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Long-term dynamic behaviour of Coode Island Silt (CIS) containing different sand content

Hassan Jamali [a], Ali Tolooiyan [b,*], Masoud Dehghani [a], Adel Asakereh [a], Behzad Kalantari [a]

[a] Department of Civil Engineering, Faculty of Engineering, University of Hormozgan, Bandar Abbas, Iran
[b] Geotechnical and Hydrogeological Engineering Research Group (GHERG), Federation University Australia, Gippsland Campus, Victoria, Australia

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ABSTRACT

The foundations of nearshore and offshore structures are always subjected to long-term cyclic loading which is often a one-way, with low amplitude and a large number of cycles. Hence, the long-term dynamic behaviour of shoreline soils and sediments should be understood to avoid excessive deformation and liquefaction. As one of the most problematic soft soils in Melbourne, Coode Island Silt (CIS) at the northern shoreline of Port Phillip Bay contains a considerable but variable amount of sand. This paper explores the dynamic response of CIS containing different sand content subjected to a large number of cycles. To determine the liquefaction potential, and the effect of sand content on the resilient modulus and permanent strain of CIS, a series of long-term cyclic triaxial tests at a sinusoidal loading frequency of 1 Hz is performed. Based on the test results, it is found that CIS with varying sand content up to 30%, does not liquefy under the cyclic stress ratios and frequency applied in this study. Also, a sand content of 10% causes CIS to degrade more under cyclic loading. In the end, an empirical model to predict the permanent strain of CIS with a variable sand content is calibrated.

1. Introduction

Coode Island Silt (CIS) is a young sedimentary soil in the low-lying land of the Yarra Delta located in Melbourne, Australia. The Yarra Delta consists of sediments deposited in previous decades when the sea was higher than the current level. Considering the history and conditions of the formation of CIS, this soil is known as a normally consolidated soft soil. CIS has expanded in many areas to a depth of 30 m below the ground level (bgl), and depending on its organic content it is classified as inorganic silty clay (ML) or organic silty clay (OL), with low permeability, high moisture content, high compressibility and low bearing capacity [1,2]. Due to its low bearing capacity and high compressibility, CIS is one of the most problematic soils in the state of Victoria. Today, the low-lying lands of the Yarra Delta, due to their close proximity to Melbourne port and Swanson and Appleton docks are developing rapidly. In addition to a large area around the Yarra Delta, from north to south, CIS is extended from Coode Island to the northern shoreline of Port Phillip Bay (see Fig. 1). The existence of CIS naturally mixed with different sand contents along the shoreline, makes severe constraints for the construction of nearshore and offshore structures when there is no information about the dynamic behaviour of this problematic soil.

The foundations of nearshore and offshore structures are subjected to long-term cyclic loading. The loading caused by waves and vibrations of machines are examples of long-term cyclic loading. Long-term cyclic loading, unlike earthquake and storm loading, is often a one-way loading with low amplitude (stress level below shear strength) and a large number of cycles. In the context of offshore engineering, the term "short-term dynamic loading" refers to the cyclic loading with a number of cycles between 2 and 10^4, while the term "long- term dynamic loading" refers to the cyclic loading with a number of cycles beyond 10^4 [3]. Although long-term cyclic loading in a short period does not cause failure, due to the accumulation of excess pore water pressure and strain degradation, it can cause large uniform or differential settlements in foundations of structures over time [4,5]. In many cases, the deformations do not tend to a constant value even after applying a large number of cycles (100,000 cycles). On the other hand, studies carried out to investigate the constitutive behaviour of CIS are rare; therefore, the study of CIS behaviour under cyclic loading with a large number of cycles is essential.

Fig. 2 shows a schematic representation of the axial strain (ε_a) versus the number of cycles (N). The total axial strain consists of resilient strain (ε_r) and permanent strain (ε_p). The stress-strain

* Corresponding author.
E-mail address: ali.tolooiyan@federation.edu.au (A. Tolooiyan).

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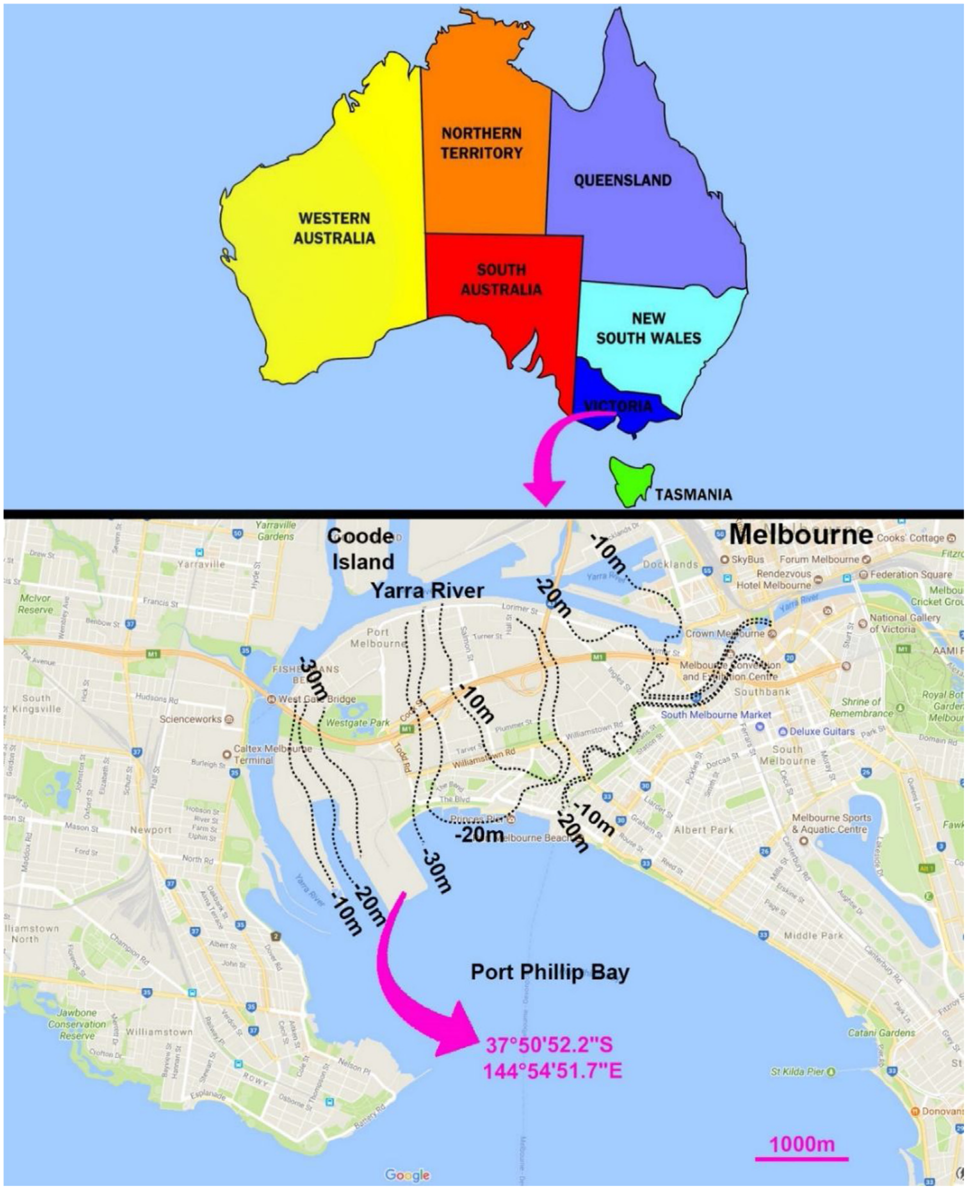

Fig. 1. Area of interest and contour lines for the base of CIS in the region between Coode Island and northern shoreline of Port Phillip Bay.

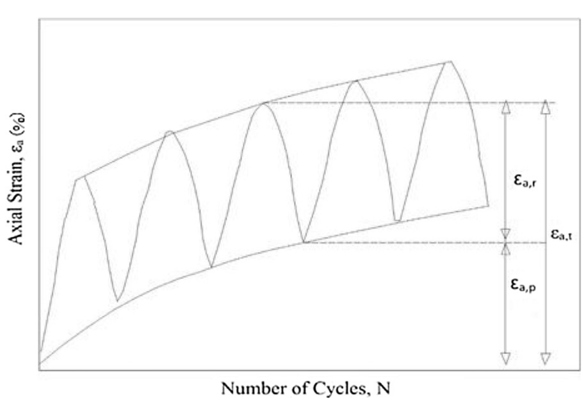

Fig. 2. Typical behaviour of soil under cyclic loading redrawn from [8].

relationship under cyclic loading is nonlinear. To better understand this behaviour, Seed et al. [6] defined the resilient modulus parameter (M_r) according to Eq. (1):

$$M_r = {}^{q_{cyc}}/_{\varepsilon_r} \quad (1)$$

where, q_{cyc} is cyclic deviatoric stress.

By increasing the number of cycles, clayey soils degrade gradually, and the resilient modulus decreases. The amount of decrease depends on many parameters, such as Cyclic Stress Ratio (CSR), Over Consolidation Ratio (OCR), loading frequency (f), stress history, and so on [7]. CSR is defined based on Eq. (2):

$$CSR = {}^{q_{cyc}}/_{p'_0} \quad (2)$$

where, p'_0 is effective confining pressure at rest.

Guo et al. [8] carried out a series of strain-controlled monotonic and stress-controlled cyclic tests on the soft clay. The cyclic tests are conducted under 50,000 cycles and the confining pressures of 50, 100 and 200 kPa. The results showed the stress-strain hysteretic loop, the resilient modulus and the permanent strain are strongly dependent on the confining pressure and CSR. By increasing the confining pressure and CSR, the resilient modulus decreased and