A Study on the Evaluation of Reliability for Settlement Predictions by Hyperbolic Method

침하예측을 위한 쌍곡선 식의 신뢰성 평가에 관한 연구

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요 지

연약지반 개량을 위한 프리로딩 공법에서 침하 예측은 시공관리상 매우 중요한 요소이다. 지반의 비균질성, 지반 물성치 조사의 한계 등의 이유로 설계시에 침하속도 및 침하량을 실제 발생치와 근접하게 예측하기는 매우 어렵다. 이러한 문제점 때문에 쌍곡선법, 아사오카법 등 초기 침하계측을 이용한 장래 침하 추정법들이 침하 예측 기법으로 활발하게 이용되고 있으나, 예측 시점에서 추정된 장래 침하량의 신뢰성에 대한 평가 방법에 대하여서는 제시된 바가 없다. 본 연구는 사례연구를 통하여 쌍곡선법으로 예측된 장래침하량들과 실 침하량들을 비교하고, 초기 계측기간에 따른 장래 침하량 예측의 신뢰성에 관한 분석을 통하여, 쌍곡선법을 이용한 장래 침하량 추정의 신뢰성 평가 방법을 제시하고자 한다.

Abstract

Predictions of settlements under preloading for the improvement of soft soil is a very important element of construction management. Due to the non uniformity, difficulty of estimating resonable soil properties, predictions of settlements and settlement velocities at the design stage seldom agree with the actual future settlements. To overcome this problem, the prediction methods based on the settlement observation of initial preloading stage such as hyperbolic method and Asaoka method have been employed frequently. However the estimating method for the reliability of these predictions at the time of prediction has

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not been suggested. In this study, comparisons of predicted settlements by hyperbolic method and observed settlements are explored through case studies. And a stratagem of estimating reliability of settlement predictions by hyperbolic method is suggested as the result of investigation on the relationship between the initial observed time and error of settlement prediction by hyperbolic method.

Keywords : Hyperbolic method, Settlement observation, Preloading, Reliability

1. Introduction

Prediction of future settlements is one of very important engineering procedures for preloading construction management. The planning of preloading period and fill height is usually established on the basis of the future settlement prediction to prevent shear failure of soft ground and to satisfy the final surface level. Since it is very difficult to predict accurate future settlement at the design stage, observed-prediction methods based on the initial settlement measurements of preloading period are frequently used to modify the original plan. Hyperbolic method is one of these methods. Assuming the relationship between settlement and time is hyperbolic, the following equations are suggested by Miyakawa (1967).

$$S_t = S_o + \frac{t}{\alpha + \beta \times t} \tag{1}$$

$$S_f = S_o + \frac{1}{\beta} \tag{2}$$

S_o : Settlement at the completion of Initial Embankment Fill

S_f : Final Settlement

S_t : Settlement at a Time (t)

t : Time after the Completion of Initial Embankment Fill

α, β: Coefficient of Hyperbolic Equation

Hyperbolic method may be considered as a simple and relatively reliable settlement prediction method and employed in many preloading construction monitoring. However it is difficult to recognize the reliability of prediction at the time of prediction. The reliability of prediction by hyperbolic method depends on many factors such as measurement error, measurement duration and similarity between hyperbolic curve and actual settlement curve. This study is mainly concerned with influence of measurement duration on the reliability of future settlement prediction. It is interesting to find how the predictions of future settlements at time t_{c1}, t_{c2} and t_{c3} are varied and what is the resonable initial measurement period for the reliable prediction.

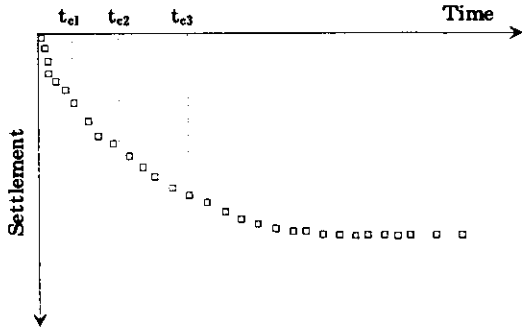

Fig 1. Schematic example of prediction time

2. Case Study

To investigate the variation of future settlement predictions due to the measurement per iod, settlement predictions on 10 settlement observation in 4 construction site are performed by hyperbolic method with variation of initial measurement period.

In this example site, the subsoil profile reveals the three topmost sublayers of Bangkok marine clay deposits underlaid by alternating layers of very dense sand and stiff clay exten ding to depths of more than 500m. The Bangkok clay at the site consists of the uppermost 14~15m, which can be divided into three distinct layers: namely, weathered clay, soft clay, and stiff clay(Fig. 2-1). The depth of water table varies seasonally from 0.5~2.5m, averaging about 1. 5m. The index properties of the compressible soft clay are shown in Fig. 2-2. Field vane tests were carried out by using a Geonor vane apparatus at the depth of 8

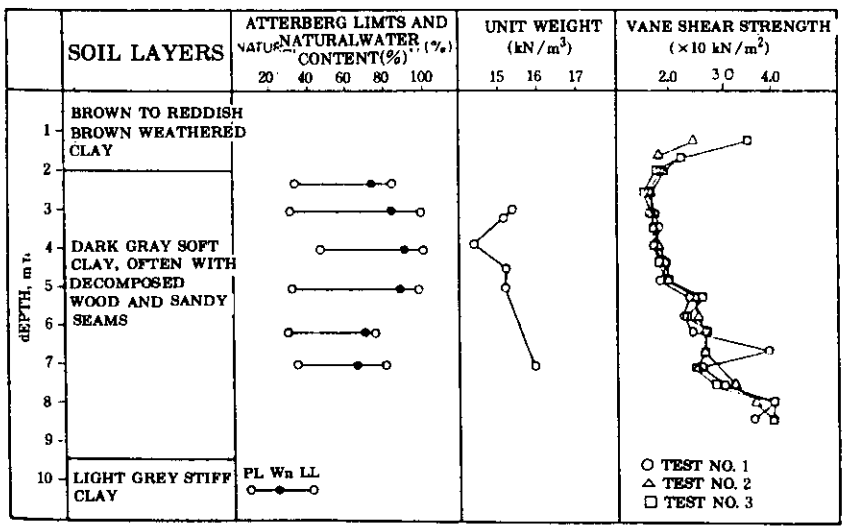

Fig 2-1 Subsoil profile at site with corresponding index properties and undrained shear strengh

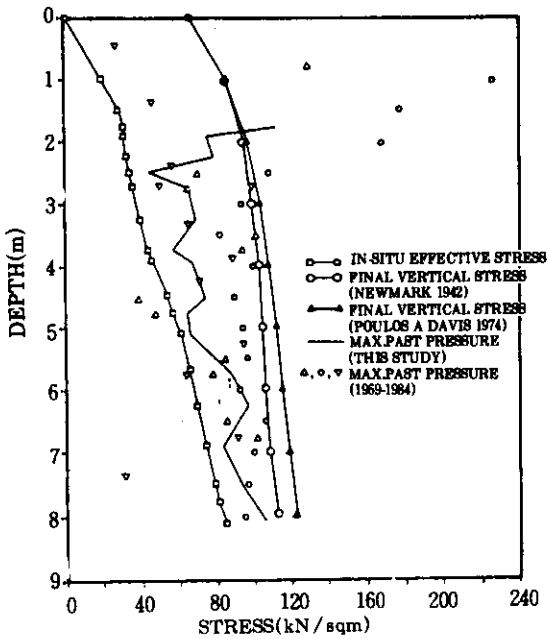

Fig 2-2. Stress history at site with results of previous investigations

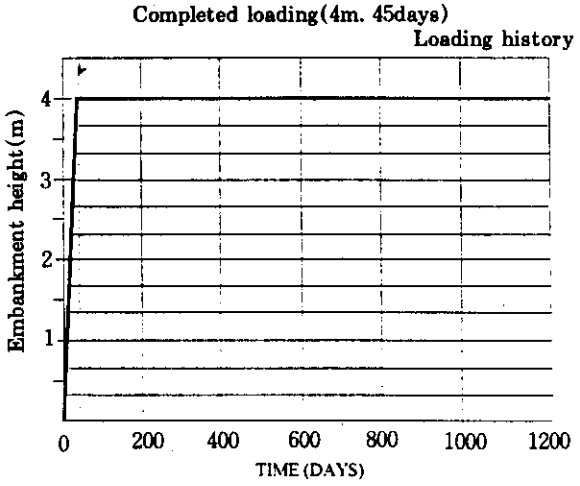

Fig 2-3. Embankment loading history at PVD site

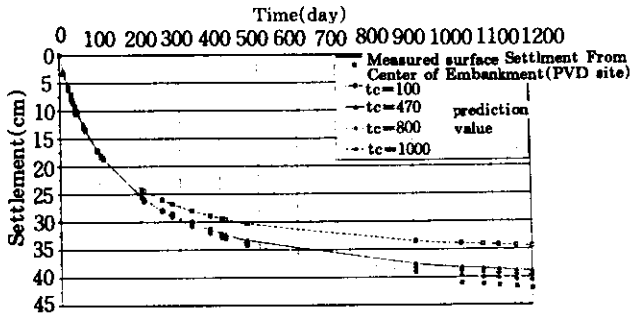

Fig 2-4. Case study(Bangkok test embankment)

to 9m. Typical results are also shown in Fig. 2-1. 4m high test embankment preloading was constructed on improved ground with prefabricated vertical drain(PVD). Embankment loading rate on the PVD site is shown in Fig. 2-3.

An example of case studies for settlement is shown in Fig. 2-4.

As the measurement period increases, the future settlement prediction by hyperbolic method approximates to the actual measurements as shown in Fig. 2−4. As an example, the prediction at the time of 1000 day shows better agreement with the measurement than the prediction at the time of 100 day. However the reliability of future prediction cannot be recognized at the time of prediction. Therefore it cannot be determined whether the prediction of future settlement predictions are reliable or not at the time of prediction.

3. Stratagem to Evaluate Reliability of Settlement Prediction

Since actual future settlements cannot be compared with settlement prediction at the time of prediction, the reliability of future settlement prediction cannot be determined at the time of prediction. Therefore it is needed to compare the hyperbolic settlement prediction with known value of future settlement through case studies. A stratagem is suggested to evaluate the reliability of future settlement prediction at the time of prediction here. To generalize the influence of intial measurement period on the reliability of future settlement prediction in a systematic manner, it may be needed to define the initial measurement period and error of prediction in non dimensional form. The parameters tc/T_{50} and tc/T_{90} are defined to express the influence of intial measurement period in non dimensional form.

$$\frac{tc}{T_{50}}=tc\frac{\beta}{\alpha} \tag{3}$$

$$\frac{tc}{T_{90}}=tc\frac{\beta}{9\times\alpha} \tag{4}$$

Where α, β is the coefficient of hyperbolic equation and tc is initial measurement period. The values of T_{50} and T_{90} can be obtained from the hyperbolic equation parameters.

$$T_{50}=\frac{\alpha}{\beta} \tag{5}$$

$$T_{90}=\frac{9\times\alpha}{\beta} \tag{6}$$

The description of T_{50} and T_{90} is shown in Fig. 3.

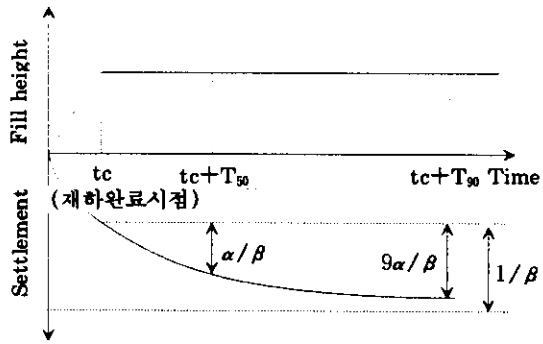

Fig 3. Description of T_{50} and T_{90}

Since α, β are changed with variation of initial measurement period before predictions, T_{50} and T_{90} can also be changed with variation of initial measurement period. And the error of settlement predictions by hyperbolic method can be defined as following equations:

$$E_{50}=\frac{S_{m50}-S_{h50}}{S_{m50}} \tag{7}$$

$$E_{90}=\frac{S_{m90}-S_{h90}}{S_{m90}} \tag{8}$$

Where S_{h50} and S_{m50} are hyperbolic prediction and actual measurement of settlement at T_{50} respectively and S_{h90} and S_{m90} are hyperbolic prediction and actual measurement of settlement at T_{90} respectively. The purpose of defining two functions of error (Eq. 7 and Eq. 8) is to express settlement prediction error at the different time. One defines error at the time of about 50% consolidation and the other defines error at the time of about 90% consolidation. Therefore overall difference of settlement between prediction and actual value can be examined. As examples, relationship of $E_{50}-t_c/T_{50}$ and $E_{90}-t_c/T_{90}$ for case study BKS 2 (Fig. 2-4) are presented in Fig. 4 and Fig. 5.

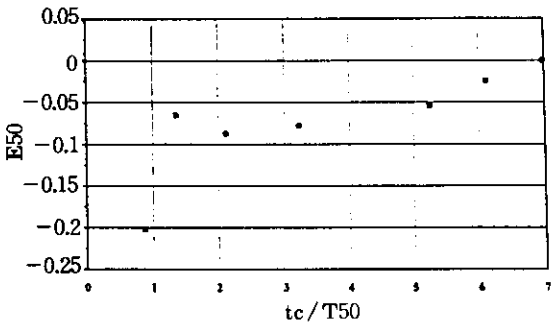

Fig 4. E50-tc/T50 for case study BKS2

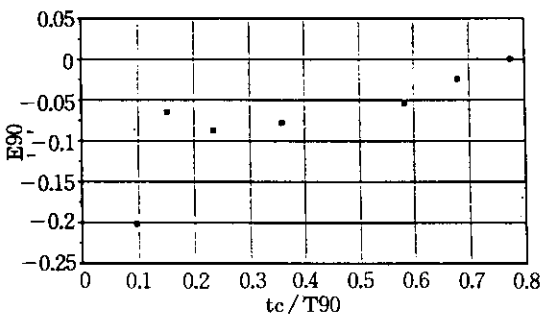

Fig 5. E90-tc/T90 for case study BKS2

4. Influence of Initial Measurement Period on the Reliability of Predictions

The error of prediction may be influenced by several factors such as quality of measurements, similarity of hyperbolic and actual measurement curve as well as initial measurement period. However it is very difficult to evaluate the effects of quality of measurements, similarity of hyperbolic curve and actual measurement curve quantitatively. Providing a criterion of initial measurement period on the reliability of hyperbolic settlement predictions may be very useful in the judgement of practical engineering. To investigate the influence of initial measurement period on the reliability of hyperbolic settlement predictions, relationship of $E_{50}-t_c/T_{50}$ and $E_{90}-t_c/T_{90}$ of 10 observation points in 4 construction site is examined(Fig. 6 and Fig. 7).

Both Fig. 6 and 7 show that reliability of hyperbolic settlement predictions increases as t_c/T_{50} and t_c/T_{90} are longer in a similar way. This may indicate the good similarity of hyperbolic curve and actual settlement time history curve. When t_c/T_{50} is 2.2, maximum error of prediction is less then 10% and when t_c/T_{50} is 1.5, maximum error of prediction is less then 15% for all investigated case studies. When t_c/T_{90} is 0.25, maximum error of pre-

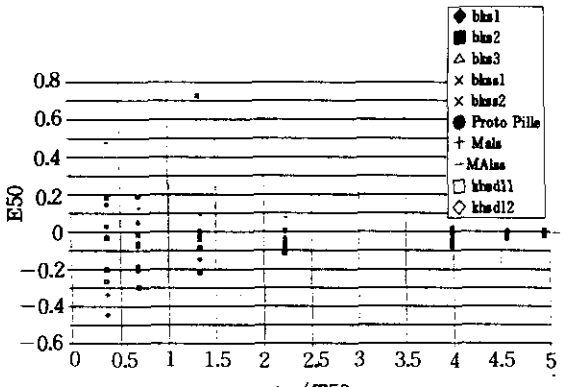

Fig 6. E50-tc/T50

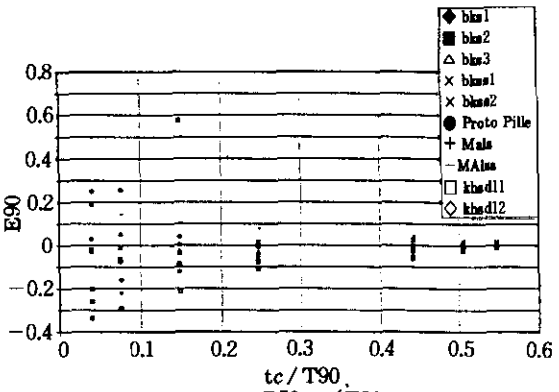

Fig 7. E50-tc/T90

diction is less then 10% and when t_c/T_{50} is 0.2, maximum error of prediction is less then 15% for all investigated case studies.

5. Summary and Further Study

Influence of initial measurement period on the reliability of hyperbolic settlement prediction is investigated. In order to provide generalized parameter of initial measurement period, t_c/T_{50} and t_c/T_{90} are defined in non dimensional form. And both of these two parameters can be obtained from hyperbolic method itself at the time of prediction. The results of case studies may suggest that t_c/T_{50} be larger than 2.2 and t_c/T_{90} be larger than 0.25 to keep the error of hyperbolic settlement predictions less than 10%. However this result is based on limited case studies, and those suggested value can be considered as a reference. In fact, to collect qualified and valuable settlement measurement record was very difficult. To make this study more useful, analysis of quality of measurements and evaluation of the influence of soil characteristics such as plastic index, compressibility are needed in further extensive case study. And similar studies can be explored in the other observed settlement prediction methods such as Asaoka method and Hoshino's method.

References

1. Daewoo(1995), "Soil investigation for municipal waste water plants" 1995.
2. Dennes T. B., Apollo. S. E., Casan L. S. & Marolo. C. A. (1992), "Inverse Analysis Of Geotechnical Parameters On Improved Soft Bangkok Clay" Proc. ASCE J. Geotechnical Engineering, Div. Vol. 118, No. 7, July, pp. 1012~1030.
3. Indraratna B., Balasubramaniam A. S. & Ratnayake. P. (1994), "Performance Of Embankment Stab ilized With Vertical Drains On Soft Clay" Proc. ASCE J. Geotechnical Engineering, Div. Vol. 120, No. 2, Feb. , pp. 257~273.

4. Indraratna B. & Redana I. W. (1997), "Plane-Strain Modeling Of Smear Effects Associated With Vertical Drains" Proc. ASCE J. Geotechnical & Geoenvironmental Engineering, Div. Vol. 123, No. 5, May, pp. 474~478.
5. Hird C. C. et al. (1995), "Modelling The Effects Of Vertical Drain In 2-D Finite Element Analysis Of Embankment On Soft Ground" Can. Geotech. J. Vol. 32, pp. 795~807.
6. Miyakawa Ichiro. (1967), "A Research On Preloading by Sand Mat and Drain", Soil and Foundation, Vol. 15, No.3.

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