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ESTIMATING LOAD-DISPLACEMENT BEHAVIOR OF SOFT CLAYS

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Prediction of long term settlement of soft soils below civil engineering structures is an important issue in geotechnical engineering. The data from laboratory consolidation tests are used to estimate the ultimate settlement and problems arise in predicting settlement-time behavior in the field. In order to overcome this difficulty some empirical models or adjustments have been proposed based on field settlement measurements, even if they are available at least for the early stages of loading. In this study, laboratory test results and field settlement measurements obtained for the long term settlement of clayey layers underlying the Alibey Dam in Istanbul, Turkey are used in conjunction with a model proposed by Edil and Mochtar (1984) for peat-like soils. The soil parameters of the proposed model have independently been obtained using both laboratory test data and field measurements, and model predictions are compared with actual recorded settlements. It is observed that the field measurements could be predicted more closely if the model parameters are obtained from field measurements, but predictions based on laboratory consolidation and creep test results also provide satisfactory results following the initial stages of loading.

Keywords: Consolidation, Strain, Strain rate, Long-term settlement, Peat, Field measurement.

1 INTRODUCTION

Over the years, the prediction of long term in-situ settlement-time behavior of clay layers underlying civil engineering structures has been a common topic for many researchers. Similarly, in this study, a method proposed by Edil and Mochtar (1984) for peat-like soils, which is a simplified approach to Gibson-Lo (1961) model, is utilized to model the long-term compressive behavior of organic clayey soils comprising the foundation of Alibey Dam in Istanbul, Turkey. This unique dam was constructed in approximately fifteen years using a staged construction approach. Furthermore, it was monitored by the installed instrumentation for more than twenty-five years (Berilgen *et al.* 2005, Berilgen *et al.* 2006, Ozcoban *et al.* 2007). Both laboratory incremental loading consolidation and creep test results and recorded field settlements at different stages of embankment construction of the dam are used in conjunction with a prediction approach proposed by Edil and Mochtar (1984) for long term field settlement of clayey with organic content. Computed values are compared with the actual recorded values.

2 MODEL FOR SETTLEMENT-TIME BEHAVIOR

The model proposed in the study by Edil and Mochtar (1984), which is similar to that by Edil and Dhowian (1979), is used to predict the long-term compression of peat-like soils. In this model, the strains due to the long-term compression of soils are obtained using the following equation;

$$\varepsilon(t) = \Delta\sigma\left[a + b(1 - e^{-(\lambda/b)t})\right] \quad (1)$$

here, $\varepsilon(t), \Delta\sigma, a, b, \dfrac{\lambda}{b}$ are the time-dependent vertical displacement, stress increment, primary and secondary compressibility parameter, and the rate factor for the secondary compression respectively. These empirical parameters are obtained by first drawing the $(t - \log\dot{\varepsilon}_v)$ curve to form a linear set of points at the time interval corresponding to the portion of secondary compression of the total settlement. Secondly, the slope of the best straight line is drawn through the linear portion and the intersection point of the straight line and the vertical y-axis is calculated to determine the needed parameters:

$$\text{The slope, m} = -0.434\lambda/b \quad (2)$$

$$\text{The intersection} = \log(\Delta\sigma\lambda) \quad (3)$$

$$a = \frac{\varepsilon(t_k)}{\Delta\sigma} - b + be^{-(\lambda/b)t_k}\Delta\sigma\left[a + b(1 - e^{-(\lambda/b)t})\right] \quad (4)$$

where, the parameter $\Delta\sigma$ in Eq. 3 is the difference between the value of stress at any time and stress at the ultimate time during a stage. The parameter t_k in Eq. 4 represents the time at which the last strain readings were taken at a specific loading stage.

3 APPLICATION OF MODEL

The suggested model has been applied to results from multiple stage consolidation and creep tests with corresponding $\log\dot{\varepsilon}_v - t$ curves for each loading stage to obtain the model parameters. However, in multiple staged loading tests the loading is usually terminated before long-term compressions are completed and the obtained data is not sufficient for a long-term prediction model. Therefore, a best-fit curve is drawn through available experimental measurements to obtain a continuous compression curve and then these settlement-time curves are used to obtain $\log\dot{\varepsilon}_v - t$ curve. It is worthwhile to note that a linear behavior is observed in these curves after the initial stages of loading. As mentioned above, if the slope of the linear section is denoted with *m* and the intersecting point of the extension of linear portion with the vertical axis with *n*, Eqs. 2,3 and 4 can be used to obtain model parameters and strain values at any time can be determined using Eq. 1. Comparison of the compression-time curves obtained by using the above relationships with the laboratory test readings are shown in Figure 1 for a load of 250 kPa and the model parameters used in analysis are listed in Table 1.

Although the model by Edil and Mochtar (1984) is not able to predict the early stages of the compression-time behavior observed in laboratory tests, the match with laboratory measurements is very well for the points after approximately 300 minutes.

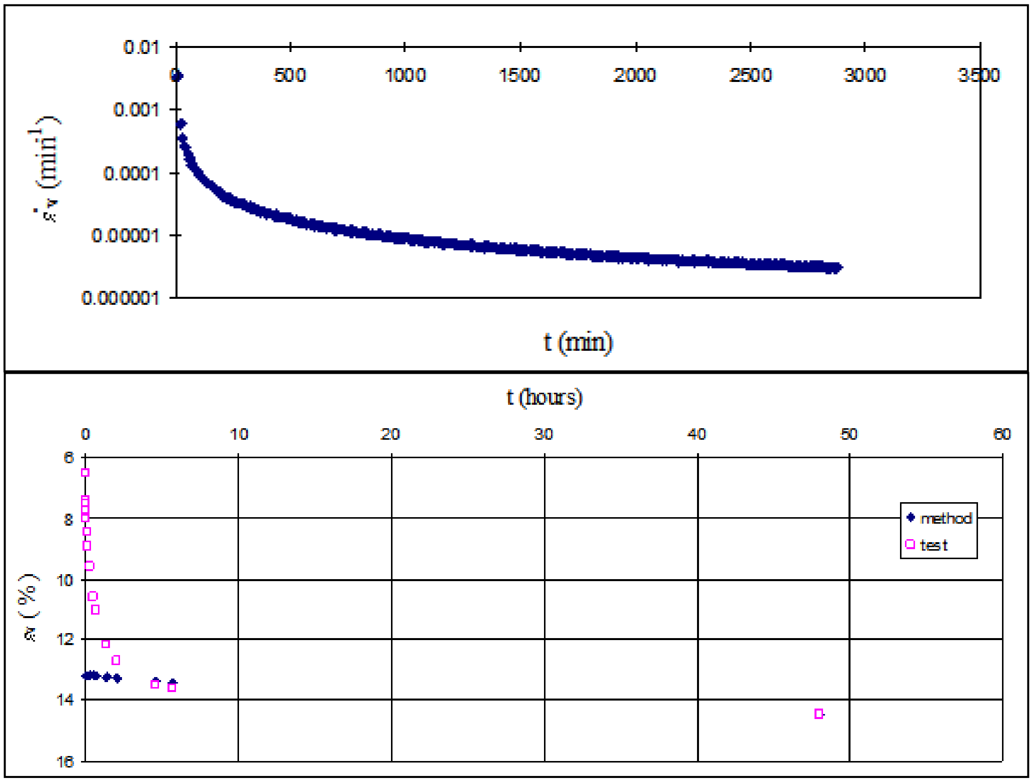

Figure 1. Consolidation data for staged loading and comparison the suggested method.

Table 1. The values of model parameters obtained from a creep test.

Model parameters	λ / b (min^{-1})	b (kPa^{-1})	a (kPa^{-1})
$\sigma'_V = 250kPa$	4x10^{-4}	1.2x10^{-4}	1x10^{-3}

In the second step of the study, settlements of soft clayey underlying Alibey Dam foundation layers are attempted to be predicted utilizing the same methodology. The embankment for the Alibey Dam in Istanbul, Turkey was constructed in stages with extended periods of waiting during loading stages in order to avoid bearing capacity problems and excessive displacements. A comprehensive in-situ measurement scheme was employed to monitor the field behavior during and after construction. The in-situ settlement readings at the dam cross-section during two of the stages (2 and 3) of construction are compared with the settlements calculated by the method (Figure 2). The model parameters obtained from in-situ measurements for all six stages of construction are presented in Table 2.

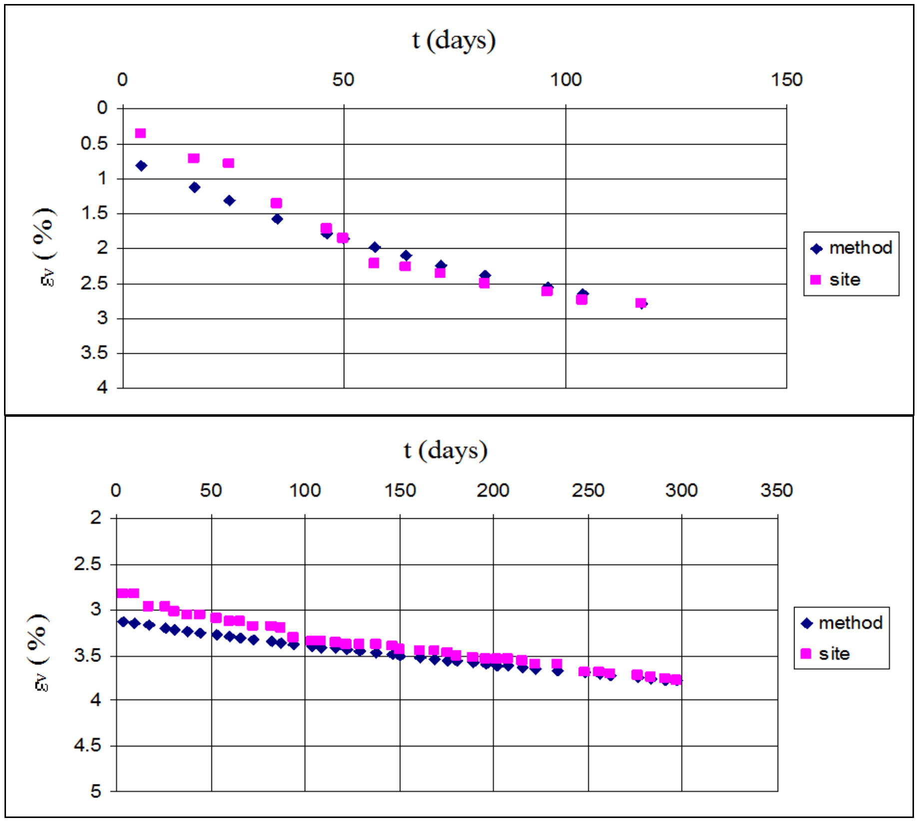

Figure 2. Comparison of computed and recorded strain curves for several loading stages.

Table 2. The values of model parameters obtained from in-situ measurements for six stages.

Model parameters	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
λ / b (min^{-1})	$1\text{x}10^{-5}$	$6.2\text{x}10^{-6}$	$1.3\text{x}10^{-6}$	$2\text{x}10^{-6}$	$4\text{x}10^{-7}$	$1.5\text{x}10^{-7}$
b (kPa^{-1})	$9\text{x}10^{-7}$	$5.8\text{x}10^{-4}$	$2.7\text{x}10^{-4}$	$1\text{x}10^{-4}$	$3\text{x}10^{-4}$	$2\text{x}10^{-4}$
a (kPa^{-1})	$7\text{x}10^{-6}$	$1.3\text{x}10^{-4}$	$5.7\text{x}10^{-4}$	$1\text{x}10^{-3}$	$2\text{x}10^{-3}$	$2\text{x}10^{-3}$

Starting with the second stage of loading there is an increasing degree of agreement between the computed and measured settlement. The computed and recorded values are observed to be particularly close at final stages of loading at each loading stage. Thus, it can be stated that for the case of model parameters being obtained from in-situ measurements, the model is very successful in predicting the long-term settlements. In the last step of this study, the method has been utilized with the model parameters obtained from laboratory consolidation tests selected based on the loading conditions in the field. The model parameters obtained from laboratory consolidation tests carried out in loading increments compatible with the field embankment construction program are given in Table 3. The computed and measured settlements under the dam for a period of more than twenty years at the considered section are shown in Figure 3. Settlements computed with parameters obtained from both laboratory tests and field measurements are provided on the same figure together with the measurements. Considering the complicated field soil conditions and staged embankment construction extending over 15 years, it can be said that a reasonable degree of agreement is achieved between the predicted and recorded settlements starting with the second stage of the loading.

Table 3. The values of model parameters obtained from laboratory consolidation tests.

Model parameters	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
$\lambda / b\ (\min^{-1})$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$	$3x10^{-4}$
$b\ (kPa^{-1})$	$2x10^{-4}$	$2x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$
$a\ (kPa^{-1})$	$2x10^{-4}$	$2x10^{-4}$	$9x10^{-4}$	$9x10^{-4}$	$1.8x10^{-3}$	$1.8x10^{-3}$

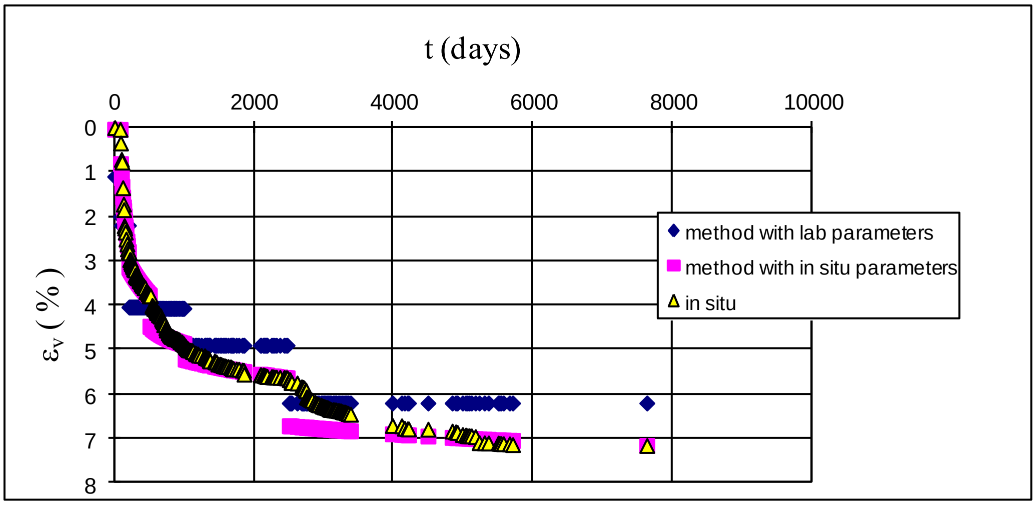

Figure 3. The comparison of all strain values obtained using methods with actual measurements.

Based on the findings of this study, the use of the method with parameters obtained from short-term in-situ readings is quite successful in predicting the field settlements. However, when the model parameters are obtained from laboratory tests, the compatibility between computed and recorded values are not as good especially at the initial stages of loading steps.

4 CONCLUSIONS

In this paper, findings of a study in which the prediction of long term settlements of soft clayey soils underlying an earth dam embankment constructed through a staged fill approach are presented. A soil compression model proposed by Gibson-Lo (1961) and modified for peat-type soils by Edil and Mochtar (1984) is used to predict the long-term settlements below an earth dam constructed over a period of about fifteen years. Comparisons with the field settlement measurements indicate that if model parameters are obtained from laboratory tests performed by taking into account the loading and stress conditions in the actual construction, although at the initial stages of loading the agreement is not very good, there is an increasing degree of agreement with increased settlements, and ultimate values especially are predicted quite accurately. On the other hand, if the model parameters are obtained from in-situ measurements ability to predict the settlement- time behavior improves considerably. In general, it may be stated that the proposed methodology may be utilized as a good tool to predict the long-term field behavior from laboratory test data and/or field settlement readings recorded for a limited time.

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