Soils and Foundations 2012;52(2):207–215

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Combined effects of strain rate and temperature on consolidation behavior of clayey soils

Ayato Tsutsumi[a,*], Hiroyuki Tanaka[b]

[a]Foundations Group, Geotechnical Engineering Field, Independent Administrative Institution, Port and Airport Research Institute, Japan
[b]Division of Field Engineering for the Environment, Graduate School of Engineering, Hokkaido University, Japan

Available online 11 April 2012

Abstract

It is considered that the long term settlement of clay deposits, known as secondary consolidation, is caused by clay viscosity. In this paper, the viscous property of clayey soils is examined from two viewpoints: one is temperature and the other is the effect of the strain rate. To investigate these effects, a special constant rate of strain (CRS) loading test, in which the strain rate is changed during the test, was carried out at temperatures of 10 and 50 °C on reconstituted clay samples. Under the normal strain rate, such as the order of $10^{-6}\,s^{-1}$, well-known temperature effects on the consolidation behavior were confirmed. That is, the high temperature condition leads to increased hydraulic conductivity due to the reduction in the viscosity of pore water at higher temperatures. It is also observed that the yield consolidation stress decreases with increasing temperature due to the viscous properties of soil skeletons. However, it is found that with higher temperature and smaller strain rates, the clay specimen does not follow conventional viscous behavior, like the Isotache model, but the gradient of stress–strain curve considerably decreases. The reason for different behavior from the Isotache model may be attributed to the creation of a new structure to resist the external deformation, under high temperature and a slow strain rate.

Keywords: Clay; One-dimensional consolidation; Strain rate effect; Temperature effect

1. Introduction

The long term settlement of soft clay deposits after the dissipation of excess pore water pressure, which is sometimes called secondary consolidation or creep deformation, has been an important but difficult issue in geotechnical engineering. A consensus seems to exist among researchers that such creep settlement is caused by viscous properties of the clay skeleton. Hence, it is very important to understand and evaluate the viscous behavior of clayey soils in order to predict the ground settlement during and after dissipation of the excess pore water pressure with more accuracy. In the laboratory, the viscosity can be expressed in terms of the strain rate effect in one-dimensional consolidation tests, and test results may be interpreted by consolidation models which take the strain rate into consideration. A typical model is the Isotache model proposed by Šuklje (1957). In the Isotache model, the compression behavior is determined by the order of the strain rate (see for example, Leroueil et al., 1985; Imai and Tang, 1992; Imai et al., 2003; Tanaka, 2005a and b; Watabe et al., 2008). Kobayashi et al. (2005) have reported that the Isotache model provides accurate predictions of the settlement in the Pleistocene clay layers at the Kansai International Airport, Japan, than the conventional Terzaghi's consolidation model. However, making settlement based on the Isotache model requires the consolidation soil parameters under extremely

*Corresponding author.
E-mail address: tsutsumi-a@pari.go.jp (A. Tsutsumi).

Peer review under the responsibility of The Japanese Geotechnical Society
http://dx.doi.org/10.1016/j.sandf.2012.02.001

Production and hosting by Elsevier

small strain rates in the field, i.e., smaller than $10^{-10}\ s^{-1}$ (see Leroueil, 2006).

Tsutsumi and Tanaka (2011) have developed a special CRS test apparatus and conducted the CRS test, in which the strain rate is changed during the test from 10^{-6} to $10^{-10}\ s^{-1}$. According to the Isotache model, when the strain rate is changed, the stress–strain curve immediately shifts to that corresponding to the new strain rate, and as expected, when the strain rate suddenly decreased, the effective stress decreased due to the viscous property of clay skeleton. However, some interesting behavior was also observed: the clay specimen under very small strain rates did not follow the stress–strain curve expected from the Isotache model. Actually, gradient of the curve was markedly smaller than that of virgin compression curve, which the specimen would be expected to follow if the strain rate was not changed. Furthermore, when the strain rate went back to the original rate from very small strain rates, the stress–strain curve overshot the expected virgin compression curve, as if the clay specimen had developed structure in the previous loading process under small strain rates. Hence, the Isotache model cannot be directly applied to the compression behavior under small strain rates. Such non-Isotache stress–strain behaviors have also been reported by Tatsuoka et al. (2008), who conducted drained triaxial compression tests for granular materials. They proposed other viscosity models, such as TESRA, Combined and P & N.

It is well known from previous studies that the viscous property of soft clayey soils is strongly related not only to the strain rate, but also to temperature: the yield consolidation pressure decreases with increasing temperature (see for example, Eriksson, 1989; Boudali et al., 1994; Akagi and Komiya, 1995; Marques et al., 2004). In addition, another important temperature effect on consolidation has been reported: the development of a structure resisting deformation accelerates under long-term consolidation at high temperature (see Tsuchida et al., 1991; Towhata et al., 1993). Change in the temperature may provide a clue for understanding the non-Isotache behavior reported by Tsutsumi and Tanaka (2011). In this study, CRS consolidation tests with varying strain rates at different temperature levels were carried out for three different clayey soils.

2. Testing method and samples

2.1. CRS test apparatus and testing procedures

In order to study the temperature effect, it is preferable to carry out CRS test using the same specimen, i.e., by changing the temperature during the testing, to avoid any differences in soil properties for different specimens. However, changing the temperature during the testing is very difficult in practice. When the temperature is changed, the measuring system as well as the specimen itself is influenced. One example is the zero drift of the sensors. For this reason, the CRS tests were carried out at two constant temperatures: 50 and 10 °C. Although it is recommended to carry out the CRS test under large different temperature levels to identify the temperature effect, the sustainability of the test is very important to obtain stable test data for a long period of more than a week. Taking into account these demands and the capability of the apparatus used in this study, testing temperatures of 50 and 10 °C were adopted.

The CRS apparatus followed JIS A 1227 (Japanese Standards Association, 2009b): the specimen was 60 mm in diameter and 20 mm in initial height. Fig. 1 shows a schematic view of the consolidation cell. Drainage was allowed through the upper end of the specimen. The bottom of the specimen was connected to a transducer to measure the water pressure. The load generated by applying a constant strain was measured by a load cell at the bottom of the consolidation cell. A back pressure of 100 kPa was applied to assure good saturation of the specimen during the test. The effective vertical pressure (p') was calculated assuming that the excess pore water pressure in the specimen is distributed in a parabolic manner as expressed by the following equation:

$$p' = \sigma - \frac{2}{3}\Delta u \quad (1)$$

where σ is the total pressure on the specimen and Δu is the excess pore water pressure.

To generate a stable and extremely small strain rate, a special loading apparatus was developed, consisting of a Step Motor System whose resolution is as accurate as 2,621,440 pulses per revolution, and this was controlled by a personal computer (see Tsutsumi and Tanaka, 2011).

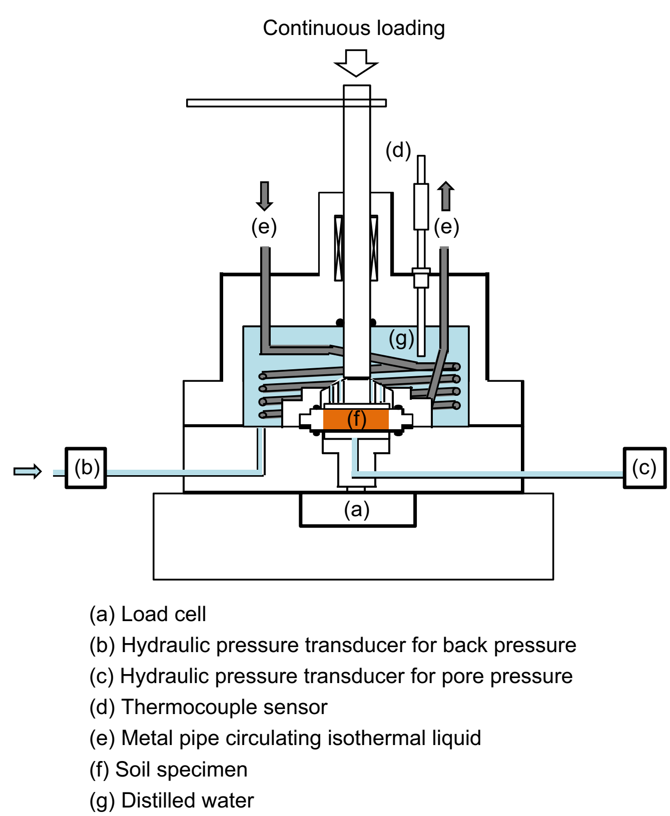

Fig. 1. Schematic view of consolidation cell.