Cyclic Behavior of Marine Silty Sand

Muhammad Safdar

Graduate Student, School of Civil and Environmental Engineering,
Pusan National University, Pusan, South Korea
e-mail: safdar@pusan.ac.kr

Jin Man Kim

Associate Prof., School of Civil and Environmental Engineering,
Department of Civil Engineering, Pusan National University, Pusan, South Korea
Corresponding author; e-mail: jmkim@pusan.ac.kr

ABSTRACT

Foundations for offshore wind turbines are predominantly demanding due to the dynamic nature of the offshore loading. A greater understanding of the behaviour of wind turbine foundation soil, will certainly lead to the stable construction of foundations which in turn, will make offshore wind farms a more feasible part of the solution to the global energy problem. This paper presents the results of cyclic direct simple shear test to explain the long term cyclic behavior of marine silty sand. All the tests are performed with relative density of 65% and 70%.Cyclic behavior of marine silty sand are based on the number of loading cycles, cyclic shear strain amplitude, relative density, and cyclic stress ratio.

KEYWORDS: Cyclic Loading, Offshore Wind Turbine, CDSS, Cyclic Stress Ratio

INTRODUCTION

Understanding the behavior of offshore marine silty sand subjected to long term cyclic loading is very vital in solving offshore geotechnical problems. A number of researchers have studied behavior of clay and sand subjected to cyclic loading.

Vucetic et al. (1988) studied the degradation of marine clays under cyclic loading. D. Wijewickreme et al. (2005) studied the cyclic loading response of loose air-pluviated Fraser river sand. K.H. Andersen (2009) investigated in detail, the bearing capacity of the soil under cyclic loading, and stated that the cyclic shear strength and the failure mode under cyclic loading depend on the stress path and the combination of average and cyclic shear stresses. Different approaches have been made as an attempt to include cyclic loading in the design procedure of offshore wind turbine foundation (Soren et al., 2012).

Over the past few decades, cyclic direct simple shear test has been being used for investigation of cyclic behavior of soils. Hence, this study compares the work performed on new cyclic direct simple shear apparatus with previous research performed.

CYCLIC DIRECT SIMPLE SHEAR TEST

Constant volume direct simple shear (DSS) test is a reliable method for measuring undrained shear strength of undisturbed or compacted soil samples. The DSS test is most similar to the CU triaxial test in that samples are consolidated prior to shearing. The simple shear is the test condition that only normal and shear stress acting on top face of a specimen is defined, whereas the displacement constraints exist for the other boundaries: The bottom face of specimen is theoretically fixed, and the radial strain on specimen is zero.

The CDSS test procedure is based on that of a constant-volume direct simple shear testing of soils, which has been studied extensively for half a century and is described in the standard ASTM D6528-07. The sample is consolidated under a normal load within a wire-reinforced membrane (in this study) or a stack of thin rings that provide lateral confinement.

Once consolidation is complete, a horizontal shear force is applied to one end of the sample. The sample height is continuously maintained during shear to ensure constant volume. Rather than measuring pore pressures, which would require complete saturation of the sample, the pore pressure response is inferred from the change in vertical stress which is monitored throughout the test (Baxter et al, 2010). In this way changes in applied vertical stress ($\Delta\sigma_v$), which are required to keep the sample height constant, are assumed to be equal to the excess pore water pressure (Δu) that would develop if the test were truly undrained with pore pressure measurements (Finn, 1985, Dyvik et al. 1987).

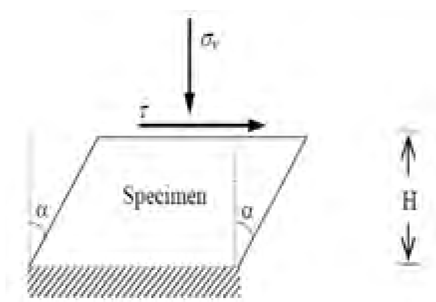

Figure 1: Simple Shear Condition (Dyvik et al., 1987)

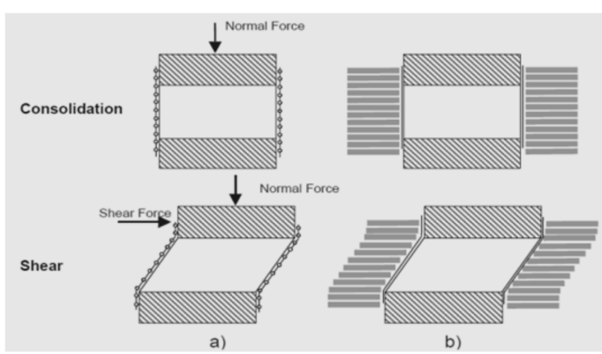

Figure 2: Wire Reinforced Membrane and Stacked Rings (Baxter et al., 2010)

The cyclic shear response of natural low-plastic Fraser River silt was investigated using constant-volume direct simple shear (DSS) testing Wijewickreme (2010). A soil can be subjected to many different stress conditions, being purely cyclic stress, static or average stress, or a combination of both. Andersen (2009) shows this clearly in a study on Drammen clays at the NGI. Drammen clays samples are tested in cyclic triaxial and cyclic simple shear conditions for different combinations of static and cyclic shear stresses. In this study cyclic simple shear tests have been performed with zero static or average shear stress.

SAMPLE PREPARATION

Dry compaction approach was developed to produce samples of the silty sand with consistent heights and initial void ratios Wijewickreme (2010). The equipment used consists of the shear box having bottom cap, two o-rings, wire-reinforced membrane, top cap, triaxial pressure panel, and compacting hammer. Sample diameter is 63.5mm and height is varied from 20 to 25 mm to maintain height to diameter ratio less than 0.4, in order to fulfill the ASTM D6528-07 criteria.

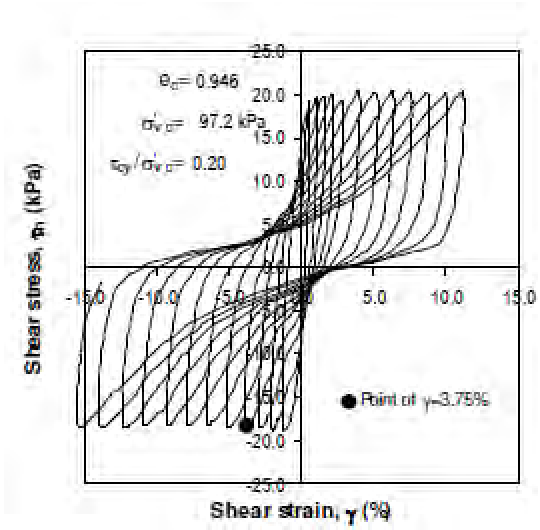

Figure 3: Stress-strain responses of NC Fraser River silt under constant volume cyclic DSS loading (σ'_v = 97 kPa; CSR = 0.20; α = 0; OCR = 1.0) Wijewickreme (2010).

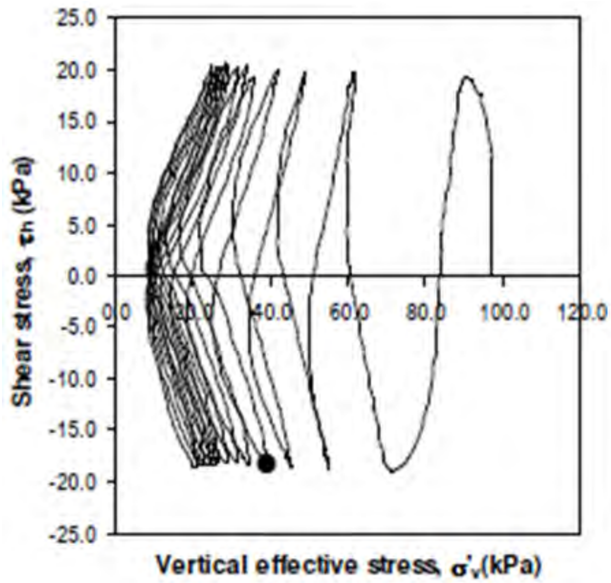

Figure 4: Stress-path responses of NC Fraser River silt under constant volume cyclic DSS loading (σ'_v = 97 kPa; CSR = 0.20; α = 0; OCR = 1.0) (Wijewickreme, 2010).

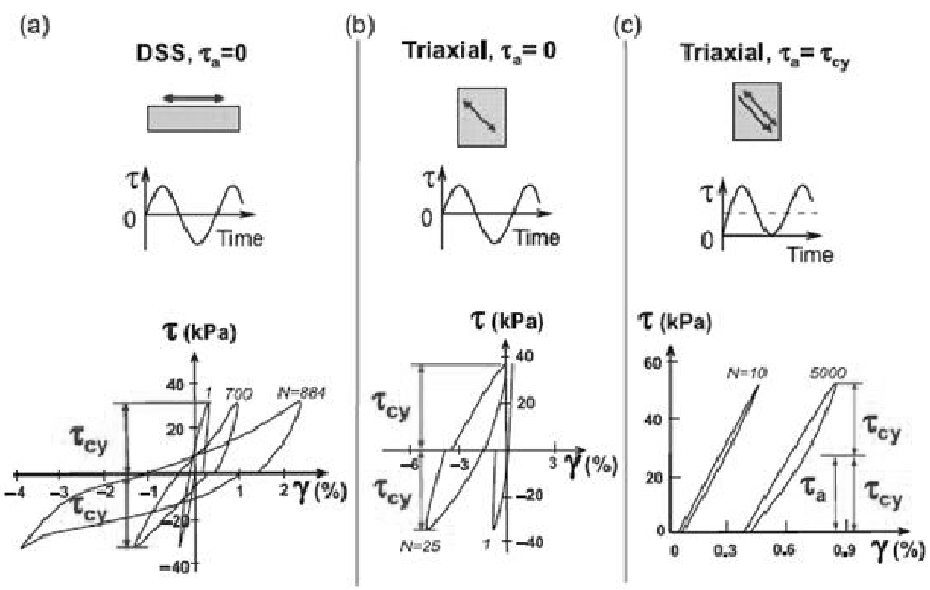

Figure 5: Stress-strain behavior under different loading conditions (Andersen, 2009)

EXPERIMENTAL PROGRAM

The laboratory testing program for this study was designed to analyze the behavior of marine silty sand when subjected to cyclic loads for different combinations of parameters such as cyclic stress ratio, no. of loading cycles, and relative density.

For marine silty sand, tests were performed at a frequency of 0.1 Hz. Effect of Relative Density (Dr) for 65%, and 70% percent is studied for various CSR and no. of loading cycles. Marine silty sand has minimum voids ratio of 0.745 and maximum voids ratio of 1.183. Specific gravity of Gs=2.65.

To produce in-situ (Ko) stress conditions, a vertical consolidation stress must be applied to the sample prior to shearing. Applied vertical stresses simulate the loads from overburden material located over the soil sample. For marine silty sand, a normal consolidation stress of 100 KPa was applied in one step for all the specimens.

TEST RESULTS

In this study, the failure criterion was established as 4% peak to peak double amplitude shear strain. The results of tests are shown in Figures 6, 7 and 8. Figure 6 shows the development of shear strain throughout the test, which reaches 4% double amplitude shear strain at nearly 295 cycles. Figures 7 and 8 show the stress paths for 0.1 CSR and 0.2 CSR. It is found that effective stress decreases with cycles rapidly at higher CSR. Figures 9 and 10 show stress-strain responses for CSR = 0.12. The responses are quite symmetrical, implicating that specimens were well constituted and the tests were carefully executed.

Total 8 CDSS tests were conducted, 4 tests at voids ratio of 0.898 (Dr 65%) and CSR range of 0.10, 0.12, 0.14, and 0.16. Another 4 tests were performed at voids ratio of 0.847 (Dr 70%) and at CSR range of 0.10, 0.12, 0.14, and 0.20. Those results are plotted in Figure 11. As expected, the specimens reach large shear strain faster at high CSR and void rario. It was observed that specimens having higher relative densities require higher no. of loading cycles to reach 4% double amplitude shear strain. Also, increasing the cyclic stress ratio (CSR) reduces the no. of loading cycles to reach 4% double amplitude shear strain. Same trend was observed in majority of the literature referenced in this paper. . Degradation of silty sand was also observed with increasing no. of loading cycles. This kind of information can be used to incorporate the cyclic degradation effect in the wind turbine foundation design.

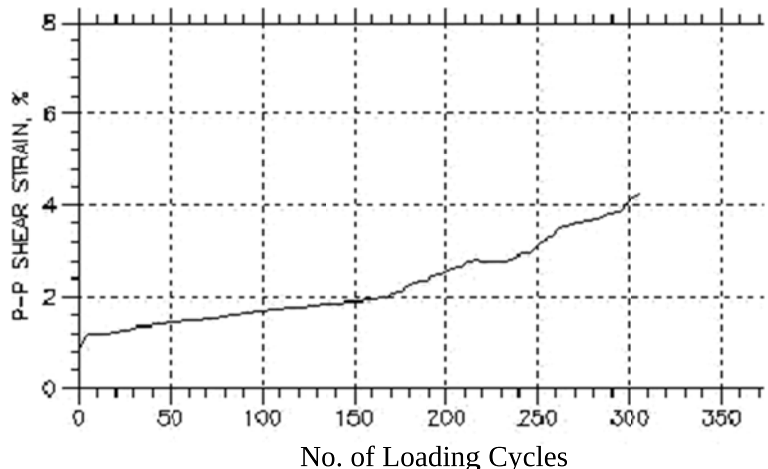

Figure 6: Peak-Peak Shear Strain versus No. of Loading cycles for CSR=0.10 and e_c=0.898.

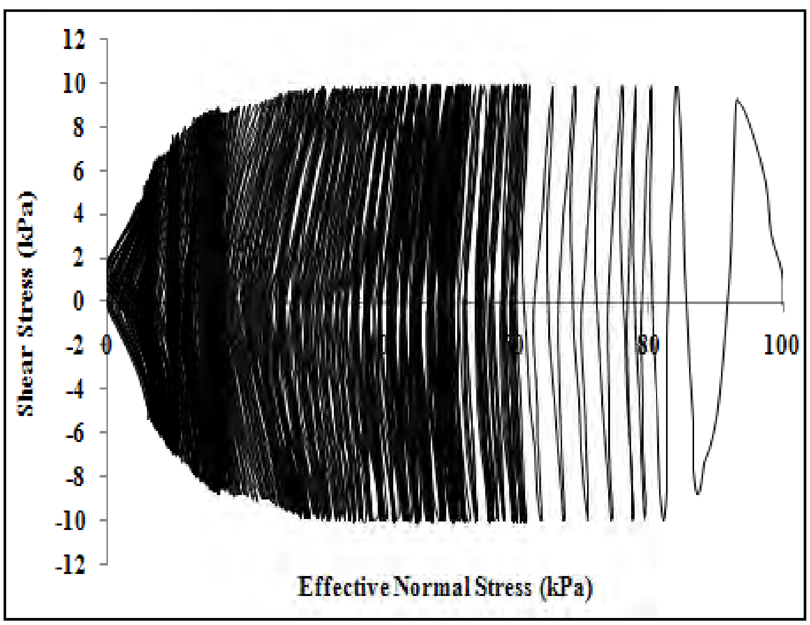

Figure 7: Stress Path during constant volume cyclic DSS loading of silty sand for CSR=0.10 and e_c=0.898

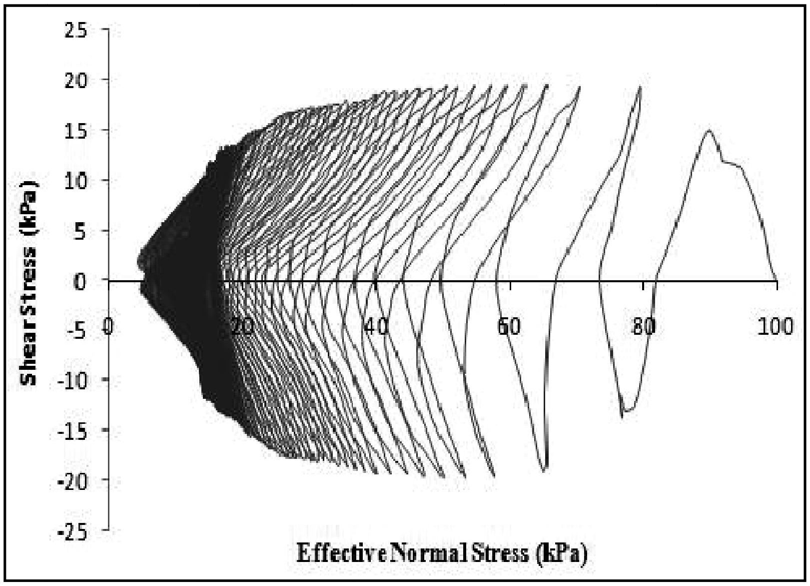

Figure 8: Stress Path during constant volume cyclic DSS loading of silty sand for CSR=0.2 and e_c=0.898

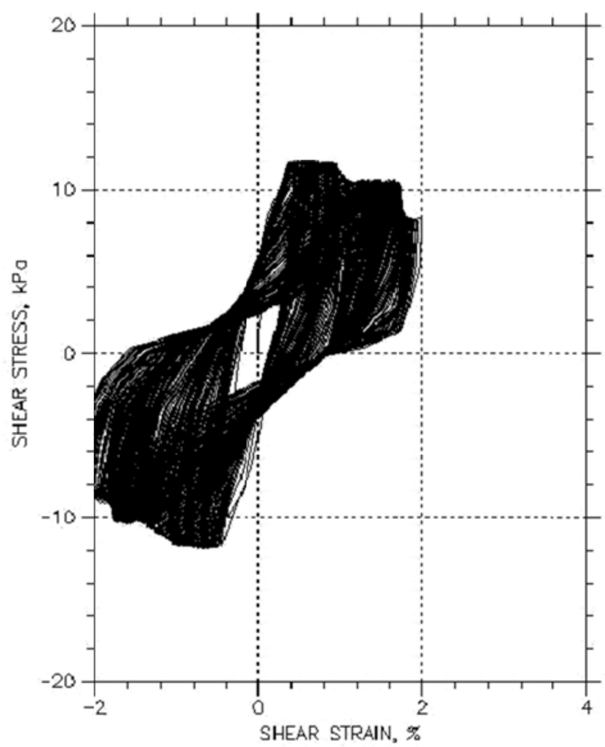

Figure 9: Stress-strain response of marine silty sand under constant volume cyclic DSS loading. (σ'_v = 100 kPa; CSR = 0.12; e_c = 0.847; α = 0; OCR = 1.0)

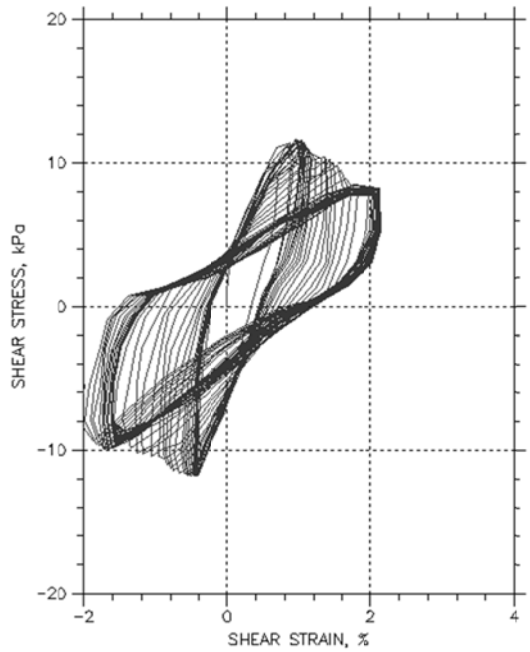

Figure 10: Stress-strain responses of marine silty sand under constant volume cyclic DSS loading (σ'_v = 100 kPa; CSR = 0.12: e_c = 0.898; α = 0; OCR = 1.0).

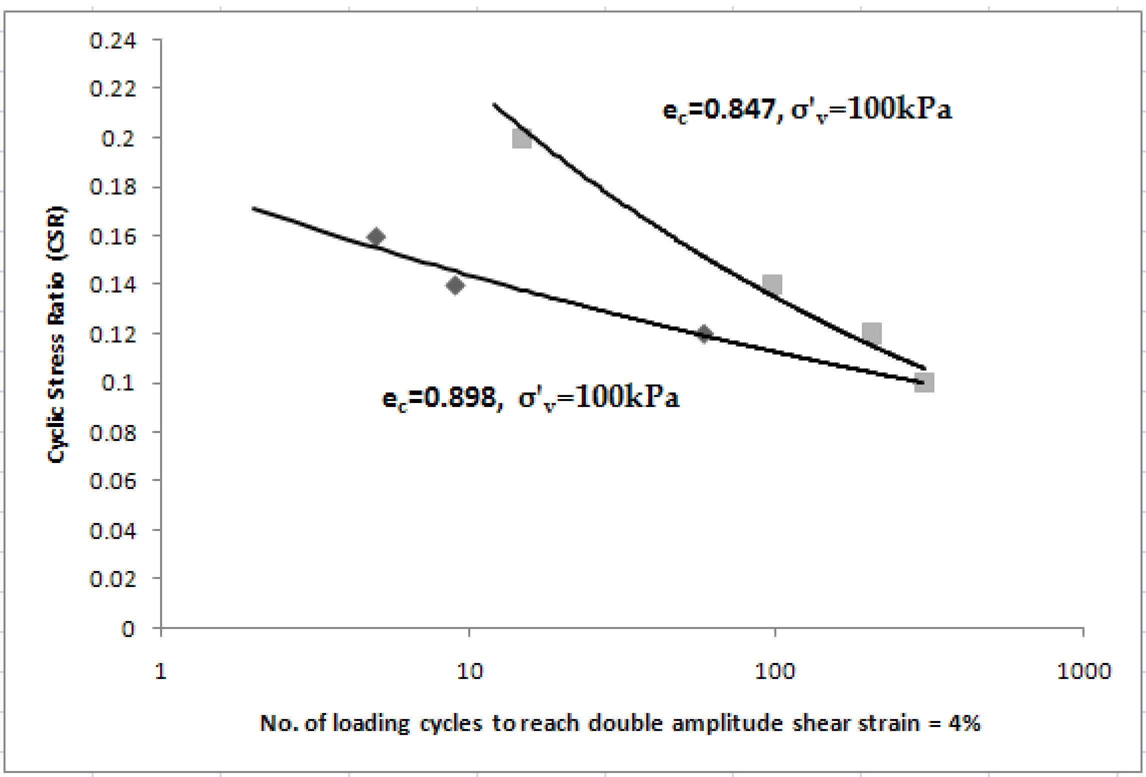

Figure 11: CSR versus No. of Loading cycles to reach 4% double amplitude shear strain

Cyclic tests with extensive laboratory testing are necessary for understanding the detailed dynamic properties of silty marine sand.

CONCLUSION

Cyclic shear response of West Sea marine silty sand, Korea was investigated. In this study it is observed that cyclic degradation of all specimens occurs rapidly at high CSRand low relative density

It was also observed that specimens having higher relative densities require higher no. of loading cycles to reach 4% double amplitude shear strain. Also, increasing the cyclic stress ratio (CSR) reduces the no. of loading cycles to reach 4% double amplitude shear strain. .

Degradation of silty sand was also observed with increasing no. of loading cycles. The effect of initial or average shear stress will be considered in the future.

ACKNOWLEDGEMENT

This research was supported by a grant from the Korea Institute of Construction and Transportation Technology Evaluation and Planning (KICTTEP), and by the Ministry of Land, Transport, and Maritime Affairs (MLTM) R&D program (2010 Construction Technology Innovation Program, 10-CTIP-E04).

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