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Applicability of settlement prediction method to peaty ground

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Abstract

This paper describes the applicability of a method, proposed by Noto (1991a), to the prediction of the settlement of a peaty ground from an engineering viewpoint. The settlement of peaty grounds cannot be fully explained by Terzaghi's theory. Noto proposed a method for predicting the settlement behavior in peaty grounds on the basis of the 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 comparison quantitatively revealed the primary consolidation rate and the coefficient of secondary consolidation of the peaty ground as well as the prediction accuracy of the Noto method.

Keywords: Peat; Settlement; Prediction; Noto method; Full-scale test embankment; Monitoring; Primary consolidation; Secondary consolidation (**IGC**: E02)

1. Introduction

Peat, which forms when undecomposed plant remains are deposited under conditions of low temperature or high humidity, is a problematic soil. Peaty grounds are widely distributed in the cold regions of North America, Europe and Asia, as well as in Southeast Asian countries such as Indonesia and Malaysia (Lappalainen, 1996). Since peat is very soft, the consolidation settlement of road embankments or river levees constructed over peaty grounds (Fig. 1) poses a serious threat (e.g., Kurihara et al., 1993).

Previous studies, based on laboratory tests, have discussed that the consolidation behavior of peat is significantly different from the consolidation behavior of clay from a microscopic perspective (e.g., Oikawa, 1987; Noto, 1987; Mesri and Ajlouni, 2007). According to these studies, it is difficult to accurately predict the settlement behavior of peaty grounds, particularly in terms of temporal changes, with Terzaghi's theory (den Haan, 1993; Kogure, 1998).

In Noto (1991a), the results of more than 2000 oedometer tests on peat were statistically analyzed from a macroscopic perspective, and a novel method for predicting the settlement of peaty grounds (i.e., the Noto method) was proposed. Since peat is heterogeneously deposited in the ground (Noto, 1991b), and thus, the use of a theoretical approach is difficult, the Noto method is useful as a realistic means of settlement prediction.

With the aim of providing helpful information to engineers for practical works on peaty grounds, this paper shows data on the settlement of full-scale test embankments built on a peaty ground in Hokkaido, Japan, as well as analyses of the data from an engineering viewpoint. In addition, the values calculated by the Noto method are compared with the

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Fig. 1. Typical differential settlement of road embankment constructed on peaty ground.

measured values for the test embankments in order to verify the practical applicability of the Noto method.

2. Noto method for predicting settlement of peaty ground

The process for developing the Noto method and the test data used in that process are fully shown in Noto (1987) and Noto (1991a). Since the purpose of this paper is to verify the applicability of the Noto method from an engineering perspective, on the basis of field data on the settlement of a peaty ground, the main portion of the results from the tests that Noto (1991a) performed is presented in this paper.

Fig. 2 shows an example of the relationship between the final strain in primary consolidation, obtained from oedometer tests (ε_f), and the water content (W) of peat. It can be seen that ε_f increases with increases in the W of peat, and that the relationship between ε_f and W depends on the consolidation pressure. Eq. (4), described later, approximates the relationship of the experimental results shown in Fig. 2. Fig. 3 shows an example of the relationship between the slope for the temporal changes in compressive strain rate (i.e., α which is detailed in Section 4) in the primary consolidation and W. Based on the results shown in Fig. 3, the Noto method assumes α to be a constant value of -0.62, which is used as a coefficient in Eq. (1). The C_p, which is expressed by Eq. (5), is a coefficient related to the primary consolidation rate. C_p is derived from both the results shown in Fig. 3 ($\alpha = -0.62$) and the similarity law with the thickness of peat being between that of the laboratory sample and that of the field. It was also revealed that the coefficient of secondary consolidation (C_α) increases linearly with increases in the W of peat, based on the laboratory and field data. Eq. (6) is derived from the approximated relationship of the experimental results. As briefly summarized above, the characteristics of consolidation for peat (i.e., primary and secondary consolidation) can be approximately explained using the consolidation pressure, the water content and the thickness of the peat.

In this way, the Noto method is developed to predict the settlement of a peaty ground, led by the approximate relationship between the consolidation properties obtained from oedometer tests and the water content of the peat. The detailed procedure of the Noto method is given below.

The Noto method assumes the temporal changes in the settlement of a peaty ground, as shown in Fig. 4. The primary consolidation process is represented by a curve in this figure (i.e., Eq. (1)). It ceases at time t_s, which is calculated by Eq. (2). Following the completion of primary consolidation (i.e., after 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 region, S_p (cm):

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

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:

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

where the dimension of the constant (0.0055) is day/cm^2.

Settlement in the secondary consolidation region, S_s (cm):

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

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 (%).

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

$$\varepsilon_f = 1/(1 + (2.74 \times 10^4/(W \times P^{0.8}))) \quad (4)$$

$$C_p = 0.0044\, H^{1.25} \quad (5)$$

$$C_\alpha = 3.3 + 0.0043\, W \quad (6)$$

In the Noto method, the settlement, including secondary consolidation and the temporal changes in settlement, can be easily calculated on the basis of the known values for the water content of peat, the peat layer thickness and the incremental load due to the embankment. As peat is heterogeneously deposited in the ground (Noto, 1991b), many tests and large expenses are involved in accurately determining the soil parameters that are applicable to the conventional methods of settlement prediction. The costs necessary for settlement prediction by the Noto method are very reasonable, because the tests required to determine the soil parameters are simple. Generally, the consolidation behavior of a soft ground depends on the compressibility and the permeability of the soil, as well as on the boundary conditions of the ground. As the Noto method is composed of the experimental equations obtained from tests on peat, it is noted that the method should be applied only to peaty grounds.

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