

Comparative Analysis of Cyclic Shear Behavior in Sand and Marine Clay Under Strain-Controlled Conditions

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Abstract - In this research, the cyclic behavior of Silty Sand and marine clay is studied under controlled conditions by employing the cyclic simple shear test. The main aim is to compare the behavior of these two geomaterials (Fine Silty Sand and Marine Clay) when subjected to the same normal stress (150 kPa), loading frequency (0.50 Hz), amplitude (0.10 mm, 0.20 mm, 0.4 mm & 0.5 mm) and number of shear cycles (30 Nos). By keeping test parameters constant, the study isolates the effect of soil type on cyclic deformation behavior, such as shear strain accumulation, shear modulus and cyclic shear variation. The findings indicate unique behavioral modes between Silty Sand and marine clay, which reflect the control exercised by particle structure, drainage conditions, and plasticity on cyclic response. These results add to the understanding of soil behavior under cyclic loading and the design and durability of geotechnical structures in seismic and offshore soils.

Key Words: - Shear Stress, Shear Strain, Hysteric loop, Shear Modulus

INTRODUCTION

The cyclic response of soils during dynamic loading is an important aspect of geotechnical engineering, especially in seismically active areas. Earthquakes and other cyclic loading conditions have the potential to cause dramatic deformation of the soil layers, producing such effects as accumulation of shear strain, excess pore pressure development, and in the worst instances, liquefaction. The cyclic response of various soils plays a key role in the design of foundations, embankments, and earth-supported retaining structures that are strong enough. Among different types of soils, Silty Sand and marine clay are two opposite poles of the geotechnical world. Silty Sand is a non-cohesive granular soil with a high tendency to liquefy because of its loose nature and fast pore pressure response. Marine clay is a cohesive fine-grained soil with high plasticity and low permeability, characterized by intricate cyclic behavior with an

incorporation of strain softening and retarded pore pressure development.

In spite of massive investigation on individual types of soil, comparative studies, which bring out the pivotal differences in cyclic behavior between Silty Sand and marine clay, are scarce. The contribution of particle structure, drainage conditions, and plasticity to controlling the above behaviors is not comprehensively known, especially under laboratory-controlled conditions. This lack of knowledge makes seismic risk assessment and soil-structure interaction modeling challenging.

MATERIAL

The soil samples selected for this study consist of marine clay and fine Silty Sand, representing two distinct geotechnical profiles. The marine clay is characterized by a high plasticity index, with a liquid limit of 75% and a plastic limit of 40%, indicating significant water retention and deformation capacity. The fine content in the clay sample is 95%, classifying it as a highly cohesive soil with low permeability and strong potential for cyclic degradation under undrained conditions. In contrast, the fine Silty Sand sample contains less than 15% fines, making it a non-cohesive, free-draining material with relatively low plasticity. This stark contrast in particle size distribution and plasticity between the two soils provides a robust basis for evaluating their cyclic behavior under identical loading conditions.

Table 1- Properties of soil sample (Silty sand and Marine clay)

Property	Marine Clay	Fine Silty Sand	Unit
Percentage Fine	95.00	< 15.00	%
Liquid Limit	75.00	Non Plastic	%
Plastic Limit	40.00	Non Plastic	%
Specific Gravity	2.66	2.63	
Water Content	27.00	43.05	%

Bulk Density	1.63	1.68	gm/cc
Dry Density	1.27	1.18	gm/cc

TESTING APPRATUS

The cyclic simple shear tests conducted herein were conducted on the Wykeham Farrance WF7500, which is a next-generation cyclic shear testing system designed for next-generation geotechnical research. The apparatus is specifically designed to duplicate earthquake-induced shear stresses within controlled laboratory conditions, and as such, is perfectly suited to assessing soil behavior under dynamic repeated loading.

The WF7500 employs pneumatic actuators, which provides repeatable and accurate shear displacement without using hydraulic systems. Its modular construction enables versatile configurations, from manual to full automatic control, to suit an array of laboratory configurations and research applications. figure-1 shows the test setup for test. The test facility is available with COMACOE Advance Geo-tech lab located in Mira road Mumbai.

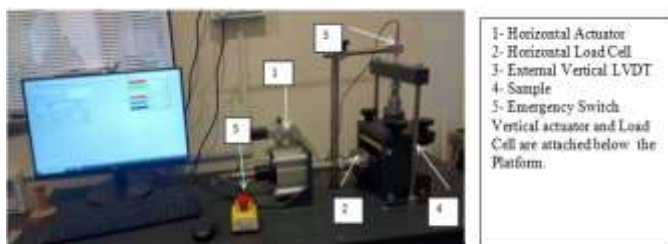


Figure 1-Test Setup

TEST PROGRAM

The test procedure entailed cyclic shear loading of two types of soils—Silty Sand and marine clay—under laboratory conditions. Each of the samples was subjected to a vertical stress of 150 kPa, to which it was left to consolidate for 30 minutes. The consolidation load was kept constant throughout the whole process of testing in order to achieve long-term field stress conditions. The cyclic shear testing was performed with displacement-controlled loading at amplitudes of 0.1 mm, 0.2 mm, 0.4 mm, and 0.5 mm to assess the strain-dependent characteristics of the soils. For every amplitude level, the test was extended to 30 cycles to study the gradual changes in shear resistance and deformation behavior. This configuration allowed for a comparative evaluation of the cyclic behavior of Silty Sand and marine clay under the same loading conditions. the test program is summarized in the table-2 below.

Table 2-Cyclic Simple Shear Test Parameters

Parameter	Marine Clay	Fine Silty Sand	Units
Consolidation Pressure	150.00	150.00	kPa
Effective vertical stress during shearing	150.00	150.00	kPa
Frequency	0.50	0.50	Hz
No of cycles	30	30	Nos
Amplitude			
1	0.10 (0.5 %)	0.10(0.5 %)	mm
2	0.20 (1.0 %)	0.20 (1.0 %)	mm
3	0.40 (2.0 %)	0.40 (2.0 %)	mm
4	0.50 (2.5 %)	0.50 (2.5 %)	mm

SAMPLE PREPERATION

Soil specimens were extruded from the sampling tubes slowly and carefully to maintain their natural structure and moisture levels. Specimens were cut to the appropriate size using a precision cutter to achieve uniformity and reduce disturbance. The sample was then positioned centrally on the shear box pedestal of the test apparatus. A thin rubber membrane was wrapped round the specimen carefully to seal it and stop lateral leakage during testing. After membrane installation, top and bottom rings were fixed to keep the sample in place and enable even shear stress application. Through this procedure, the sample's integrity was ensured during the test so that cyclic deformation characteristics could be measured accurately. Figure-2 shows the prepared soil sample and assemble.



Figure 2- Soil Sample Assemble

SCOPE OF STUDY

This paper is concerned with cyclic simple shear tests in a laboratory setting on reconstituted Silty Sand and undisturbed marine clay samples. The tests are carried out under a controlled stress state to create earthquake-like loading. Stress-strain behavior and shear modulus versus amplitude variation are included in the data analysis. The results should serve to give insight into the underlying mechanisms of cyclic instability in various types of soil.

The main goal of the present research is to examine and contrast the cyclic deformation behavior of Silty Sand and marine clay by means of cyclic shear testing.

Significance

Through the explanation of the opposing cyclic responses of Silty Sand and marine clay, this study aids the better understanding of seismic loading soil dynamics. The findings are anticipated to improve predictive models for liquefaction and cyclic degradation, guide geotechnical design practice, and aid in the formulation of site-specific mitigation strategies in earthquake regions.

The results of the cyclic shear test show significant differences in Silty Sand and marine clay's mechanical response to repeated loading. These differences highlight the role of inherent soil properties, most notably particle structure, drainage, and plasticity, in controlling the cyclic deformation behavior.

Silty Sand, with its low plasticity and granular structure, is normally prone to quick pore pressure increase under conditions of undraining. This results in the decrease in effective stress and the significant rise in shear strain, usually ending in liquefaction. The relatively free-draining character of Silty Sand also makes it vulnerable to cyclic softening, particularly if it is loosely packed.

$$t_{cyc} = \frac{t_{max} - t_{min}}{2} \quad t_{avg} = \frac{t_{max} + t_{min}}{2}$$

Conversely, marine clay, with its plastic matrix and greater plasticity, exhibits more progressive buildup of shear strain. Its low permeability and fine-grained composition resist pore pressure dissipation, leading to a lagged but sustained excess pore pressure buildup. Although liquefaction will not as violently occur as in Silty Sand, marine clay tends to exhibit cyclic degradation, expressed in the form of cumulative strain buildup and reduction in strength during repeated cycles. These observations emphasize the pivotal role of soil fabric and drainage conditions in determining cyclic response. Comprehending these differences is fundamental to reliable seismic hazard assessment and designing robust geotechnical structures.

RESULTS AND DISCUSSION

Figure 3 & 4 shows the stress strain hysteric loop response of Silty Sand and marine clay. For normally consolidated specimen subjected to strain-controlled tests at $\gamma_{cy} = \pm 0.5\%, 1\%, 2\%$ and 2.5% (strain calculated with respected to original specimen height 20mm) the t_{cyc} for Silty Sand degrade in the range of ± 0.50 to 1.90 kPa while for clay soil sample it ± 0.5 to 4.68 kPa.



Figure 3- Stress Strain hysteric loop response of Clay



Figure 4-Stress Strain hysteric loop response of Silty Sand

Table 3 and 4 shows the shear stress and shear strain value for 30th cycle. The cyclic shear stress and average shear stress are calculated as below.

- t_{cyc} - cyclic shear stress during a given cycle, kN/m^2
- t_{avg} - Average shear stress during a given cycle, kN/m^2
- t_{max} - maximum shear stress during a given cycle, kN/m^2
- t_{min} - minimum shear stress during a given cycle, kN/m^2 ,
- g_{max} - maximum shear strain during a given cycle, %.
- g_{min} - minimum shear strain during a given cycle, %.

Table 3 the shear stress and shear strain value for 30th cycle Silty Sand.

Amplitude	t _{max}	t _{min}	g _{max}	g _{min}	t _{cy}	t _{avg}
mm	kPa	kPa	%	%	kPa	kPa
0.10	11.95 3	14.03 2	0.44 5	0.60 2	12.9 9	1.0 4
0.20	23.38 6	24.94 5	0.84 0	1.21 9	24.1 7	0.7 8
0.40	49.89 0	49.37 1	1.69 9	2.37 7	49.6 3	0.2 6
0.50	67.56 0	63.92 2	2.04 3	3.04 5	65.7 4	1.8 2

Table 4 the shear stress and shear strain value for 30th cycle Clay.

Amplitude	t _{max}	t _{min}	g _{max}	g _{min}	t _{cy}	t _{avg}
mm	kPa	kPa	%	%	kPa	kPa
0.10	7.79	11.95	0.46	0.61	9.87	-2.08
0.20	11.93	21.56	0.85	1.26	16.76	-4.81
0.40	17.92	38.45	1.73	2.46	28.19	10.26
0.50	24.68	45.47	2.08	3.14	35.08	10.39

Figure 5,6,7, and 8 shows the response comparison of the Silty Sand and clay for 30th cycle for amplitude 0.1mm, 0.2mm, 0.4mm and 0.5mm respectively. From the graph it is observed that the stress is accumulated in the Silty Sand sample with increase in strain while for clay soil sample its increases gradually.



Figure 5-Stress Strain Hysteric loop response for 30th cycle (amplitude+0.1)

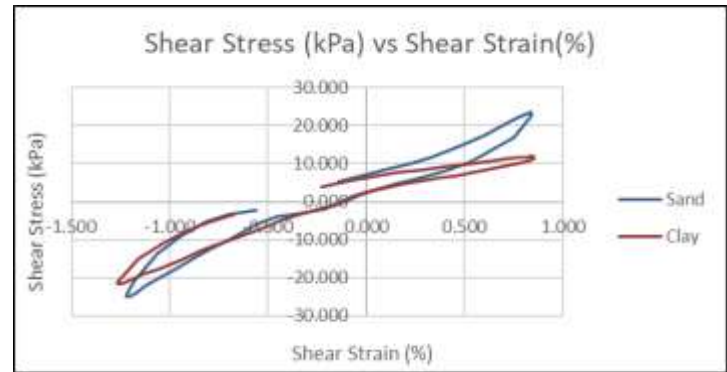


Figure 6-Stress Strain Hysteric loop response for 30th cycle (amplitude+0.2)

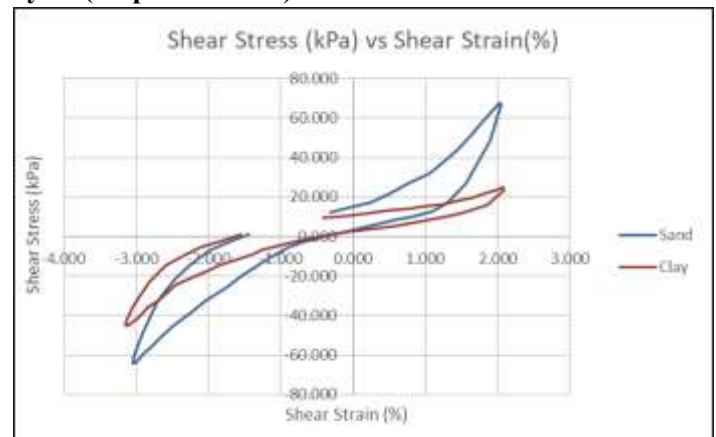


Figure 7-Stress Strain Hysteric loop response for 30th cycle (amplitude+0.4)

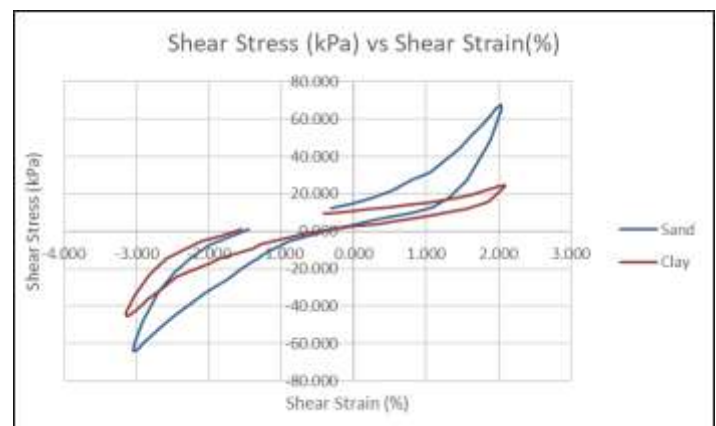


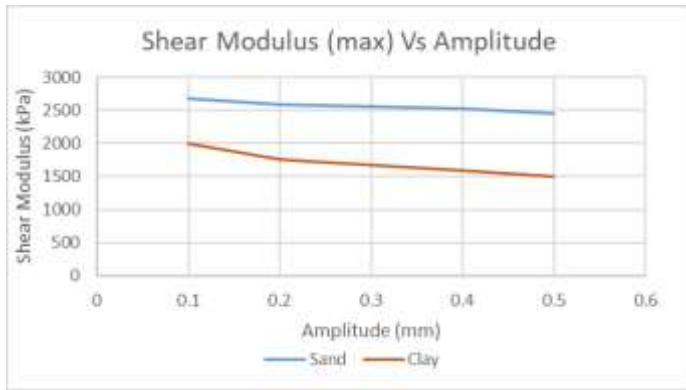
Figure 8-Stress Strain Hysteric loop response for 30th cycle (amplitude+0.5)

The shear modulus (G) was calculated using the formula given below. For each amplitude the maximum shear modulus obtained during any loading cycle for particular amplitude is reported in the table 5. the variation of shear modulus for different amplitude is plotted in the figure 9. The variation of G_{max} value is from 2456 to 2685 kPa for Silty Sand and 1503 to 2000 kPa for clay soil.

$$G = \frac{(t_a - t_b) \times 100}{(g_a - g_b)}$$

Table 5 Shear modulus (G) for various amplitude .

Amplitude(mm)	Shear Modulus (G) kPa	
	Silty Sand	Marine Clay
0.10	2456.57	1503.63
0.20	2524.20	1591.33
0.40	2591.92	1753.89
0.50	2685.00	2000.18


Figure 9- Variation of shear modulus of Silty Sand and clay for different amplitude

CONCLUSION

This research examined the cyclic shear behavior of clay and sand in response to different displacement amplitudes of 0.10 mm, 0.20 mm, 0.40 mm, and 0.50 mm. Through close examination of hysteresis loops and degradation of shear modulus, it was found that:

- Differences in Material Response:** Sand displayed comparably stable and narrow hysteresis loops over all amplitudes, showing higher elasticity and less energy dissipation. Clay, on the other hand, displayed increasingly wider loops with rising amplitude, illustrating greater damping and plastic deformation.
- Shear Modulus Trends:** Both materials showed a reduction in shear modulus with increasing amplitude, consistent with strain-dependent stiffness loss. The reduction was more significant for clay, however, which implies higher sensitivity to cyclic loading.
- Amplitude Influence:** At lower amplitudes (0.10 mm and 0.20 mm), sand was more stiff and less damping than clay. At greater amplitudes (0.40 mm and 0.50 mm), clay's modulus fell drastically, and its hysteresis behavior became progressively more nonlinear.
- Impact on Geo technical Design:** The opposing cyclic behaviors of sand and clay highlight the significance of material-based factors in seismic and dynamic load conditions. Sand could be more

appropriate in circumstances demanding stiffness retention, whereas clay's damping quality might be preferable in energy dissipation applications.

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