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Post-long-term cyclic behaviour of Coode Island Silt (CIS) containing different sand content

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ABSTRACT

It is widely accepted that the post-cyclic stiffness and shear strength of marine clays may alter as a consequence of experiencing a large number of deviatoric load cycles. Most marine clays in bay areas are already undergoing long-term one-way and low amplitude ocean and wind waves either because of the seabed topography or existing infrastructures. For the engineering of such clays, particular attention should be given to the post-cyclic behaviour of the material when investigating the effect of alteration in loading regimes exerted by human-made or natural phenomena such installation of new infrastructure, earthquake, tsunami and port upgrade construction, in which the magnitude of the applied load changes. As one of the most sensitive soft soils in Melbourne, Coode Island Silt (CIS) at the northern shoreline of Port Phillip Bay comprises a considerable and variable amount of sand. This paper explores the post-cyclic constitutive behaviour of CIS containing variable sand content. To investigate the stiffness and shear strength of CIS subsequent to experiencing a large number of low amplitude cycles, a series of post-cyclic triaxial tests are performed on CIS specimens with varying sand content ratio up to 30%, immediately after applying 30,000 semi-sinusoidal load cycles. Based on the test results, it is found that the undrained shear strength of CIS, does not alter considerably as the results of long-term cyclic loading. However, a significant increase in the secant stiffness of CIS followed by very brittle yielding is observed. In the end, it is intended that results be summarised in a form applicable by industry. Hence, the possible effects of such alterations in the constitutive behaviour of CIS on the design of monopile foundations are discussed.

1. Introduction

The Yarra Delta is formed from a series of alluvial sediments deposited to a depth of about 50 m below the ground level (bgl) from the north end of Port Phillip Bay to the Yarra and Maribyrnong rivers in the West of the city of Melbourne, Australia. These deposits are formed during sedimentation and erosion stages by sea level changes [1]. Coode Island Silt (CIS) is the uppermost stratigraphic layer in Yarra Delta. From the geotechnical engineering point of view, CIS is a normally consolidated or slightly over-consolidated silty clay, which mainly includes inactive minerals of kaolinite and illite. The CIS's low plasticity (plasticity index of 5.9%) makes some mechanical characteristics of the CIS similar to those of silts and far from that of pure clay. As a widespread Holocene-age deposit, CIS causes serious construction challenges due to its low bearing capacity, high moisture content and high compressibility [2,3]. The existence of the CIS, as one of the most problematic soils in the state of Victoria, had led to the development of these areas limited to isolated industrial or port facilities in the past decades. This is due to the fact that, the compressibility and poor shear strength of CIS (the maximum deviatoric stress that CIS can sustain) impose construction of expensive pile foundation systems to transfer the structure load to the deeper mudstone or sandstone layers underlying the CIS [4]. However, nowadays proximity to the city and demands for development and access to the coastline are gradually pushing those limits. Although the nearshore and offshore development in this area attract huge interest by industry, developing the safe and low-cost design of nearshore and offshore infrastructure in this marine environment is still considered as a challenge for geotechnical engineers. This is due to the fact that, at the coastline, the saturated CIS extends to a depth of up to 30 m bgl (see Fig. 1), while there is a severe lack of knowledge of the long-term dynamic and post-dynamic behaviour of this highly sensitive and problematic material. This challenge

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Fig. 1. Contour lines for the base of CIS in the area of interest between the northern shoreline of Port Phillip Bay and Coode Island (after Jamali et al. [6]).

could become even worse when the varying sand content of the CIS in this area is taken into account. Geological filed investigations in this area indicate that CIS has been naturally mixed with marine sand (Port Melbourne Sand) brought by sea waves. Hence, the CIS in this area can be considered as an intermediate or composite clay. As defined by Jafari et al. [5], composite clays consist of clay as the main body (fine-grained) with sand, gravel or even suspended rubble (coarse-grained) in the clay matrix. Many of the characteristics of a composite clay like void ratio, shear strength and permeability are a function of relative amounts of granular and cohesive portions and interaction between particles.

Soil and foundation of structures at offshore and nearshore areas are continuously subjected to a large number of cyclic loads induced by wind and sea waves. The cyclic loading induced by sea waves is categorised as long-term cyclic or dynamic loading. Guo et al. [7] and Li et al. [8] considered a short-term cyclic loading as loadings with a reversed large amplitude and a low number of cycles below 1000 (for example earthquake or storm), whereas long-term cyclic loadings have non-reversal low amplitude and a large number of cycles. The short-term cyclic loading of some of the geomaterials can cause failure due to the accumulation of pore water pressure or the development of a shear strain induced by cyclic loading. Hana et al. [9,10] proved that at a stress level below the stress threshold level, clays behave quasi-elastic under long-term low amplitude cyclic loading and remain in a non-failure equilibrium state. However, the cumulative behaviour of clay such as excess pore water pressure and permanent strain accumulation, can have significant effects on the stress-strain characteristics which is one of the main concerns of the design of foundations subjected to long-term cyclic loading. In general, the cumulative behaviour of geomaterials can be a function of: a) loading conditions, including Cyclic Stress Ratio (CSR), number of cycles, loading frequency and stress path, and b) soil properties, including Over Consolidation Ratio (OCR) and Atterberg limits [11].

Industrial, housing and construction development in Melbourne during the last two decades has led to the construction of many new structures in the low-lying land of the Yarra Delta and Port Melbourne, which by now have been subjected to wave loading for several years. Also, the future nearshore and offshore infrastructure in this area may be constructed in the material which is already experiencing a large number of cycles. The constitutive behaviour of CIS during the long-term dynamic loading is essential, as it is required when evaluating the serviceability of the foundations of the nearshore and offshore structures. Also, the post-dynamic (post-cyclic) constitutive behaviour of the CIS is crucial to investigate the effect of alternative loading regimes where the magnitude of the applied load changes. Such changes can be imposed by human-made activities such construction of new infrastructures (e.g. wind turbine foundation and port upgrade construction, or natural phenomena such as earthquake and tsunami). The long-term dynamic behaviour of CIS containing different sand content was studied by the authors of the present article, Jamali et al. [6]. However, the post-dynamic behaviour of CIS is still unknown. In the present study, in order to investigate the post-dynamic behaviour of CIS, a series of triaxial shear tests have been performed on the CIS specimens containing different sand content, immediately after applying 30,000 semi-sinusoidal low amplitude load cycles. Considering the lack of knowledge on the post-long-term cyclic behaviour of CIS, it is believed that the outcome of this study brings a direct contribution to the geotechnical engineering, safety and reliability in southern Melbourne.

2. Research background

The post-cyclic test considered in this study is an undrained monotonic shear loading test which is performed on the soil specimen immediately after a long-term cyclic loading while allowing no drainage. In practice, this test is performed to evaluate the effect of damage (hardening or softening) due to the applied cyclic loading on the elastoplasticity of the material. The loading regime for the standard monotonic, cyclic and post-cyclic loading is schematically shown in Fig. 2.

Studies by previous researchers have shown that the post-cyclic behaviour of clay strongly depends on the cumulative behaviour (strain and pore water pressure) during the cyclic loading. To study the cumulative behaviour of CIS, Jamali et al. [6] conducted a series of long-term cyclic triaxial loading tests on CIS specimens with various sand contents, under different cyclic stress ratios. The main outcome of their research is summarised in Section 3.2.

Moses et al. [12] carried out a series of consolidated undrained standard monotonic, undrained cyclic and undrained post-cyclic tests on undisturbed cemented marine clay. Results of post-cyclic tests (immediately after cyclic loading) showed a significant decrease in the shear strength of the tested clay compared to the one measured from the standard monotonic tests (without previously applied cyclic loading). They showed that the decrease was a function of the applied loading CSR. Li et al. [13] conducted a series of consolidated (under the K_0 condition) undrained triaxial cyclic and undrained post-cyclic tests

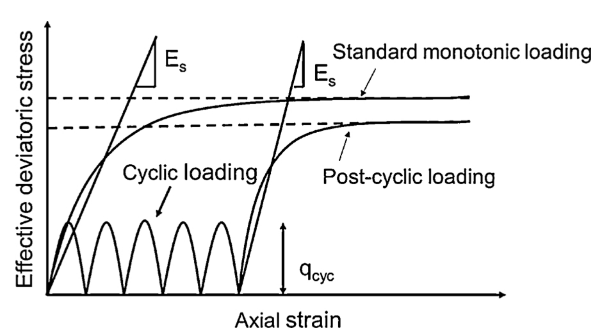

Fig. 2. The loading regime for the standard monotonic, cyclic and post-cyclic loading test.