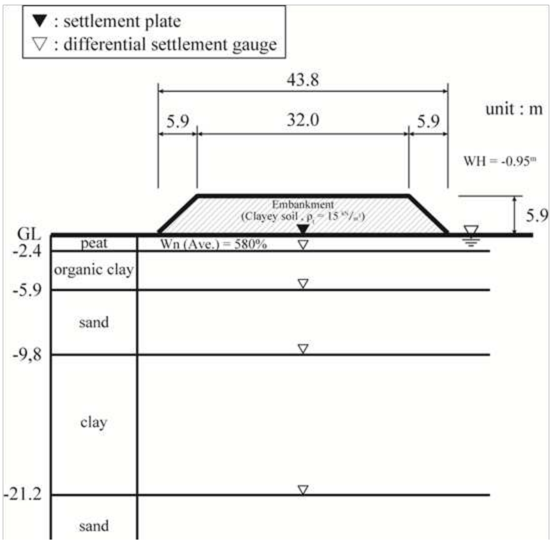
Time when primary consolidation ceases, t_s (days):

$$t_s = 0.0055\, H^2 \qquad (2)$$

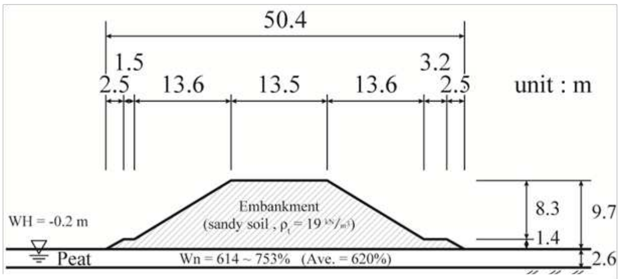
Settlement in the secondary consolidation, S_s (cm):

$$S_s = S_{pf} + C_\alpha \times H \times \log(t/t_s) \qquad (3)$$

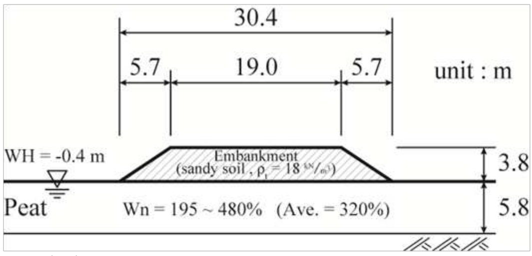
where, S_{pf} is the settlement at the time when $t = t_s$ in Eq. (1) (i.e., the total settlement due to primary consolidation), and C_α is the coefficient of secondary consolidation (%).



(a) Mihara site



(b) Kushiro site



(c) Iwanai site

ρ_t: bulk density, W_n: natural water content, WH: groundwater level

Fig. 2 Cross-section of the embankment and the subsoil profile at each site

The coefficients used in Eqs. (1) and (3) are calculated by the equations below: where, P is the incremental load due to the embankment (kN/m^2), and W is the water content of peat (%).

$$\varepsilon_f = 1/(1+(2.74\times10^4/(W\times P^{0.8}))) \quad (4)$$
$$C_p = 0.0044H^{1.25} \quad (5)$$
$$C_\alpha = 3.3+0.0043W \quad (6)$$

The cost necessary for settlement prediction by the Noto method is very reasonable, because the tests required for determining the soil parameters are simple.

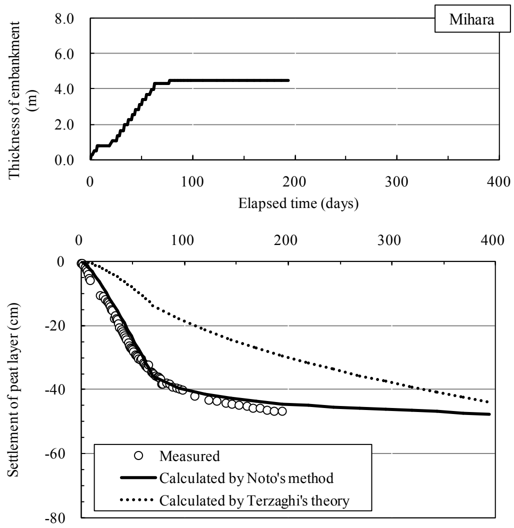


Fig. 3 Time history of embankment construction and peat settlement at the Mihara site

3 COMPARISON OF MEASURED AND CALCULATED SETTLEMENT FOR VERIFYING THE APPLICABILITY OF THE NOTO METHOD

In this section, settlement values of peaty ground measured in full-scale test embankments are compared with values calculated by the Noto method for verifying the applicability of the Noto method.

3.1 *Sites used for settlement observation*

Full-scale test embankments were built at three road construction sites in Hokkaido, Japan: Mihara, Kushiro and Iwanai. These embankments and their ground conditions are shown in Fig. 2.

3.2 *Comparison of measured and calculated settlement*

Fig. 3 shows a time history of peat layer settlement at the Mihara site in terms of the measured values and values calculated by the Noto method. At this site, conventional oedometer tests on undisturbed peat were conducted, and the test results were used for settlement calculations by Terzaghi's theory. Specifically, the settlement rate was estimated using a coefficient of consolidation (c_v = 60cm^2/day) at a consolidation pressure that is 1/2 of the incremental stress due to the embankment. The settlement rate calculated by Terzaghi's theory is significantly lower than the actual settlement rate. On the other hand, the settlement rate calculated by the Noto method is in good agreement with the actual settlement rate; thus, the Noto method is highly applicable. The applicability of the Noto method is examined in detail in Section 4.

A time history of peat layer settlement in terms of measured values and values calculated by the Noto method is shown in Fig. 4 and Fig. 5 for the Kushiro site and the Iwanai site, respectively. The settlement rate calculated by the Noto method is in good agreement with the actual settlement rate at these sites as well, which indicates the excellent applicability of the Noto method.

Fig. 6 shows the relationship between the measured and the calculated settlement for the time when the embankment construction was completed and when the final measurement was taken at the three sites. It is shown that the Noto method is accurate, having a margin of error of ±10%.

4 PRIMARY CONSOLIDATION RATE

According to Terzaghi's theory, the degree of consolidation in the initial consolidation phase is linearly related to $\sqrt{t}$ (t: time). In other words, the relationship between time and the consolidation rate in the initial consolidation phase is linear on a double logarithm plot, and the slope of the linear relation (α) is - 0.5.

The changes with time in the compressive strain of peat (ε) and the rate of compressive strain ($\Delta\varepsilon$) at the Kushiro site are shown in Fig. 7 and Fig. 8, respectively. In the equations below, S is a measured value of settlement, H_0 is the thickness of a peat layer in the initial phase of consolidation, ε_{i+1}-ε_i is a difference in the value of ε between two consecutive measurements, and t_{i+1}-t_i is the time interval between two consecutive measurements.

$$\varepsilon = \Delta S / H_0 \quad (7)$$

$$\Delta\varepsilon = (\varepsilon_{i+1} - \varepsilon_i)/(t_{i+1} - t_i) \quad (8)$$

The value of α (i.e., temporal change of $\Delta\varepsilon$) in the primary consolidation region measured at the Kushiro site is -0.65. The value of α was also calculated for the other two sites in the same manner as for the Kushiro site. The relationship between these three values of α and the water content of peat is shown in Fig. 9. The values of α obtained from measurement data are within the range of -0.60 to -0.67 and are much smaller than the values in Terzaghi's theory (α = -0.5). Therefore, it is verified from the field settlement measurement data that the primary consolidation rate of peat is higher in the initial phase of consolidation and is lower in the later phase of consolidation in comparison with the rate obtained by Terzaghi's theory.

On the other hand, the value of α calculated by using the Noto method is constant at -0.62 as shown by Eq. (1). The value of α obtained from field settlement measurement data is constant regardless of the natural water content of peat, and the value is in good agreement with the value of α obtained by the Noto method. This seems to be a reason why the Noto method can adequately reproduce the primary consolidation rate of peat.

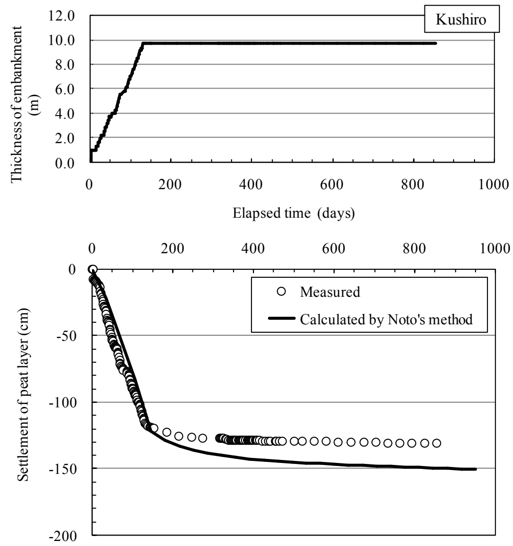


Fig. 4 Time history of embankment construction and peat settlement at the Kushiro site

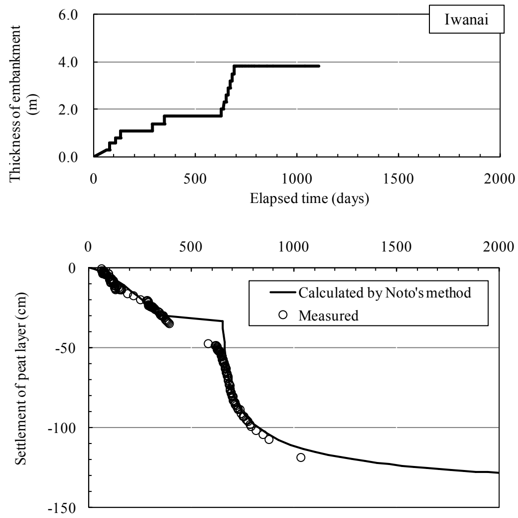


Fig. 5 Time history of embankment construction and peat settlement at the Iwanai site

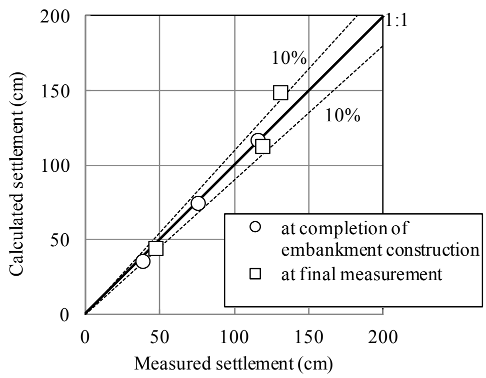


Fig. 6 Relationship between measured settlement and settlement calculated by the Noto method at all sites

5 COEFFICIENT OF SECONDARY CONSOLIDATION

The secondary consolidation of peat is another important factor in predicting settlement (e.g., Mesri, 1973). At the Kushiro site, a linear relationship to the logarithm of time first appears at around t_s=372 (days) obtained by Eq. (2) (Fig.7). The slope of this linear relation (i.e., the coefficient of secondary consolidation, $C_\alpha = \Delta\varepsilon/\Delta \log t$) is 5.3%. Fig. 10 shows the relationship between the water content and the measured C_α and C_α calculated by Eq.6. Regarding the C_α at the Kushiro site, the measured value is consistent with the value calculated by the Noto method. The settlement measurement data at the Kushiro site prove that Eqs. (2), (3) and (6) are applicable to the prediction of secondary consolidation.

6 CONCLUSIONS

The main results are summarized as follows.

(1) A comparison of the measured and the calculated settlement shows that the Noto method is accurate in predicting settlement with a margin of error of ±10%.

(2) The compressive strain rate in primary consolidation (α) based on the field settlement data is within the range of -0.60 to -0.67, showing good agreement with the value of α obtained by the Noto method.

(3) The measured value of the coefficient of secondary consolidation and the time of onset of secondary consolidation are consistent with the values calculated by the Noto method.

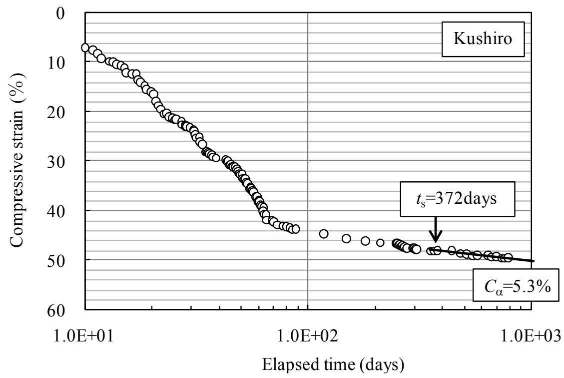


Fig. 7 Change in compressive strain at the Kushiro site

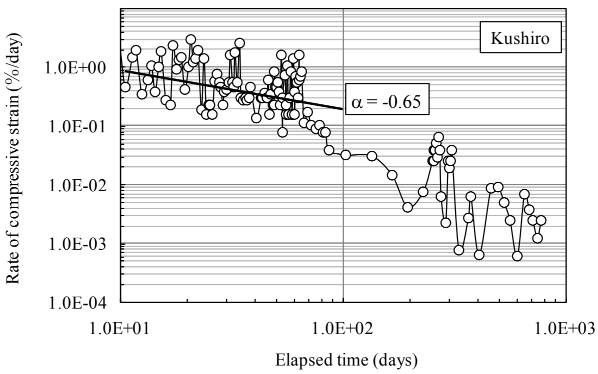


Fig. 8 Rates of compressive strain at the Kushiro site

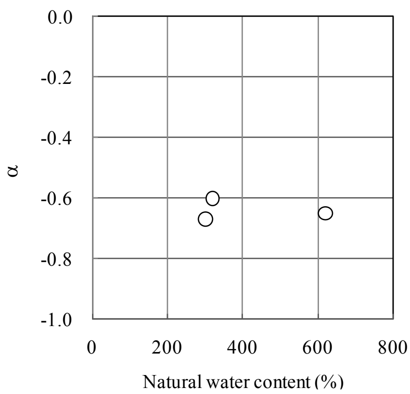


Fig. 9 Relationship between water content and α

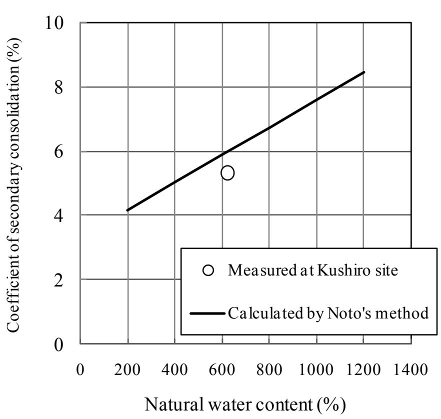


Fig. 10 Relationship between natural water content and coefficient of secondary consolidation of peat

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