ARTICLE IN PRESS
ENGEO-04443; No of Pages 8
Engineering Geology xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Engineering Geology
journal homepage: www.elsevier.com/locate/enggeo

Practical estimation of compression behaviour of dredged clays with three physical parameters

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ARTICLE INFO

Article history:
Received 14 August 2016
Received in revised form 4 December 2016
Accepted 24 December 2016
Available online xxxx

Keywords:
Dredged clays
Initial water content
Virgin compression
Remoulded yield stress
Liquid limit
Particle density

ABSTRACT

Understanding the compression behaviour of dredged clays is essential for their effective use with drainage. Measuring consolidation parameters of dredged clays at high initial water contents is a time-consuming and tough work. The research team has accumulated the database of 110 one dimensional incremental load consolidation tests for dredged clays. Based on this database, this study proposes a simple method of determining virgin compression of dredged clays using three physical parameters which can be easily measured. The compression curves of dredged clays can be divided into the pre-yield and the post-yield zones. Basic equations are suggested for describing the compression behaviour of the two zones. The associated parameters are correlated with the initial void ratio and the void ratio at liquid limit. The predicted compression curves are compared with the measured ones with the accumulated database and the independent data available from literature. The error of the void ratios predicted is found to vary within 10% compared with the measured ones. In engineering practice, the work in this study can be applied instead of the time-consuming and tough experiments to simply estimate the compression behaviour of dredged clays.

1. Introduction

The booming economy in China promotes greatly the dredging activities in recent years. The dredging activities produce at least 100 million cubic meters of fine-grained clays per year. Note that the common technique of dredging in China is the hydraulic method by mixing the sediments deposited at the beds of sea, river and lake with a large amount of water. Hence, the dredged clays often have the particularity of high water contents, consequently resulting in poor engineering properties (e.g. Xu et al., 2012; Bian et al., 2016). Drainage method (such as surcharge or vacuum preloading) is often used in engineering practice for improving the engineering properties of dredged clays for their effective use. Understanding the compression behaviour of dredged clays at high water contents is an important issue for drainage research and application (e.g. Carrier and Beckman, 1984; Chu et al., 2000; Bo et al., 2010).

One dimensional incremental load consolidation test is a common way of measuring the compression parameters of soils (e.g. Butterfield, 1979; Liu and Carter, 1999, 2000; Liu et al., 2013; Kima et al., 2013). Head (1992) addressed that adequate attention should be paid to the problem of soil squeezing out through the clearance gap between the ring and the upper porous disc for clays reconstituted at high initial water contents (w_0). Hong et al. (2010) suggested a modified consolidometer apparatus starting from a very low effective vertical stress (σ'_v) of 0.5 kPa for avoiding soil squeezing out for clays reconstituted at high values of w_0. The detail information on the modified consolidometer apparatus can be found in Hong et al. (2010).

It is worth noting that, however, obtaining the consolidation test data of various clays reconstituted at high values of w_0 is very time-consuming. For example, at least one month is required for completing a consolidation test of dredged clays with 40 mm height by adopting the modified consolidometer apparatus starting from the first step load of $\sigma'_v = 0.5$ kPa. In addition, experimental skills and enough attention are required for handing the specimens and keeping horizontal alignment of upper stone, because the reconstituted clays with high water contents have a very low stiffness. Note that dredged clays at high values of w_0 are in nature the same as the reconstituted clays at high water contents. Hence, a simple way of estimating the compression curves of dredged clays instead of the time-consuming and tough experiments is very valuable in engineering practice, especially for preliminary design on the effective use of dredged clays with drainage.

This study aims at proposing a practical approach of quantitatively estimating the virgin compression of dredged clays using simple physical parameters. The compression curves of dredged clays are divided

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http://dx.doi.org/10.1016/j.enggeo.2016.12.013
0013-7952/

Please cite this article as: Zeng, L.-L., et al., Practical estimation of compression behaviour of dredged clays with three physical parameters, Eng. Geol. (2016), http://dx.doi.org/10.1016/j.enggeo.2016.12.013

Notation

e	Void ratio
e_0	Initial void ratio
e^*_{100}	Void ratio of reconstituted clays at $\sigma'_v = 100$ kPa
e_L	Void ratio at liquid limit
e_{yr}	Void ratio of reconstituted clays at $\sigma'_v = \sigma'_{yr}$
Post-yield	Effective stress larger than yield stress
Pre-yield	Effective stress less than yield stress
w_L	Liquid limit
w_0	Initial water content
σ'_v	Effective vertical stress
σ'_{yr}	Remoulded yield stress of reconstituted clays

into two parts: the pre-yield and the post-yield zones. The remoulded yield stress (σ'_{yr}) suggested by Hong et al. (2012) is introduced to bound these two parts. The data obtained in this study together with those reported by Hong et al. (2010) and Zeng et al. (2015) provide the database of total 110 one dimensional incremental load consolidation tests. Based on this database, the values of σ'_{yr} and the void ratio (e_{yr}) at σ'_{yr} are correlated with physical parameters. Then, basic compression equations are suggested for describing the compression behaviour at the pre-yield and the post-yield zones respectively. The parameters associated with the basic equations are also discussed. Finally, the validity of the simple method proposed is investigated based on the accumulated database and the independent data available from literature.

2. Database of consolidation test data and features of compression curves of dredged clays

The research team has accumulated the database of total 110 one dimensional incremental load consolidation tests for various clays reconstituted at a wide variety of w_0, as shown in Table 1. Among the database, 20 types of reconstituted clays with different values of w_L and w_0 were firstly reported in this study and 90 types were from Hong et al. (2010) and Zeng et al. (2015). Note that Hong et al. (2010) aimed at investigating the effect of w_0 on the compression behaviour of various clays reconstituted at a wide spectrum of w_0. Zeng et al. (2015) established the empirical methods of determining the two intrinsic parameters associated with the void index proposed by Burland (1990). The modified consolidometer apparatus reported in Hong et al. (2010) was adopted to obtain the consolidation test data in Table 1.

Some physical properties of the clays in the database can be seen in Table 1. The values of liquid limit (w_L) and plastic limit (w_P) were measured using the Casagrande apparatus method and the rolling method respectively, in accordance with BS1377: Part 2, 1990. The clays have a wide spectrum of w_L, ranging from 28.1% to 100.0%. They represent most dredged clays in China that can be encountered in engineering practice. The values of w_0 for all the clays investigated fall within the range of $w_0 = 0.7$–$2.2w_L$. The detail information on specimen preparation refers to Hong et al. (2010) and Zeng et al. (2015).

It has been well documented that the compression curves of dredged clays at high values of w_0 generally show an inverse "S" shape in the e–logσ'_v plot (e.g. Hong et al., 2010; Zeng et al., 2015), as typically shown in Fig. 1. This feature is the same as the inverse "S" shape in the e–logσ'_v compression curves of naturally structured clays (e.g. Butterfield, 1979). It has been also well reported that the compression curves of both the naturally structured soils and the reconstituted clays with inverse "S" shape can be plotted as two straight lines in the bilogarithmic plot of specific volume ($1 + e$) against σ'_v (e.g. Butterfield, 1979; Hong et al., 2010), as typically shown in Fig. 2. Note that the stress range discussed in this study varies within the range of $\sigma'_v = 0$–100 kPa. Such a stress range can present the loads of drainage methods like surcharge or vacuum preloading on dredged clays encountered in engineering practice.

The intersection point of the two straight lines in the ln($1 + e$)–logσ'_v plot in Fig. 2 is responsible for yielding (e.g. Butterfield, 1979; Hong et al., 2010). The stress at the intersection point for dredged clays reconstituted at different values of w_0 was termed as "suction pressure" by Hong et al. (2010) following the term "pore water suction" used by Mitchell and Soga (2005). Such a term is easily confused with that for the descriptions of unsaturated soils. Hence, it was later called as "remoulded yield stress" (σ'_{yr}) in Hong et al. (2012) following the remoulded state defined by Leroueil et al. (1985).

3. Basic equations of virgin compression

The role of σ'_{yr} for dredged clays is the same as the consolidation yield stress for naturally structured clays. That is, the compression curves can be divided into two parts: the pre-yield zone when $\sigma'_v < \sigma'_{yr}$ and the post-yield zone when $\sigma'_v \geq \sigma'_{yr}$. The pre-yield zone is characterized with small deformation and can be approximately regarded as an elastic zone. Hence, it is assumed that the relationship between e and σ'_v is linear. That is, the compression curve of dredged clays at the pre-yield zone can be expressed as follows:

$$e = e_0 - (e_0 - e_{yr}) \times \sigma'_v/\sigma'_{yr} \text{ for } \sigma'_v < \sigma'_{yr} \tag{1}$$

where e_0 is the initial void ratio.

When σ'_v reaches the order of σ'_{yr}, the compression curve of dredged clays can be expressed by a straight line in the ln($1 + e$)–logσ'_v plot, as typically shown in Fig. 2. Hence, the following equation can be obtained for describing the virgin compression of dredged clays at the post-yield zone:

$$\ln(1+e) = \ln(1+e^*_{100}) + (\ln(1+e^*_{100}) - \ln(1+e_{yr})) \times ((2 - \log(\sigma'_v)/\left(2 - \log\left(\sigma'_{yr}\right)\right) \text{ for } \sigma'_v \geq \sigma'_{yr} \tag{2}$$

where e^*_{100} is the void ratio of dredged clays at $\sigma'_v = 100$ kPa.

Note that a linear e–logσ'_v compression line has been widely used for representing reconstituted soil behaviour (e.g. Nagaraj and Srinivasa Murthy, 1986; Liu and Carter, 1999, 2000). However, the experimental results on the compression behaviour of clays reconstituted at high values of w_0 often indicate the divergence from the linear e–logσ'_v compression line. Burland (1990) illustrated that the e–logσ'_v compression curves of reconstituted clays at $w_0 = 1.25w_L$ are in a shape slightly concave upwards when $\sigma'_v > 10$ kPa. Hong et al. (2010) and Zeng et al. (2015) also addressed the non-linearity in e–logσ'_v compression curves of reconstituted clays with high values of w_0/w_L.

Fig. 3 typically shows the compression curves linking three data points (the first step load at $\sigma'_v = 0.5$ kPa, yielding point at σ'_{yr} and e^*_{100} at $\sigma'_v = 100$ kPa) expressed in three different linear forms: e–σ'_v, e–logσ'_v and ln($1 + e$)–logσ'_v, respectively. The experimental results expressed by data points are also shown in the same figure for comparisons. It can be seen that all the three linear forms can be used for describing well the compression behaviour at the pre-yield zone. For simplicity and the advantage of using the data of e_0, the linear relationship of e against σ'_v expressed in Eq. (1) is adopted in this study for presenting the compression behaviour of dredged clays at the pre-yield zone.

On the other hand, the linear e–σ'_v relationship is not applicable for describing the compression behaviour of dredged clays at the post-yield zone. The linear relationship in the ln($1 + e$)–logσ'_v plot is found to fit better the test data at the post-yield zone than the linear e–logσ'_v line, especially for the dredged clays with high values of w_0/w_L. Note that several researchers also pointed out the advantages of the ln($1 + e$)–

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