The Failure Criterion of $K_0$-Consolidated Saturated Clay under Combined Static and Cyclic Stresses

Jianhua Wang¹ Yangrui Zhou² Qu Yanda²
¹ Geotechnique Engineering Institute of Tianjin University
² Geophysical-China Oilfield Services Limited
Tianjin, China

ABSTRACT

There are some studies about failure behavior of saturated ocean clays under combined static and cyclic stresses so far. But they more concentrated on general analysis about cyclic failure behavior of isotropic and anisotropic consolidated clays. In this paper, the cyclic strength and the failure criterion of $K_0$-consolidated clays were researched under combined static and cyclic stresses. Test samples were prepared using the vacuum preloading method. A method, which was used to consolidate specimens under $K_0$ condition in the triaxial cell, was developed. Cyclic undrained triaxial tests of $K_0$-consolidated specimens were conducted to study effects of the confining consolidation pressure and static and cyclic stresses on cyclic undrained strengths of $K_0$-consolidated specimens. Internal friction angles and cohesions corresponding to various number of cycles to failure were determined based on test results and their variations were analyzed. Results showed that internal friction angles and cohesions could be used to describe the variation of cyclic undrained strengths of $K_0$-consolidated saturated clays with confining consolidation pressures for a specified static stress and the number of cycles to failure under combined the static and cyclic stresses. Therefore, cyclic undrained strengths obeyed the Mohr-Coulomb failure criterion for $K_0$-consolidated saturated clays under combined static and cyclic stresses. Results in this paper are important references for further researching constitutive relationships describing cyclic failure of $K_0$-consolidated saturated clays and developing the method evaluating the stability of offshore platform foundations on clay strata under wave loads.

KEY WORDS: cyclic behavior of clays, cyclic strength of clays, cyclic triaxial tests, constitutive relationship of clays, failure of clays under cyclic loads.

INTRODUCTION

Saturated clays are strata that are often encountered in shallow range of ocean foundations. It is an important content for ocean platform foundation design to evaluate the stability of ocean platform foundations on saturated clay strata under combined sustained and wave loads. An approach evaluating the stability of ocean platform foundations on clays under wave loads is to develop the constitutive relationship of clays with sustained and cyclic loads and calculate cyclic and accumulative displacements of clay strata using the incremental elasto-plastic numerical method tracing cyclic stress paths (Prevost, 1981; Marr, 1981; Wang, 1995). But there are two difficult problems not to be solved for the approach so far. (1) Because the failure mechanism of saturated clays is very complex under sustained and long-term cyclic wave loads, a good and practical constitutive relation describing the stress-strain relation of clays with sustained and cyclic loads has not been established. (2) Because the number of wave loading cycles caused by a storm may be on the order of hundreds or more, the incremental elasto-plastic calculation is extremely large and onerous and the calculation result may not be convergent due to error accumulation during calculation process. The pseudo-static method is another approach evaluating the stability of ocean platform foundations on clays under sustained and cyclic loads. Wang et al. (1998, 1999) developed a pseudo-static method evaluating the failure of soft clay foundation under cyclic loading. In their approach, the effect of the cyclic loading on failure of soft clays was equivalent to the strength variation and cyclic strength was defined as the sum of static and cyclic stresses corresponding to a specified number of cycles to failure. The variation relationship of the cyclic strength with the static stress, the cyclic stress and the number of cycles to failure was determined using cyclic triaxial tests. The relationship was used to evaluate the stability of soft clay foundation under cyclic loads, its validity for three-dimension stress states should be first extended based on the failure criterion theory. Then, the cyclic strength of any soil element in foundations can be determined using the extended relationship and the stability of soft clay foundations is further evaluated by the pseudo-static numerical analysis using the perfect elasto-plastic constitutive model. In order to establish the relationship for the three-dimension stress state, Wang, Li et al. (2001, 2005, 2008) researched the unconsolidated and undrained strength of saturated soft clays under combined static and cyclic stresses using cyclic triaxial and cyclic torsion tests. Results showed that the Mises failure criterion could be used to describe the failure of soft clays under combined static and cyclic stresses. Therefore, the cyclic strength relationship determined using cyclic triaxial tests could be used for general stress states. Andersen et al. (1980, 1988) studied the strength behavior of the $K_0$-consolidated clay using cyclic triaxial and DSS tests. A series of plots were used to describe variations of the cyclic undrained strength of $K_0$-consolidated clays with combined static and cyclic stresses and the