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Undrained dynamic behaviour of peaty organic soil under long-term cyclic loading, Part I: Experimental investigation

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ABSTRACT

To investigate the undrained cyclic behaviour of peaty organic soil under long-term cyclic loading, a series of undrained cyclic triaxial compression tests was conducted. The permanent axial strain, accumulated excess pore pressure as well as secant shear modulus during the loading cycles were studied and their dependencies on variables such as confining pressure, cyclic deviator stress and static deviator stress were summarized. Distinctive characteristics of the peaty organic soil under long-term cyclic loading were presented in comparison to a soft clay from Wenzhou. For a given stress state, the permanent strain over the initial limited loading cycles was smaller for the peaty organic soil than for the inorganic soft clay for the higher static strength of peaty organic soil. The peaty organic soil displayed distinct viscous nature and higher permanent strain rate under long-term cyclic loading. Due to the highly decomposed and often amorphous organic components in the peaty organic soil, which results in a weak structure strength, the development of permanent strain was found to be insensitive to confining pressure. In addition, for a given shear strain, the secant modulus of peaty organic soils increased with decreasing organic content and degree of decomposition or with increasing confining pressure. While the equivalent damping ratio was found to generally decrease as the confining pressure, organic content or degree of decomposition increased.

1. Introduction

Peat and peaty organic soil are organic rich materials, which are formed by the gradual accumulation of the remains of dead plant under waterlogged conditions. From a geotechnical perspective, peat and peaty organic soil would generally be viewed as ‘problematic’ soil. In contrast to inorganic soils such as clay and sandy soil, the peat and peaty organic soils have particular physical and mechanical properties, e.g. high porosity, high moisture contents, low bulk density, high compressibility and creep behaviour, which are resulted from the open cellular structure due to the remains of plants. For example, the water contents can often range from 200 to as high as 2000% [1]. A peat stratum can reduce in thickness by more than 50% under a relatively modest increase in effective stress of the order of 50 kPa [2]. Peat and peaty organic soil also show higher tendency to creep than inorganic soils as displayed by the greater ratios of secondary compression index to compression index [3,4]. In addition, evidences from consolidation undrained triaxial compression testing of peat and peaty organic soil indicated high effective friction angles of typical 40–68° [3,5–7], which can be attributed to the reinforcing effect of the peat fibres. Recently, an increasing number of traffic infrastructures have been constructed on this kind of soil. During the operation of these traffic infrastructures such as railway and highway, large settlements have been observed. For example, a settlement of 36.5 cm of peaty soil foundation was reported in the Nanning - Kunming railway in China [8]. Moreover, two incidents of train derailment were reported in Canada [9,10]. The first derailment was a result of the failure of a rail joint due to large cyclically induced deformation of peat foundation. The second derailment was a result of the instability of embankment and peat foundation due to recent increases in rail traffic volume. An adequate understanding of the response of peat and peaty organic soil to cyclic loading is needed to mitigate the risks inherent to these soils.

Most of researchers performed investigations on the behaviour of peat and peaty organic soil in term of static loading, but little research has been done on the dynamic behaviour, especially on the accumulative behaviour under long-term cyclic loading. The existing investigation of dynamic behaviour of peat and peaty organic soil can be divided into two groups. One focused on the evaluation of seismic hazards, and the other was aimed at describing the accumulative properties under long-term cyclic loading. Preceding works on the former

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type included the efforts by Boulanger et al. [11], Kramer [12], Kishida et al. [13], Seed and Idriss [14] and Wehling et al. [15]. It has been found that the normalized secant shear modulus values increased with increasing confining pressure and organic contents, while the equivalent damping ratios decreased as confining pressure and organic contents increased. The latter group mainly included the work by Hendry et al. [16], Konrad et al. [17] and Wong et al. [18], which were prompted by the aforementioned derailment of two trains in Canada. Based on these excellent work as to the response of peat foundations to long-term train loading, the peat and peaty organic soil were found to behave in an undrained manner. The deformation was also found to be predominantly elastic and recoverable by the finding that the measured residual excess pore pressures after the passage of trains were relatively low. Even so, there were also significant long-term settlements due to the accumulation of small permanent deformations induced by each passing train. In addition, Yasuhara et al. [19] indicated that the destruction of peat fabric during undrained cyclic triaxial testing was significant as peat subjected to large cyclic strains, which resulted in a loss of post-cyclic undrained shear strength.

The composition and forming mechanism of natural peat deposits varied significantly in different sites, which results in different organic contents (high to low) and degree of decomposition (fibrous to amorphous). This also makes the in-situ physical and mechanical behaviour of peat and peaty organic soil region-specific [20]. Around Lake Dian located in the southwest of Kunming, Yunnan province, China, there are continuous quaternary sequences, where soft soils especially peaty organic soil are widely distributed. The rapid development of transportation in Kunming has been confronted by the challenge posed by the peaty organic soils which are involved with excessive settlements and subsequent potential failures. The previous studies provided a preliminary understanding of the dynamic properties based on limited types of peat and peaty organic soil. However, there is still lack systematical knowledge. For example, how factors such as confining pressure, cyclic deviator stress and static deviator stress influence the accumulative deformation, excess pore pressure and structural degradation? What is the difference of cyclic behaviour between peaty organic soil and inorganic soil? Consequently, an in-depth exploration into the cyclic accumulative behaviour of the peaty organic soil is necessary for evaluation of the long-term performance of infrastructures throughout the Lake Dian Basin.

This paper presented the results of in-situ site characterization and one-way cyclic triaxial compression tests with a large number of loading cycles, and discussed the undrained accumulative behaviour such as permanent axial strain, accumulated excess pore pressure and secant shear modulus. Furthermore, the tests results of the peaty organic soil are compared with the results of a soft clay form Wenzhou, an amorphous peaty organic soil from Montezuma Slough and a fibrous peaty organic soil from Sherman Island in respect of the accumulative deformation behaviour.

2. Sampling method and soil properties

As shown in Fig. 1, the drilling site for this study is located on the northern side of Lake Dian. A profile of the sampling site is shown in Fig. 2 with the measurements of shear wave velocity V_s, CPT tip resistance q_c, friction ratio R_f, and SPT N-value. The explorations were approximately 10–20 m from the sampling site. The groundwater table after drilling of the boreholes varied from 0.5 to 1.5 m beneath the ground. Based on these measurements, it was easy to distinguish the two layers of peaty organic soil, as illustrated in Fig. 2. And the upper layer between the depths of 5.0 and 9.5 m beneath the ground was chosen as the object of this study.

In order to obtain intact samples suitable for laboratory testing, thin-walled tube sampling technique corresponding to ASTM D1587/D1587M-15 [21] was performed. The dimensions of the tubes with sharpened ends are 508 mm in length, 101.6 mm in external diameter and 2.2 mm in wall-thickness. Firstly, a reasonably clean hole was made firstly using hollow-stem augers. The water level inside the hollow stem augers was kept high enough during drilling and sampling to prevent inward seepage at the bottom of the boring. Then, thin-walled tube sampler was lowered plumb into the hole until the sample tube's bottom rested on the bottom of the hole. The corresponding depths were recorded. Subsequently, the sampler was advanced smoothly and continuously into the peaty organic soil with a relatively rapid speed not less than 0.1 m/s. In no case shall a length of advancement be greater than the sample-tube length minus an allowance for the sampler head. In order to avoid the loss of soil core, a waiting period of 10 min after sampling before withdraw was set to both dissipate excess pore pressures from the push and to build some adherence/adhesion of the soil core inside the tube. After the waiting period, the sampler was rotated one revolution to shear off the bottom of the sample. Upon removal of the tube, recovery may be recorded. The sample quality appeared very high, with 98% – 100% recoveries in all cases. Finally, the samples were immediately sealed with plastic caps and fresh keeping membrane, then placed in a padded box and stored in a chamber in laboratory with a relative humidity of 98% and temperature of 20 °C.

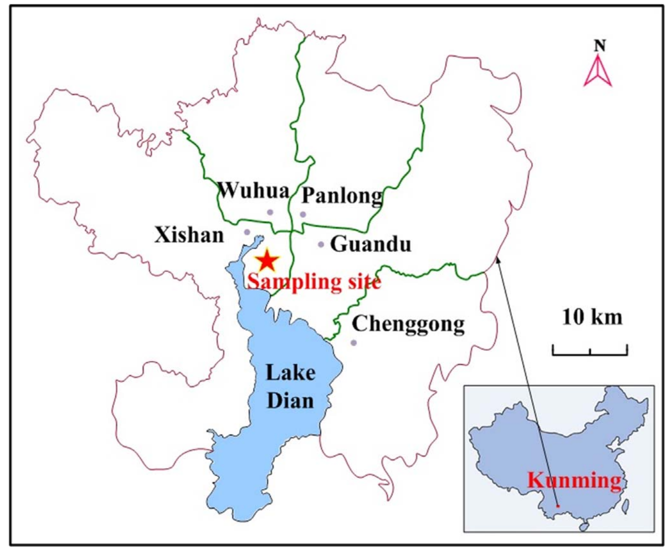

Fig. 1. Location of sampling site.

In-situ tests results showed that for the upper peaty organic soil layer, V_s varied from 49.25 to 67.0 m/s, and q_c and R_f were typically 0.13–0.45 MPa and 7.5–16.1%, respectively. SPT N-value in this peaty stratum was typically 2–4 blows. Properties of the peaty organic soil samples used for cyclic triaxial testing are summarized in Table 1. Laboratory oedometric tests showed that the in-situ peaty organic soil was normally consolidated in general. The organic contents (OC) ranged from 29.9% to 53.0% (39.3% average); the initial water contents ranged from 181.5% to 259.3% (221.8% average), and the initial densities ranged from 1.10 to 1.22 g/cm^3 (1.20 g/cm^3 average). The content of fibre (> 150 μm) was determined to be 6.3–8.1% (7.1% average) via wet sieving, indicating that the organic components were highly decomposed and often amorphous. Currently, there are a number of classification systems for peat, such as those suggested by Landva et al. [22], von Post [24], Radforth [25], Hobbs [1,26]. In this investigation, the modified von Post peat classification system [1] was employed, and the peaty organic soil could be classified as $H_{7–8}B_2F_1R_1W_0$ with a high degree of humification (H7-8), water content < 500% (B2), a low content of fine fibres (F1), very few coarse fibres (R1), no wood remnants (W0).