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A simplified method for prediction of embankment settlement in clays

Chunlin Li*

Institute of Civil Engineering, Tongling University, Tongling 244000, China

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ABSTRACT

The prediction of embankment settlement is a critically important issue for the serviceability of subgrade projects, especially the post-construction settlement. A number of methods have been proposed to predict embankment settlement; however, all of these methods are based on a parameter, i.e. the initial time point. The difference of the initial time point determined by different designers can definitely induce errors in prediction of embankment settlement. This paper proposed a concept named "potential settlement" and a simplified method based on the in situ data. The key parameter "*b*" in the proposed method was verified using theoretical method and field data. Finally, an example was used to demonstrate the advantages of the proposed method by comparing with other methods and the observation data.

1. Introduction

The one-dimensional (1D) consolidation equations proposed by Terzaghi are the cornerstone of soil mechanics. Settlement calculated using Terzaghi's 1D consolidation theory (Terzaghi, 1925) has been widely used, but it is not always effective due to the uncertainty of coefficient (Asaoka, 1978). Many methods for settlement prediction based on observation data have also been proposed, for example, Asaoka method, hyperbolic method (Tan et al., 1991), parabola method (Xu and Xu, 2000), and in situ tests (Bergado et al., 1991). The Asaoka method and hyperbolic method are widely used due to their simplicity (Anderson et al., 1994; Tan, 1994, 1995, 1996). However, limitations still exist in both methods that the initial time point is necessary to be determined first; and the difference of the initial time point determination can significantly influence the accuracy of the settlement prediction. Therefore, this paper proposed a simplified method based on the Terzaghi's 1D consolidation equation irrelevant to the initial time point and compared it with other methods to verify its effectiveness.

* Tel.: +86 13856250392.
E-mail address: lichunlin111@126.com

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2. Theory of Asaoka's method

In 1978, Asaoka proposed a new settlement prediction method, the philosophy of which is based on "observational procedure". The theory is derived from 1D consolidation equation. He combined Mikasa's (1965) equation with Terzaghi's (1925) equation, and obtained the vertical strain as

$$\varepsilon(t,z) = T + \frac{1}{2!}\left(\frac{z^2}{c_v}\dot{T}\right) + \frac{1}{4!}\left(\frac{z^4}{c_v}\ddot{T}\right) + \cdots + zF + \frac{1}{3!}\left(\frac{z^3}{c_v}\dot{F}\right) + \frac{1}{5!}\left(\frac{z^5}{c_v}\ddot{F}\right) + \cdots \tag{1}$$

where $\varepsilon(t,z)$ is the vertical strain of z at time t; T and F are unknown functions of time; c_v is the coefficient of consolidation.

With the two boundary conditions, i.e. drainage from both top and bottom boundaries and upward drainage, the following equations can be derived:

$$S + \frac{1}{3!}\left(\frac{H^2}{c_v}\dot{S}\right) + \frac{1}{5!}\left(\frac{H^4}{c_v}\ddot{S}\right) + \cdots = \frac{H}{2}(\bar{\varepsilon} + \varepsilon) \tag{2a}$$

$$S + \frac{1}{2!}\left(\frac{H^2}{c_v}\dot{S}\right) + \frac{1}{4!}\left(\frac{H^4}{c_v}\ddot{S}\right) + \cdots = H\bar{\varepsilon} \tag{2b}$$

where S is the settlement, H is the thickness of clay stratum, and $\bar{\varepsilon}$ is the vertical strain at initial time.

The discrete time can be introduced as

$$t_j = \Delta t \cdot j \quad (j = 0, 1, 2, \ldots) \tag{3}$$

where Δt is the equal time interval.

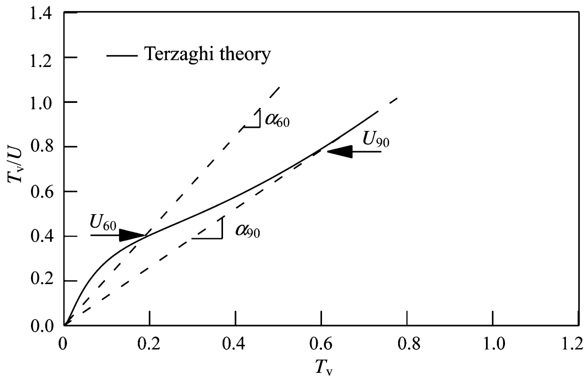

Fig. 1. Hyperbolic plots of Terzaghi theory (after Tan, 1995).

From Eqs. (2) and (3), the settlement at time j can be written as

$$S_j = \beta_0 + \beta_1 S_{j-1} \tag{4}$$

where S_j and S_{j-1} are the settlements at time j and $j-1$; β_0, β_1 are unknown parameters.

When the state is stable, the final settlement S_f can be obtained by the following equation:

$$S_j = S_{j-1} = S_f \tag{5}$$

where S_f is the final settlement.

From Eq. (5), we realize that the final settlement is the intersection of relationship line between S_j and S_{j-1} with 45° line in the $S_j - S_{j-1}$ plot.

If S_j and S_{j-1} are substituted by S_f in Eq. (4), Eq. (4) can be simplified to

$$S_f = \frac{\beta_0}{1-\beta_1} \tag{6}$$

And the settlement $S(t)$ at time t can be calculated as follows:

$$S(t) = \frac{\beta_0}{1-\beta_1} - \left(\frac{\beta_0}{1-\beta_1} - S_0\right)\beta_1^t \tag{7}$$

where S_0 is the settlement at the initial time.

In Eq. (7), S_0 should be determined firstly before settlement prediction. The different values of S_0 can result in different values of $S(t)$, thus the precision depends greatly on the selection of the initial time. However, the selection of the initial time point will be different by different designers, which can cause the deviation of settlement calculation.

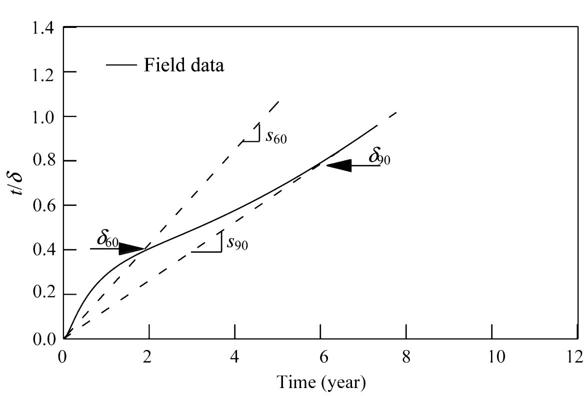

Fig. 2. Hyperbolic plots of field settlement (Tan, 1995).

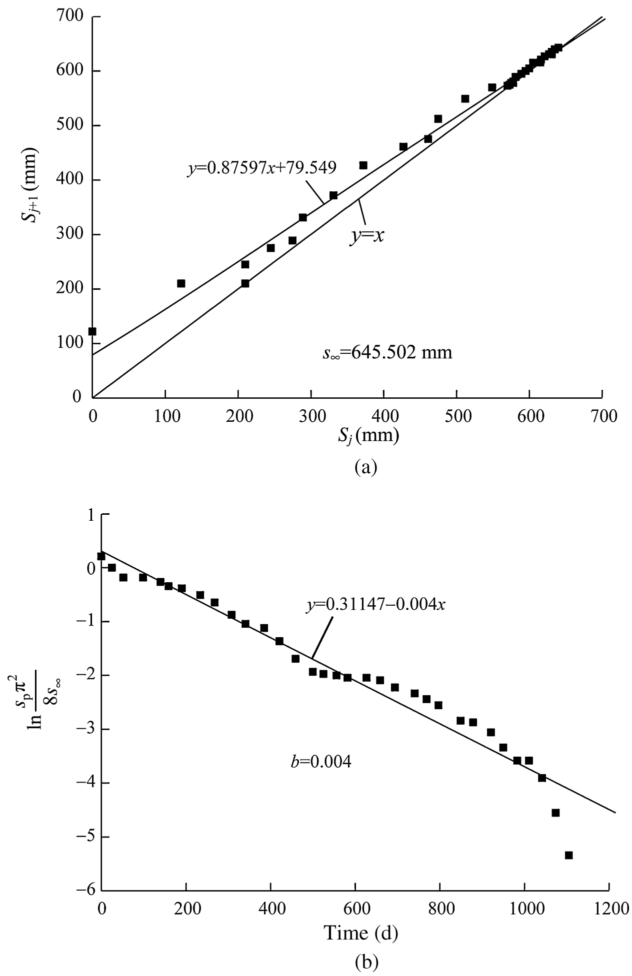

Fig. 3. The determination of parameter b in the section K5+800.

3. Theory of hyperbolic method

The hyperbolic method proposed by Tan et al. (1991) has its origins in the rectangular hyperbolic fitting method proposed by Sridharan and Rao (1981) and Sridharan et al. (1987). According to the Terzaghi's theory of consolidation (1925), the settlement-time relationship can be expressed using U and T_v. The relationship between T_v/U and T_v is shown in Fig. 1. From Fig. 1, we can see that the linear portion is between U_{60} and U_{90}, which can be represented as

$$\frac{T_v}{U} = \alpha T_v + \beta \tag{8}$$

where α is the slope and β is the intercept of the hyperbolic plot.

Based on the field data (Tan, 1995), the relationship between settlement δ and time t is shown as t/δ vs. t in Fig. 2.

The slopes of s_{60} and s_{90} can be determined by

$$s_{60} = s_i\frac{\alpha_{60}}{\alpha_i} \tag{9}$$

$$s_{90} = s_i\frac{\alpha_{90}}{\alpha_i} \tag{10}$$

where s_i and α_i are the initial slope of linear segment in Figs. 1 and 2, respectively. So the final settlement δ_f can be calculated by the following equation:

$$\delta_f = \frac{\alpha_i}{s_i} = \frac{\delta_{60}}{0.6} = \frac{\delta_{90}}{0.9} \tag{11}$$