Applied Clay Science 123 (2016) 320–328

Contents lists available at ScienceDirect

Applied Clay Science

journal homepage: www.elsevier.com/locate/clay

Research paper

Time-dependent compression behaviour of dredged clays at high water contents in China

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ARTICLE INFO

Article history:
Received 16 December 2015
Received in revised form 22 January 2016
Accepted 26 January 2016
Available online 2 February 2016

Keywords:
Dredged clays
Ageing
Yield stress
Consolidation
Soil structure
Volumetric strain

ABSTRACT

Incremental load one-dimensional consolidation tests were performed on dredged clays with and without ageing to investigate their time-dependent compression behaviour. The dredged clays investigated had a wide spectrum of liquid limits within 55.6% to 100% and a predominant clay mineral of illite. It is found that vertical yield stresses develop notably during ageing. The developed vertical yield stresses vary within the range of 1.2 to 1.8 times the specifically assigned vertical effective stress under which ageing is allowed for 15 to 105 days. But the corresponding ageing volumetric strains are small, varying within the range of 0.6% to 3.4% with most being less than 2%. The test results obtained also allow proposing an empirical equation of assessing vertical yield stress. The changing law of vertical yield stress with stress level for ageing, ageing time, soil properties is investigated based on the empirical equation. Moreover, it is found that the structural resistance of dredged clays developed during ageing for a period of consolidation time up to 105 days is weak compared with the sedimentation compression line of natural clays developed during long geological ageing. But the compression curves of dredged clays with ageing converge slowly to the intrinsic compression line over a wide range of stresses, like natural clays subjected to the effect of soil structure developed during long depositional and post-depositional processes.

1. Introduction

Recent years in China, more than 100 million cubic metres of fine-grained clays are produced per year from dredging activities. As hydraulic dredging is the common technique employed in China, the dredged clays in general have the particularity of high water contents, consequently resulting in poor engineering properties. Hence, the dredged clays have been considered as waste slurries since long time. Nowadays, as land demand sharply increases, finding a land to stack the waste clays from dredging activities becomes more and more difficult. In the meanwhile, the economic progress boosts the requirement of reclaimed land. To handle this dilemma in China, dredged clays are generally used as filling materials to form reclaimed lands. The hydraulic reclamation in the field generally sustains several months even several years. It has been well documented that both natural and artificial soils with ageing possess time-dependent behaviour (e.g., Schmertmann, 1991; Yin and Hicher, 2008; AL-Zoubi, 2010; Deng et al., 2012; Yin et al., 2014). Several researchers also reported that the creep deformation in terms of volumetric change during ageing gives a hardening effect to the yield stress (e.g., Leroueil and Vaughan, 1990; Karstunen and Yin, 2010; Yin et al., 2015; Zhu et al., 2015). Hence, it can be logically expected that the mechanical behaviour of dredged clays will undergo ageing effect during the construction process of reclaimed land.

Carrier and Beckman (1984) stated that the compression behaviour of dredged clays at high initial water contents is an important issue for an effective use of reclaimed lands. The time-dependent compression behaviour of dredged clays will significantly affect the design capacity of a storage pond and the subsequent technique for ground improvement of the reclaimed land. Note that experimental studies have seldom been carried out by former studies on the time-dependent compression behaviour of dredged clays at high initial water contents. Leonards and Altschaeffl (1964) performed incremental load one-dimensional consolidation tests on an artificially sedimented clay with and without ageing to study the influence of ageing on the compression behaviour, and identified the obvious development of quasi-preconsolidation pressure during ageing. They explained it as the increase in bond strength developed during the period of time in which the applied stress was constant. That is, the reconstituted clays subjected to ageing will behave differently from the reconstituted clays without ageing. Note the compression behaviour is associated with many important consolidation parameters, such as the compressibility (e.g., Liu and Carter, 1999, 2000; Alawaji, 1999; Horpibulsuk et al., 2007; Liu et al., 2013; Zeng and Hong, 2015), the change hydraulic conductivity during compression (e.g., Tavenas et al., 1983; Berilgen et al., 2006; Dolinar, 2009; Horpibulsuk et al.,

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http://dx.doi.org/10.1016/j.clay.2016.01.039

Notation

C_c^*	intrinsic compression index of dredged clays without ageing, equal to $(e^*_{100}–e^*_{1000})$
C_c	compression index of dredged clays with ageing, equal to $(e_{100}–e_{1000})$
e	void ratio
e^*_{EOP}	void ratio of EOP compression curve
EICL	extended intrinsic compression line
e_L	void ratio at liquid limit
e_n	in-situ void ratio
EOP	end of primary consolidation
e_t	void ratio at t for aged clays
e_0	initial void ratio
e_{100}	void ratio of aged clays at $\sigma'_v = 100$ kPa
e_{1000}	void ratio of aged clays at $\sigma'_v = 1000$ kPa
e^*_{100}	void ratio of EOP compression curve at $\sigma'_v = 100$ kPa
e^*_{1000}	void ratio of EOP compression curve at $\sigma'_v = 1000$ kPa
ICL	intrinsic compression line
I_v	void index
I_{v0}	in-situ void index
w_L	liquid limit
w_P	plastic limit
w_0	initial water content
PI	plasticity index
SCL	sedimentation compression line
t	consolidation time, including primary consolidation time and ageing time
XRD	X-ray diffractometry
YSR	ratio of vertical yield stress to effective vertical stress
σ'_v	effective vertical stress
σ'_{veop}	stress on the EOP line
σ'_{vy}	vertical yield stress developed during ageing
σ'_{v0}	effective overburden pressure
ε_{ageing}	ageing volumetric strain

2011; Zeng et al., 2011), the coefficient of consolidation used in deformation analysis and settlement rate estimation (e.g., Parkin, 1978; Sridharan et al., 1995; Mesri et al., 1999; Gurtug, 2011), etc.

The objective of this study is to investigate the time-dependent compression behaviour of dredged clays with high initial water contents. Incremental load one-dimensional consolidation tests were performed on dredged clays with and without ageing. The time-dependent vertical yield stress is investigated, and the main factors influencing the relationship between vertical yield stress and consolidation time are also discussed. Then, the notion of ageing volumetric strain is introduced for describing the deformation behaviour of aged clays. The relationship between vertical yield stress and ageing volumetric strain is studied. Finally, the intrinsic compression concept proposed by Burland (1990) is used as a reference to compare with the aged clays for describing the change in structural resistance developed during ageing with stress level.

2. Materials and methods

Three clays were taken from Huaian city and Lianyungang city of Jiangsu province in China. They are denoted herein as Huaian clay A, Huaian clay B and Lianyungang clay, respectively. Note that these three clays were used by Zeng and Hong (2015) for comparing the primary consolidation time determined by pore pressure dissipation with that determined by the Taylor method and the Casagrande method using settlement-time observations. The samples of Huaian clay A and Huaian clay B were obtained from a reclaimed land which was made by deposition of soils dredged from the Grand Canal bed located at Baima Lake in Huaian city. The samples of Huaian clays were taken after dredged and resedimented for 3 days, the clays being probably still under self-weight consolidation. Their in-situ water contents were very high, about 2.5–3.0 times their liquid limits. The samples of Lianyungang clay were taken at a depth of about 3 m at a construction site of the Lianyungang-Linhai highway using a polyvinyl chloride tube of 300 mm in diameter and 300 mm in height, and its natural water content was about 50%.

The physical properties of the three clays are shown in Table 1. The liquid limits (w_L) measured using Casagrande Method (BS1377: Part 2: 1990: 4.3) range from 55.6% to 100.0%. The plastic limits (w_P) were determined in accordance with BS1377: Part2: 1990: 5.3, as suggested by Head (1992). Fig. 1 shows the plasticity chart, indicating that all the clays lie slightly above or on the A-line defined by $PI = 0.73(w_L - 20)$, where PI is the plasticity index. The mineralogical compositions of the three clays investigated were reported by Zeng and Hong (2015) based on X-ray diffractometry (XRD) tests. The X-ray diffraction patterns of the three clays were illustrated in Zeng and Hong (2015), as shown in Fig. 2. Following Mitchell and Soga (2005), a semi-quantitative method by comparing the reflection areas of the X-ray diffraction patterns was adopted to determine the clay minerals. The clay minerals are illite, chlorite, kaolinite and smectite, as shown in Table 2. The predominant clay mineral is illite, with a proportion being 61%, 59% and 68% for Huaian clay A, Huaian clay B, Lianyungang clay respectively.

For simulating the initial conditions of dredged clays, different initial water contents (w_0) ranging from 0.8 to 1.8 times their corresponding liquid limits were considered by mixing the clays and distilled water. When the target initial water content was greater than the in-situ one, distilled water was added and mixed to reach the target initial water content. By contrast, when the target initial content was lower than the in-situ one, the specimen was firstly air-dried to let the water content to be slightly lower than the target value. Then, the required quantity of distilled water was added and mixed to reach the target initial water content. Several researchers reported that the water contents of dredged soils after self-weight consolidation are very high (e.g., Been and Sills, 1981; Xu et al., 2012). In fact, even for natural sedimentary clays, the in-situ water contents of the upper 200 mm layer of sea and lake beds are often higher than 1.5 times their respective liquid limits (Tsuchida and Gomyo, 1995; Buchan and Smith, 1999). The initial water contents considered in this study were lower than the highest ones of dredged slurries after sedimentation, because there were technical difficulties in putting the upper porous stone in alignment for specimens at very high water contents.

Table 3 shows the test programme including 40 incremental load one-dimensional consolidation tests — 13 end of primary consolidation (EOP) tests and 27 ageing tests. Note that data from 6 EOP tests data on Huaian clay A and from 3 EOP tests data on Lianyungang clay were used by Zeng et al. (2015) for developing empirical equations of determining the intrinsic compression parameters with other available data. The incremental load one-dimensional consolidation tests were carried out using a modified oedometer apparatus with the first step load as low as 0.5 kPa (Hong et al., 2010). All specimens had a diameter of 61.8 mm, and an initial height of 40 mm. The duration of consolidation under each loading step was controlled by the pore pressure dissipation.

Table 1
Basic physical properties of dredged clays.

Soil	Density of soil particles (Mg/m^3)	Liquid limit w_L (%)	Plastic limit w_P (%)
Huaian clay A	2.70	100.0	38.8
Huaian clay B	2.70	70.8	33.5
Lianyungang clay	2.70	55.6	28.8