Ocean Engineering 147 (2018) 45–50

Contents lists available at ScienceDirect

Ocean Engineering

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

Short communication

Laboratory study for soil structure effect on marine clay response subjected to cyclic loads

Jian Leng [a], Chencong Liao [a,*], Guanlin Ye [a], D.-S. Jeng [a,b]

[a] State Key Laboratory of Ocean Engineering, Department of Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China
[b] Griffith School of Engineering, Griffith University Gold Coast Campus, Queensland, QLD 4222, Australia

ARTICLE INFO

Keywords:
Soft clay
Soil structure
Cyclic loads
Axial strain
Effective stress path
Pore water pressure

ABSTRACT

In this paper, a series of undrained dynamic cyclic triaxial tests were conducted to investigate structure effect on soil response due to cyclic loads. Soil samples used in this study are 1) undisturbed Shanghai marine clay and 2) artificially disturbed and remoulded Shanghai marine clay. Dynamic response, including strain development, effective stress path and pore water pressure, of both clay samples that subjected to cyclic loads were measured, respectively. Test results between undisturbed and remoulded disturbed samples were compared in detail to clarify the role that soil structure may have played during repeated loadings. It is found that the soil structure has significant influence on residual pore water pressure development. Based on the experimental results, a partition diagram is proposed to evaluate the accumulated pore water pressure of clay in different sensitivities when estimating liquefaction potential subjected to cyclic loads.

1. Introduction

In recent years, an increasing amount of offshore and coastal infrastructure has been constructed in clayey seabed in marine environments, including pile foundations, spudcans and anchors (Gaudin et al., 2011; Zhu et al., 2012; Bao et al., 2014; Abbasa et al., 2015; Tian et al., 2015). Since these structures are subjected to repeated environmental loadings such as wave or wind loadings, cyclic response needs to be taken into consideration in the design of these foundations. Marine clay deposits generally in a sedimentary environment and usually formed specific structure during tens of thousands of years. The influence of this special structure, especially when subjected to cyclic loads, is one of the major concerns in the design of foundations for marine and onshore structures.

Many experimental studies have been conducted on response of clays due to cyclic or repeated loads in the last few decades (Sangrey et al., 1978; Procter and Khaffaf, 1984; Ansal and Erken, 1989; Hyde et al., 1993; Matasovic and Vucetic, 1995; Zhou and Gong, 2001; Li et al., 2011; Gu et al., 2012; Wichtmann et al., 2013). The results of these studies indicate that the soil response are progressive; the effective stress and pore water pressure depend on several factors, which can be classified into two categories: (1) loading conditions, including cyclic stress level, loading frequency, and loading directions; and (2) soil characteristics, including over-consolidation ratio, stress status, and Atterberg limits. However, to authors' best knowledge, researches that focused on the influence of soil structure on Shanghai marine clay under repeated loads are quite limited.

Burland (1990) reported that the soil structure could make a significant difference on mechanical properties between natural undisturbed and artificial remoulded clay; thus they have proposed the concept of porosity index to measure soil structure influence. Leroueil and Vaughan, 1990 summarized previous studies and concluded that the soil structure led to a stiffer and lower compression property of soil and the soil structure should be treated as a basic concept of equal importance to initial void ratio and stress history. Many other static experimental researches were conducted considering the influence of the soil structure (Amorosi and Rampello, 2007; Callisto and Calabresi, 1998; Cotecchia and Chandler, 1998; Gasparre et al., 2007). The results of these studies all indicated that the soil structure had a significant influence on the soil properties. From the experimental results, many structure models have been proposed (Liu and Carter, 2002; Gajo and Muir Wood, 2001; Kavvadas and Amorosi, 2000; Rouainia and Muir Wood, 2000).

In this paper, a series of undrained dynamic cyclic triaxial tests were conducted to investigate structure effect on soil response due to cyclic loads. Section 2 introduces the Shanghai marine clay and its properties. Methods about manufacture of remoulded clay and procedures of cyclic triaxial test schemes are presented in this section. Strain development,

* Corresponding author. Shanghai Jiao Tong University, Shanghai, 200240, China.
E-mail address: billaday@sjtu.edu.cn (C. Liao).

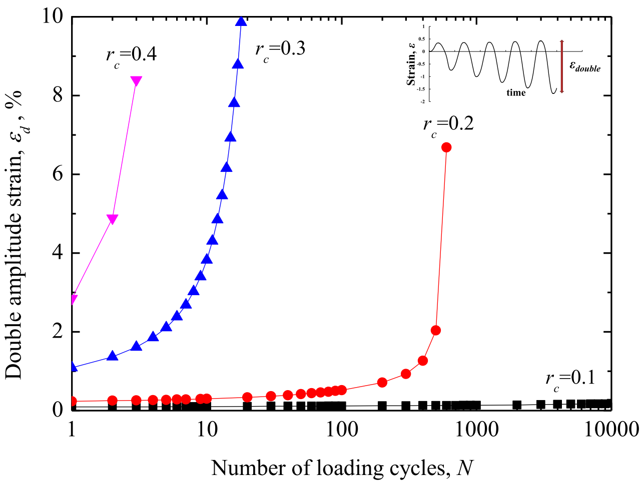
https://doi.org/10.1016/j.oceaneng.2017.10.020
Received 23 May 2017; Received in revised form 2 October 2017; Accepted 15 October 2017

Table 1
Undrained cyclic triaxal tests of Shanghai No.4 clay.

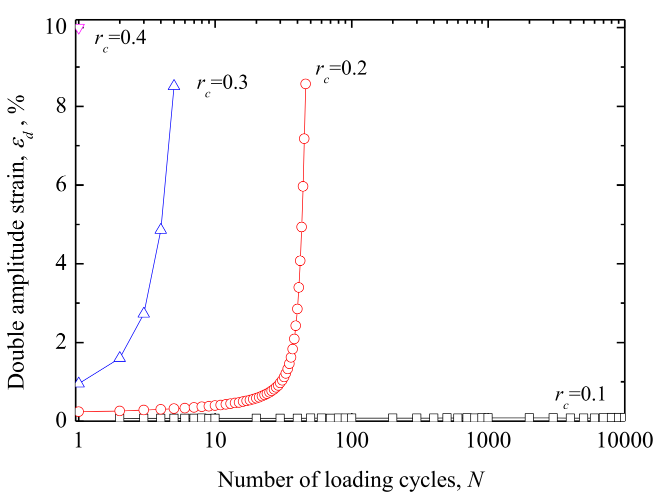
	Water content/%	Density/kg/m^3	Frequency/*Hz*	Cyclic stress ratio/r_c (=$\sigma_d/2\sigma_s$)	Number of cycles/*N*
Natural clay	45.4	1.77	2	0.4	300
	46.3	1.76	2	0.3	500
	44.5	1.75	2	0.2	6200
	45.3	1.76	2	0.1	10000[a]
	47.2	1.73	0.5	0.4	20
	47.5	1.73	0.5	0.3	180
	46.7	1.75	0.5	0.2	6500
	48.0	1.74	0.5	0.1	10000[a]
	49.8	1.71	0.02	0.4	4
	48.8	1.73	0.02	0.3	20
	47.5	1.74	0.02	0.2	670
	48.2	1.74	0.02	0.1	10000[a]
Remolded clay	37.4	1.87	0.02	0.4	1
	37.1	1.88	0.02	0.3	5
	37.4	1.87	0.02	0.2	50
	37.2	1.88	0.02	0.1	10000[a]

[a] No failure until being loading 10000 times.

effective stress path and pore water pressure of both samples that subjected to cyclic loads were measured and analyzed in Section 3. To facilitate engineering practice, a partition diagram is proposed to evaluate the accumulated pore water pressure of clay in different sensitivities. Based on the test data and results, main conclusions are given in Section 4.



(a) Undisturbed samples



(b) Remoulded samples

Fig. 1. Relationships between double amplitude strain, ε_d and number of cycles, *N* under different cyclic stress ratio, r_c: (a) Undisturbed samples (b) Remoulded samples.

2. Shanghai marine clay and laboratory testing scheme

2.1. Shanghai marine clay

Shanghai is located in the southern edge of the Yangtze River Delta in East China. In the past 20,000 years, with the rise of sea level, a large amount of fine sediments carried by the Yangtze River have been deposited and formed the modern Yangtze River Delta. Shanghai clays are typical soft deltaic deposits with a thickness of 30–40 m. The clays are almost horizontally distributed, representing a fully Holocene transgression-regression sequence in the Yangtze Delta area. The clays can be divided into five major layers, and each layer possesses different physical and mechanical characteristics due to differences in depositional history (Wu et al., 2015). In this study, Layer #4 of Shanghai clay, which is a typical marine soft clay with a high water content and a low strength, was chosen for experiment.

Soil samples were taken from a construction site at Songjiang District, Shanghai. All samples were obtained from the same layer (about 11–13 m deep). The physical properties of the soil are as follows: specific gravity, $G_s = 2.7$, water content, $w = 48\%$, liquid limit, $w_L = 50\%$, plastic limit, $w_P = 22\%$, plasticity index, $I_p = 28$, compression index, $C_c = 0.44$, initial void ratio, $e_0 = 1.30$, and natural density, $\rho = 1.74 \times 10^3$ kg/m^3.

2.2. Remoulded clay

To achieve fully disturbed and remoulded clay, the undisturbed sample was crushed from clay lump to powder by artificial vibrations. Water was then added and mixed thoroughly so as to form slurry. The water content of the slurry was kept above twice the liquid limit. This slurry was transferred to a cylindrical mould of 150 mm diameter with 400 mm height and then it was consolidated by applying vertical stress of 100 kPa, which was the pre-consolidation pressure of the natural clay. After the consolidation drainage was completed, the remoulded clay sample was completed.

2.3. Test procedure

Both undisturbed clay and remoulded clay were made to samples with 50 mm diameter and 100 mm height. The samples were isotopically consolidated under an effective confining stress of 100 kPa. As in previous experimental studies on clays (Ye et al., 2013, 2015), the isotropic consolidation took about 5–6 days. Full saturation was confirmed by measuring the Skempton's *B* value, which was required to be greater than