



Characterization on the correlation between shear wave velocity and piezocone tip resistance of Jiangsu clays

Guojun Cai ^a, Anand J. Puppala ^b, Songyu Liu ^a

^a Institute of Geotechnical Engineering, Southeast University, Nanjing, Jiangsu 210096, China

^b Box 19308, Department of Civil Engineering, The University of Texas at Arlington, Arlington, TX 76019, United States

ARTICLE INFO

Article history:

Received 5 November 2012

Received in revised form 26 December 2013

Accepted 29 December 2013

Available online 9 January 2014

Keywords:

Soft clays

In situ testing

Shear wave velocity

Cone tip resistance

ABSTRACT

The small strain shear modulus of a soil is a fundamental parameter related to the mechanical behavior used in evaluation of dynamic behavior and seismic design of geotechnical structures. The Jiangsu soft clay is a lightly overconsolidated and sensitive clay of high plasticity in nature. A research database of piezocone penetration test (CPTU) and shear wave velocity, V_s , information for Jiangsu soft clays has been collected to study the small strain shear modulus relationships for these soils and to examine the potential use of CPTU and V_s data in combination for the purposes of characterizing these soils. Test data for sites are based on the laboratory testing performed on thin-wall tube samples and high-quality block samples. Improvements have been suggested to existing correlations between the small strain shear modulus, G_0 , or V_s and index properties for these soils for better prediction of these soil properties.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

The piezocone penetration test (CPTU) is a standard in situ test method utilized in the construction projects for geotechnical site characterization works. In recent years, the CPTU has been fitted with sensors to provide measurements of shear wave velocity, V_s and this new device is termed as seismic CPTU (SCPTU) (Campanella et al., 1986; Lunne et al., 1997; Cai et al., 2010, 2011a). The SCPTU has become the most used in situ method for the geotechnical investigations for determining soil properties at small to large strain levels (Mayne, 2007).

Shear wave velocity is typically measured in situ by a variety of geophysical test methods, such as crosshole testing (CHT), downhole testing (DHT), suspension logger probing (SLP), surface refraction survey (SFRS), surface reflection survey (SFLS), and spectral analysis of surface waves (SASW) (Robertson et al., 1986; Campanella and Stewart, 1992; Juang et al., 2008; Long, 2008; Long and Donohue, 2010; Ku et al., 2013). The SCPTU is a variant of the DHT method, and the measured shear wave velocity seems to be relatively independent of the technique used and of the operator.

Powell and Lunne (2005a), Boylan et al. (2008), Long (2008) and Tiggelman and Beukema (2008) have noted that for CPTU soundings in soft clays, if the pore pressure measurement system is sufficiently well saturated, then the measured pore pressure (u_2) parameter is not affected by the equipment variability. Long and Donohue (2010) demonstrated that the corrected piezocone resistance, q_t , values show minor variation from one type of equipment to another as compared with u_2 in Norwegian marine clays. They noted that the measured

sleeve friction, f_s , shows the most variation from one type of equipment to another and these values should be treated with caution. Since CPTU's u_2 (and possibly q_t) and the shear wave velocity, V_s are two of the reliable parameters that can be obtained from in situ testing, it seems logical then to attempt to use them in combination for the purposes of characterizing and classifying soft clays (Robertson, 2009; Ku et al., 2010; Cai et al., 2011b; Sun et al., 2013).

Analysis of the diversity and complexity of soils makes for a difficult task because of their many geologic origins, ages, constituents, grain sizes, mineralogy, fabrics, and histories. Therefore, parameters interpreted from CPT, CPTU or shear wave velocity tests need to be correlated to each other. The objective of the state of knowledge presented herein is not to cover every study performed on CPT, CPTU, SCPTU or V_s measurement tests. Only the elements relevant to the goals of this study, i.e., a comparison between the results generated in clay deposits previously listed, are mentioned herein. In this paper, data from seven soft to firm clay sites are collected and analyzed to investigate the potential use of CPTU and V_s data in combination for the purposes of characterizing these soils. For all these sites, high-quality CPTU and SCPTU data were available (Liu et al., 2008, 2011). In addition, results of laboratory tests on thin-wall tube samples and block samples were available for each site. Analyses of these results are attempted to validate existing relationships between V_s and q_t as well as develop new correlations between the same parameters. This paper provides a comprehensive summary of these results.

2. Site descriptions

In this study, the seven sites were chosen which contain sensitive clay deposits. All these sites are located in Jiangsu Province of eastern

E-mail addresses: fcuscai@163.com (G. Cai), anand@uta.edu (A.J. Puppala), liusy@seu.edu.cn (S. Liu).



Fig. 1. Location map for Jiangsu clay CPTU sites.

China (see Figure 1). These clay deposits are located at Nanjing, Lianyungang, Changzhou, Yancheng, Suzhou, Taizhou and Yangzhou, respectively. A summary of the seven sites is also given in Table 1.

In each of the investigated sites, the high quality samples were taken at different depths that corresponded to the depths where shear velocity measurement was made. Tube sample of 76 mm diameter was collected from boreholes, using stainless steel fixed-piston tube samplers below ground level. Once the fixed-piston sampler was withdrawn from the borehole, the soil sample at the end of the tube was excavated for waxing sealing at both ends. The area ratio of the tube samples used in this paper is 11%.

The laboratory testing program included basic soil characterization tests such as water content, unit weight, Atterberg limits, grain size distribution, and specific gravity. Soil parameters for the seven study sites, over the depth range for which shear wave velocity and high-quality sample data are available, are summarized in Table 2.

3. Test results and analysis

3.1. Effect of initial effective stress

Table 3 presents a few correlations between V_s and q_c and between V_s and q_t . Several important empirical relationships have been developed over the years to determine the in situ properties of cohesionless soil deposits including the void ratio, relative density, grain shape, and age factor from q_c -CPT (Schmertmann, 1976; Jamiolkowski et al., 1985, 2001; Baldi et al., 1986; Kulhawy and Mayne, 1990; Tanizawa et al., 1990), q_t -CPTU (Lunne et al., 1997; Mayne, 2007; Robertson, 2009; Schnaid, 2009), and V_s (Hardin and Richard, 1963; Robertson et al., 1995). The in situ measurements can be influenced by a number of factors that are probably interrelated, such as compressibility, particle distribution, mineralogy, and grain shape. Silts are really very fine sands and hence some of the general sand correlations might have application to silts and clayey silts.

For a given uncemented soil of Holocene age (<10,000 years), these relationships show that the q_c , q_t or V_s values depend mostly on the void ratio (or density index) and state of effective stress and compressibility

(Fear and Robertson, 1995). However, for a given measurement type, the function that expresses the effective stress effect is relatively constant from one study to another and the q_c , q_t or V_s values used in the different empirical relationships are first normalized for the same effective stress (100 kPa) to eliminate the effect of this variable (and therefore of the depth). The normalized test values then essentially reflect the void ratio or soil density.

The expressions currently used to standardize or correct test results for the effective stress due to overburden pressure are (Robertson and Wride, 1998; Wride et al., 2000):

$$q_{c1} = q_c C_Q \quad (1)$$

where q_{c1} (MPa) is the cone tip resistance normalized for the overburden stress (100 kPa), q_c (MPa) is the cone tip resistance measured in the CPT test, $C_Q = (P_a/\sigma'_{v0})^n$ is a correction for overburden stress with a maximum value of 2, and n is the stress exponent that varies with the soil type and ranges from 0.5 in sandy soils to 1.0 in clay soils (Robertson, 2012). It should be noted that P_a is an atmospheric pressure (100 kPa) and σ'_{v0} is the vertical effective stress (kPa).

Although cone penetration resistance is often corrected for overburden stress (resulting in the term q_{c1}), the truly normalized cone penetration resistance normalized for overburden stress (q_{c1N} , dimensionless) is given by (Robertson and Wride, 1998)

$$q_{c1N} = (q_c/P_{a2}) \times (P_a/\sigma'_{v0})^n = q_{c1}/P_{a2} \quad (2)$$

where P_a is a reference pressure in the same units as q_c (i.e., equal to 0.1 MPa for q_c or q_{c1} in MPa).

$$F = \frac{f_s}{q_c - \sigma'_{v0}} \times 100\% \quad (3)$$

where F is the standardized friction ratio, f_s is the sleeve friction measured during penetration in the CPT, and σ'_{v0} is the total vertical stress (Robertson, 1990);

$$V_{s1} = V_s \times (P_a/\sigma'_{v0})^{0.25} \quad (4)$$

where V_s is the shear wave velocity measured and V_{s1} is the shear wave velocity normalized for the vertical effective stress.

3.2. Correlations between G_o and e or w

Long and Donohue (2007) attempted to relate G_o to natural water content, w , or in situ void ratio, e_o , for Norwegian clay sites. Note that G_o is directly related to V_s by

$$G_o = \rho V_s^2 \quad (5)$$

where ρ is the mass density of the soil.

Here, data for seven additional sites is included in an attempt to improve these correlations and investigate which of the index parameters are the most useful. The overall objective of this study is to check that

Table 1
Summary of sites surveyed.

Site location	Soil type	Geological origin	V_s measured by	References
Lianyungang	Soft clay	Marine	SCPTU	Liu et al. (2008), Liu et al. (2011)
Nanjing	Silty clay	Backswamp	SCPTU, SASW	Cai et al. (2011a)
Yancheng	Soft clay	Lagoon	SCPTU, DH	Cai et al. (2010)
Suzhou	Soft clay	Alluvial and lacustrine	SCPTU, CH	Cai et al. (2011b)
Changzhou	Firm clay	Alluvial and lacustrine	SCPTU, DH	Cai et al. (2006), Cai et al. (2011b)
Taizhou	Silty clay	Alluvial and lacustrine	SCPTU, DH	Cai et al. (2011a)
Yangzhou	Soft clay	Lagoon	SCPTU, SASW	Cai et al. (2010), Cai et al. (2011b)

Download English Version:

<https://daneshyari.com/en/article/4743617>

Download Persian Version:

<https://daneshyari.com/article/4743617>

[Daneshyari.com](https://daneshyari.com)