

Mechanical Behavior of Marine Clay Under Wave Loading

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The mechanical behavior of marine clay under wave loading plays a significant role in the stability of offshore structures. A series of cyclic triaxial tests and cyclic simple shear tests was conducted on marine clays from Tianjin Port, China. The effects of loading frequency as well as stress and strain amplitudes on the degradation of cyclic shear modulus of marine clay were investigated. A piezoelectric bender element system was developed to measure the maximum shear modulus of clay samples under different confining pressures. The cyclic triaxial tests show there exists a threshold shear stress for marine clays, and when the cyclic load is smaller than the threshold the soil sample will not fail, and when the cyclic load is larger than the threshold the shear modulus will continuously decrease until failure. When the stress amplitudes of the cyclic load are identical, the decrease of loading frequency leads to an increase in the accumulated shear strain and pore pressure with respect to the number of cycles. The strain-controlled cyclic simple shear tests show the degradation of the shear modulus occurs during the initial stage of loading, and the number of loading cycles has little effect on the damping ratio.

INTRODUCTION

Engineering structures founded on any soil deposit are often designed to withstand both static and cyclic loads. In a marine environment, wave loading forms a significant proportion of the loads on offshore structures such as offshore petroleum platforms, offshore pipelines, storm surge barriers and harbor structures. Foundations of such structures transmit the cyclic loads to the marine soils below, and it is quite likely that the engineering behavior of these soils gets altered substantially under continuously cyclic loading. Marine soils near the shore and coastline in eastern China are mainly clay soils. Research on the response of marine clay to cyclic loading is one of the key problems since there are lots of coastal ports, and offshore structures are under construction in China.

The soil dynamics research has bloomed since the 1960s. Several types of testing facilities—such as cyclic triaxial shear, simple shear and ring shear—were employed to investigate the dynamic behavior of soils, and the empirical relationships were established to estimate the shear modulus, damping ratio and pore water pressure of subsoil under dynamic loads (Hardin and Drnevich, 1972a, b; Mitchell and King, 1977; Idriss et al., 1978; Vucetic and Dobry, 1988; Puzrin et al., 1997; Gratchev et al., 2007). However, most of the previous research focused on earthquake loading. Wave loading has small amplitude, low frequency and long duration, which is quite different from earthquake loads. Ocean wave frequency is usually smaller than 1 Hz. Cyclic frequency is one of the most important governing factors of cyclic loading, and the stress-controlled cyclic triaxial and torsional shear tests were conducted to investigate the undrained mechanical behaviors of remolded clays. Hardin and Black (1968) proposed that loading frequency has little effect on shear modulus when the strain

amplitude is less than 10^{-4} . Some researchers reported that loading frequency paid a significant role on the dynamic properties of soils, and secant shear modulus increased with increasing loading frequencies (Matsui et al., 1980; Procter and Khaffaf, 1984; Stokoe et al., 1994; Boulanger, 1998; Zhou and Gong, 2001; and Chen et al., 2004). However, opposite results were reported: Loading frequency has no effect on shear strength and shear modulus, as well as buildup of pore water pressure (Yasuhara et al., 1982; Hyde et al., 1993). Simple shear tests were also employed to investigate the mechanical behavior of soft clays under cyclic loading (Anderson et al., 1980; Ansal and Erken, 1989; Vucetic, 1994; Matasovic and Vucetic, 1995), and a threshold cyclic stress or strain level was reported below which no excess pore pressures will develop. The pore pressure and cyclic strain amplitude are interrelated, although the pore pressure cannot be precisely detected inside the specimen due to the low permeability of clays. The necessity for understanding the response of marine clay under cyclic loadings has long been appreciated. The mechanical behavior of marine clays under wave load has not been understood fully enough to develop practical design guides for ocean structures.

During cyclic loading, the stress-strain behavior of soils is nonlinear and hysteretic. An idealized stress-strain loop is used to simulate the mechanical response of soils under the symmetric cyclic loading. This loop is associated with a given value of maximum cyclic strain and maximum cyclic stress. The trace of tips of all hysteresis loops, associated with the different value of maximum cyclic strain, is defined as the backbone curve for the soil specimen. The backbone curve constitutes the basis for characterizing the stress-strain behavior of soils for nonlinear analysis. Hysteresis loops are often derived and modeled by applying the Masing rule. The backbone curve has a maximum slope at the origin defined as the maximum shear modulus G_{\max} (Hardin and Drnevich, 1972a). The equivalent shear modulus G at a given strain is the slope of the line connecting the origin with the tip of the loop. At very small strain, the equivalent shear modulus becomes equal to the maximum shear modulus G_{\max} . The shear modulus G will decrease with the increase of strain.

Received February 27, 2009; revised manuscript received by the editors November 12, 2009. The original version was submitted directly to the Journal.

KEY WORDS: Wave loading, marine clay, modulus degradation, cyclic triaxial test, cyclic simple shear test.