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The Effect of Rapid Loading on the Compressibility Properties of Cohesive Soils

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Abstract

When soil material is subjected to external loading (pressure), its particles tend to undergo rearrangement because of the gradual expulsion of air/water from the soil mass which gives rise to reduction in volume. The loading pattern has a significant effect on the behavior of soil as it responds to the loading. In this research, two categories of consolidation tests; namely Rapid Loading Tests and Standard loading tests were carried out on different soil samples extracted from four different locations within Port Harcourt, Nigeria to investigate the effect of rate of loading on the consolidation properties of cohesive soils. In the Rapid loading Tests, the incremental loading was done at every one-hour (1hr.) interval to simulate the rapid loading whereas in the Standard Loading Tests, the load increment was done at every 24 hours or until there was no significant change in the dial gauge reading. The results of the investigation showed that the values for the coefficient of volume compressibility (mv), and compression index (Cc) were higher by an average of 34.8% and 77.2% respectively whereas the values of Coefficient of consolidation (cv), Swelling Index (Cs), the time factor for 90% consolidation (t90) and Preconsolidation pressure (Pc) were found to be reduced by an average of 37.8%, 33.8% ,32.6% and 15.4%respectively. More so, the settlements were found to be higher by an average of 23.5% in the rapidly loaded soil samples as compared to those of the standard loading tests. Lastly, the results of the investigation, when compared to the recommended values, were found to be within the acceptable range of values. Hence, it could be concluded that soils respond differently depending on the loading pattern, and that the compressibility properties of soil materials can be affected by the rate of loading.

Keywords: Rapid Loading Test, Standard Loading Test, Cohesive soil, Consolidation Test, Compressibility.

INTRODUCTION

Buildings, earth retaining walls and other structures exert pressure on the supporting foundation which in turn is transmitted to the soil. When soil is loaded in undrained condition, this causes an increase in pore pressure. Then under site conditions, the pore pressure dissipates, and water leaves the soil resulting in Consolidation settlement (Atkinson, 2007.).

In construction, project duration can be influenced by several factors ranging from environmental conditions, improper planning, material shortages, equipment/ plant shortages, financial problems, etc. (Dominicka, 2017). For these reasons, some projects are completed even before schedule time or on schedule time while others may delay beyond scheduled time depending on the prevailing factors. For instance, some multi-storey buildings have been completed in less than one year, whereas others have taken up to five years or more before completion.

The way a particular soil will respond when subjected to a rapid rate of loading will be completely different when the same soil is subjected to slow rate of loading. It is therefore important to carry out proper consolidation and settlement analysis prior to construction of civil Engineering structures on such soil to prevent failures and subsequent loss of lives and properties due to failure of the foundation.

Consolidation and settlement, especially in cohesive soils like clay, affect the essential criteria of durability, serviceability and functionality of the structure and therefore, must be carefully considered in the design of any structure that will be sited on it. (Ademoju,2014).

Hence, this research is aimed at investigating the response of cohesive soils in Niger Delta when subjected to rapid, vertical loading. Two categories of consolidation tests (Rapid loading and Standard loading) were performed on soil samples obtained from the study area to investigate the effect of rapid loading on the compressibility properties of the soils, which include the coefficient of Volume compressibility (m_v), the coefficient of consolidation (C_v), the compression index (C_c) and the swelling Index (C_s).

The aim of the research is to investigate the effect of rapid loading on the compressibility properties and consolidation settlement of cohesive soils using the one-dimensional consolidation test (Odometer test).

The objectives of this research are to perform two types of consolidation tests in the laboratory under two loading conditions namely: rapid loading and Standard loading and thereafter, make comparison to achieve the following:

i. To determine the coefficient of consolidation (C_v) for both Rapid and Standard loading conditions.
ii. To determine the coefficient of volume compressibility (m_v) for both Rapid and standard loading conditions
iii. To determine the compression index (Cc)for both Rapid and Standard loading tests
iv. To determine the swelling index (C_s)for both Rapid and Standard loading tests
v. To determine the pre-consolidation pressure (Pc) of the soils for both Rapid and Standard loading conditions
vi. To determine the time factor for 90% consolidation to take place (t_{90}) for both the rapid and standard loadings
vii. To determine the magnitude and rate of settlement of the soils for both Rapid and Standard loading conditions

2. MATERIALS AND METHODS

2.1 Materials

Materials used in this research include

i. Cohesive soils
ii. Water.

2.2 Methods

The index properties and the specific gravities of the collected soil samples were determined. Thereafter, two types of Consolidation Tests were performed on the soil samples, namely Rapid Loading Test and Standard Loading Test.

2.3 Consolidation Tests

2.3.1 Rapid Loading Test (Loading phase)

During the loading phase of the rapid loading consolidation test, the load increment (50kN/m^2, 200kN/m^2, 200kN/m^2 and 400kN/m^2) was done at every 1hr. with the exception of the last maximum loading, which was allowed to stand until there was no change in the dial gauge reading or for a maximum of 24 hours. The dial gauge readings were recorded throughout the test period. This process was repeated for all soil samples labeled for rapid loading condition.

2.3.2 Rapid Loading Test (Unloading phase)

The unloading phase followed a similar pattern as with the loading phase but in reverse manner (400kN/m^2, 200kN/m^2, 100kN/m^2, and 50kN/m^2). The loading (pressure) was reduced at every 1hr. while recording the dial gauge readings until the minimum pressure of 50kN/m^2 was reached.

2.3.3 Standard Loading Test (Loading phase)

In the loading phase of the standard loading consolidation test, the load increment was (50kN/m^2, 200kN/m^2, 200kN/m^2 and 400kN/m^2). It was allowed to stand until there was no change in the dial gauge reading for two consecutive hours or maximum of 24 hours before increasing the load. Again, the dial gauge readings were recorded throughout the test period in accordance with ASTM D2435 for consolidation test.

2.3.3 Standard Loading Test (Unloading phase)

Similarly, the unloading phase followed a similar pattern as with the loading phase of the standard loading but in reverse manner (400kN/m^2, 200kN/m^2, 100kN/m^2, and 50kN/m^2). Again, this process was repeated for all soil samples labeled for standard loading condition.

Table 1: Index Properties of Soft Soil

Pressure (kN/m^2)	Loading				Unloading		
	50	100	200	400	200	100	50

3. RESULTS AND DISCUSSION

The results of the investigation are presented below, and the discussions are based on the findings.

Table 2: Consolidation Properties of the cohesive soils

S/N.	Sample No.	C_v (m^2/yr)	m_v (m^2/MN)	C_c	C_s	P_c (kN/m^2)	t_{90} (Min.)
BH 1	RL-1	1.08×10^{-4}	1.4×10^{-1}	2.93×10^{-1}	-1.05×10^{-2}	116	6.4
	SL-1	1.34×10^{-4}	3.0×10^{-1}	4.76×10^{-1}	-1.06×10^{-2}	221	5.8
	RL-2	1.07×10^{-4}	1.4×10^{-1}	2.91×10^{-1}	-1.04×10^{-2}	115	5.8
	SL-2	1.66×10^{-4}	1.32×10^{-1}	1.87×10^{-1}	-1.18×10^{-2}	168	5.8

S/N.	Sample No.	C_v (m^2/yr)	m_v (m^2/MN)	C_c	C_s	P_c (kN/m^2)	t_{90} (Min.)
BH2	RL-3	$1.11x10^{-4}$	$1.4x10^{-1}$	$2.93x10^{-1}$	$-1.05x10^{-2}$	116	5.8
	SL-3	$1.82x10^{-4}$	$1.03x10^{-1}$	$2.11x10^{-1}$	$-1.32x10^{-2}$	141	9.3
	RL-4	$1.04x10^{-4}$	$1.87x10^{-1}$	$2.60x10^{-1}$	$-1.02x10^{-2}$	117	5.6
	SL-4	$1.34x10^{-4}$	$1.03x10^{-1}$	$1.98x10^{-1}$	$-1.52x10^{-2}$	180	8.4
BH3	RL-5	$1.09x10^{-4}$	$2.92x10^{-1}$	$4.16x10^{-1}$	$-0.47x10^{-2}$	190	7.9
	SL-5	$1.31x10^{-4}$	$1.05x10^{-1}$	$1.47x10^{-1}$	$-1.40x10^{-2}$	205	9.9
	RL-6	$0.72x10^{-4}$	$1.4x10^{-1}$	$4.13x10^{-1}$	$-0.47x10^{-2}$	200	7.9
	SL-6	$1.31x10^{-4}$	$2.92x10^{-1}$	$1.46x10^{-1}$	$-1.39x10^{-2}$	170	9.9
BH4	RL-7	$0.83x10^{-4}$	$1.98x10^{-1}$	$4.96x10^{-1}$	$-1.11x10^{-2}$	235	5.9
	SL-7	$1.74x10^{-4}$	$1.05x10^{-1}$	$1.43x10^{-1}$	$-1.36x10^{-2}$	183	6.4
	RL-8	$0.89x10^{-4}$	$3.0x10^{-1}$	$4.77x10^{-1}$	$-1.06x10^{-2}$	200	6.7
	SL-8	$2.07x10^{-4}$	$1.05x10^{-1}$	$1.5x10^{-1}$	$-1.75x10^{-2}$	197	10.2
	AVERAGE					**172**	

3.1 Consolidation Test

Calculation of Height of solid (H_s) and Initial Void ratio (e_0)

Height of solid (Hs) = $m_s/(A^* G_s *pw)$ (1)

Initial Void ratio (e_0) = $Hs-H_0/H_s$ (2)

Where:

m_s = Mass of dry specimen

A = Area of Specimen

G_s = Specific gravity

pw = Density of water

Settlement Determination in terms of mv

Settlement (S) = mvΔσH (3)

Where:

mv = av/1+e_0 and H = Total height of clay layer (Cohesive soil)

Settlement Determination in terms of C_c

Settlement (S) = $C_c/(1+e_0)H\log[(\sigma_1+\Delta\sigma)/\ \sigma_1$ (4)

Total Settlement due to Δσ

Total = Sr + Sc (5)

Where:

$Sr = S_{rebound} = C_r/(1+e_0)H_0\log(\sigma_2/\sigma_1)$ (6)

$= C_r/(1+e_0)H_0\log((\sigma c/\sigma_1)$

$Sc = S_{co} = C_c/(1+e0)H_0\log(\sigma_2/\sigma_1)$ (7)

$= C_c/(1+e0)H_0\log[(\sigma c+\Delta\sigma)/\ \sigma_c]$

Where:

σ_1 = Initial Pressure

σ_2 = Final Pressure

Δσ = Change in pressure

σ_c = Preconsolidation pressure

Determination of Time rate of settlement

$T_{90} = 0.848 = C_v t_{90}/(H/n)^2$ (8)

$t_{90} = 0.848(H/n)^2/C_v$

Where:

C_v = Coefficient of consolidation

H = Total thickness of the clay layer

n = No. of drainage boundaries (Note n=2 for double drainage)

t_{90} = time required for 90% consolidation to occur

Table 4.1: Results for Coefficient of Consolidation (Cv)

Borehole No.	Loading Type	Sample No.	Cv (x10^-4 m2/yr)
BH-1	RAPID	RL-1	1.08
BH-1	RAPID	RL-2	1.07
BH-2	RAPID	RL-3	1.11
BH-2	RAPID	RL-4	1.04
BH-3	RAPID	RL-5	1.09
BH-3	RAPID	RL-6	0.72
BH-4	RAPID	RL-7	0.83
BH-4	RAPID	RL-8	0.89
BH-1	STANDARD	SL-1	1.34
BH-1	STANDARD	SL-2	1.66
BH-2	STANDARD	SL-3	1.82
BH-2	STANDARD	SL-4	1.34
BH-3	STANDARD	SL-5	1.31
BH-3	STANDARD	SL-6	1.31
BH-4	STANDARD	SL-7	1.74
BH-4	STANDARD	SL-8	2.07

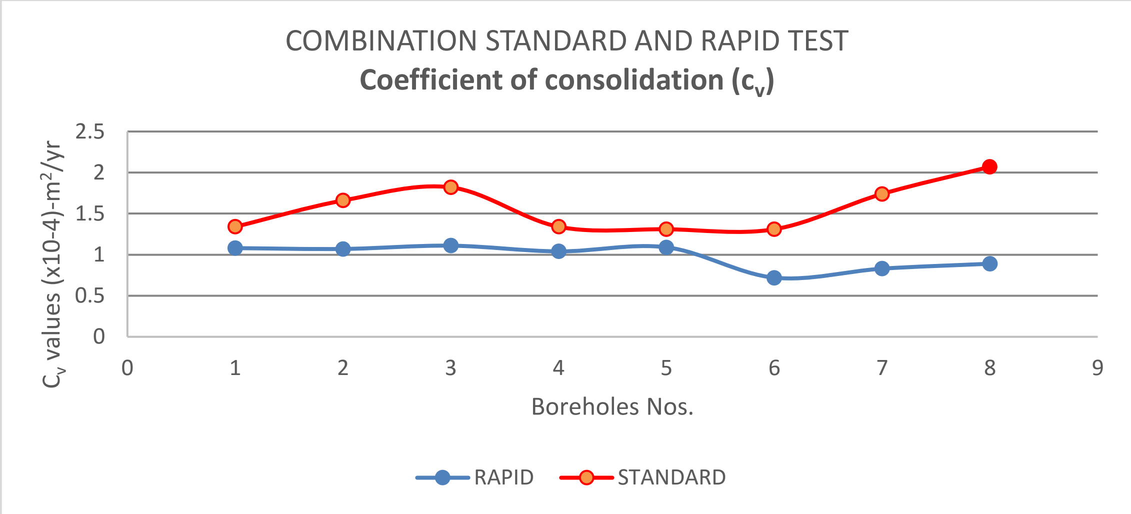

Figure 4.1: C_v plots for Combined Standard and Rapid load Tests

From Table 4.1, the Coefficient of consolidation (cv) values were plotted against the Boreholes number. The graph in figure 4.1 shows a 37.8% average reduction in cv values for the rapid loading as compared to the standard loading. Hence, it can be deduced that the rapid loading resulted in lower cv values in the tested samples.

Table 4.2: Results for Coefficient of Volume Compressibility (mv)

Borehole No.	Loading Type	Sample No.	mv (x10^-1 m2/MN)
BH-1	RAPID	RL-1	1.40
BH-1	RAPID	RL-2	1.40
BH-2	RAPID	RL-3	1.40
BH-2	RAPID	RL-4	1.87
BH-3	RAPID	RL-5	2.92
BH-3	RAPID	RL-6	1.40
BH-4	RAPID	RL-7	1.98
BH-4	RAPID	RL-8	3.00
BH-1	STANDARD	SL-1	3.00
BH-1	STANDARD	SL-2	1.32
BH-2	STANDARD	SL-3	1.03
BH-2	STANDARD	SL-4	1.03
BH-3	STANDARD	SL-5	1.05
BH-3	STANDARD	SL-6	2.92
BH-4	STANDARD	SL-7	1.05
BH-4	STANDARD	SL-8	1.05

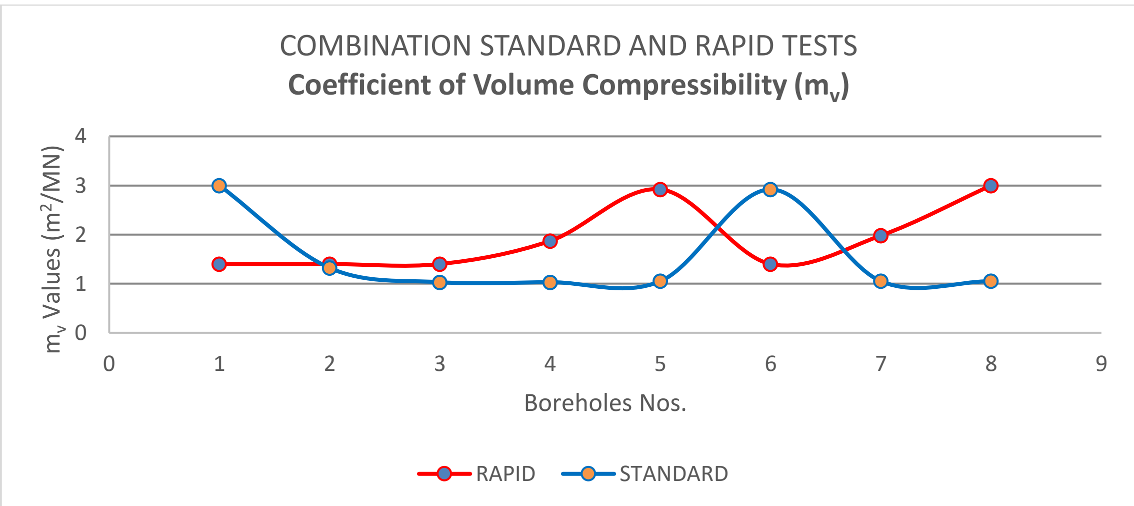

Figure 4.2: m_v plots for Combined Standard and Rapid load Tests

From Table 4.2, the Coefficient of volume compressibility (mv) values were plotted against the Boreholes number for all the tested samples. It was observed from figure 4.2 that there was an average increase of 34.8% in mv values for the rapidly loaded soil samples as compared to those of the standard loading. This shows that the rapid loading resulted in higher Coefficient of volume compressibility (mv) values.

Table 4.3: Results for Compression Index (Cc)

Borehole No.	Loading Type	Sample No.	Cc (x10^-1)
BH-1	RAPID	RL-1	2.93
BH-1	RAPID	RL-2	2.91
BH-2	RAPID	RL-3	2.93
BH-2	RAPID	RL-4	2.60
BH-3	RAPID	RL-5	4.16
BH-3	RAPID	RL-6	4.13
BH-4	RAPID	RL-7	4.96
BH-4	RAPID	RL-8	4.77
BH-1	STANDARD	SL-1	4.76
BH-1	STANDARD	SL-2	1.87
BH-2	STANDARD	SL-3	2.11
BH-2	STANDARD	SL-4	1.98
BH-3	STANDARD	SL-5	1.47
BH-3	STANDARD	SL-6	1.46
BH-4	STANDARD	SL-7	1.43
BH-4	STANDARD	SL-8	1.50

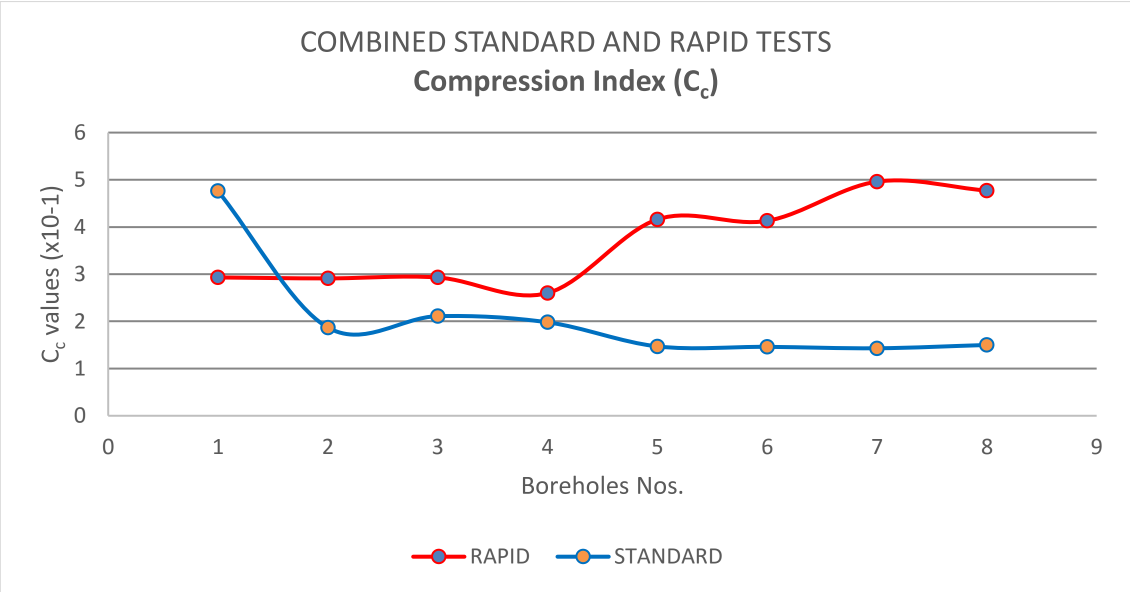

Figure 4.3: C_c plots for Combined Standard and Rapid load Tests

From Table 4.3 and Figure 4.3, the Compression index (Cc) values were plotted against the Boreholes number for all the tested samples. It was observed that there was an average increase of 77.2% in Cc values for the rapidly loaded soil samples as compared to those of the standard loading. This shows that when soils are subjected to rapid loading, the compression index increases.

Table 4.4: Results for Swelling Index (Cs)

Borehole No.	Loading Type	Sample No.	Cs (x10^-2)
BH-1	RAPID	RL-1	-1.05
BH-1	RAPID	RL-2	-1.04
BH-2	RAPID	RL-3	-1.05
BH-2	RAPID	RL-4	-1.02
BH-3	RAPID	RL-5	-0.47
BH-3	RAPID	RL-6	-0.47
BH-4	RAPID	RL-7	-1.11

Borehole No.	Loading Type	Sample No.	Cs (x10^-2)
BH-4	RAPID	RL-8	-1.06
BH-1	STANDARD	SL-1	-1.06
BH-1	STANDARD	SL-2	-1.18
BH-2	STANDARD	SL-3	-1.32
BH-2	STANDARD	SL-4	-1.52
BH-3	STANDARD	SL-5	-1.40
BH-3	STANDARD	SL-6	-1.39
BH-4	STANDARD	SL-7	-1.36
BH-4	STANDARD	SL-8	-1.75

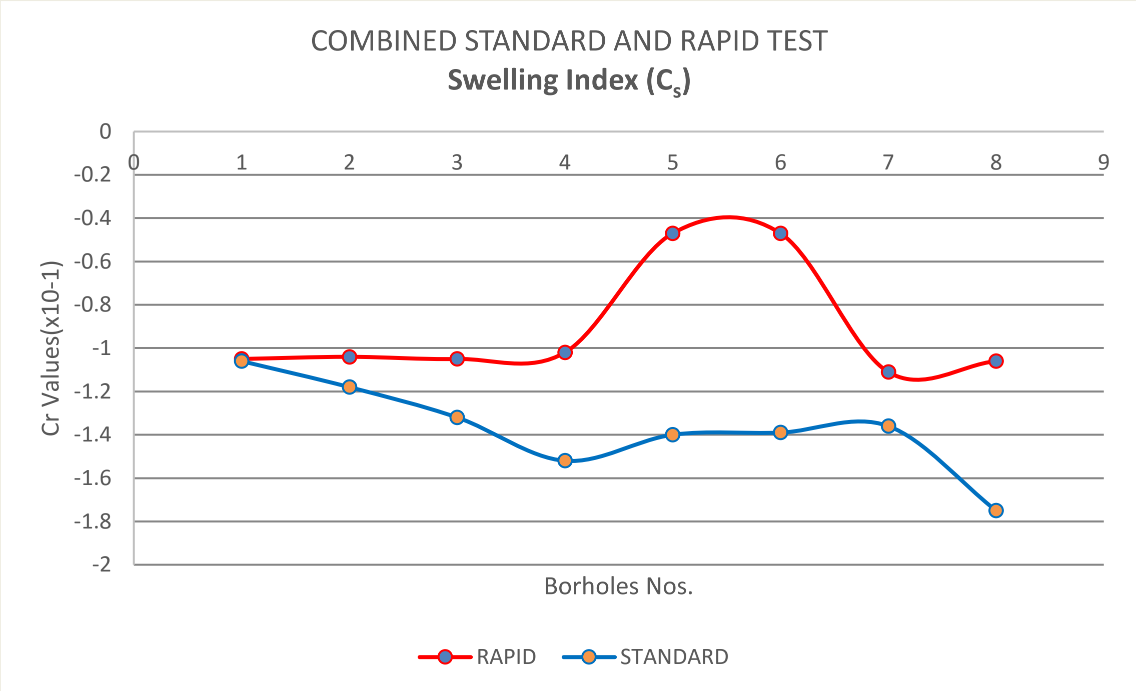

Figure 4.4: C_s plots for Combined Standard and Rapid load Tests

From Table 4.4, the Swelling index (Cs) values were plotted against the Boreholes number for all the tested samples. It was observed from figure 4.4 that there was an average reduction of 33.8% in Cs values for the rapidly loaded soil samples as compared to those of the standard loading.

Table 4.5: Results for Preconsolidation Pressure (Pc)

Borehole No.	Loading Type	Sample No.	Pc (kN/m2)
BH-1	RAPID	RL-1	116
BH-1	RAPID	RL-2	115
BH-2	RAPID	RL-3	116
BH-2	RAPID	RL-4	117
BH-3	RAPID	RL-5	190
BH-3	RAPID	RL-6	200
BH-4	RAPID	RL-7	235
BH-4	RAPID	RL-8	200
BH-1	STANDARD	SL-1	221
BH-1	STANDARD	SL-2	168
BH-2	STANDARD	SL-3	141
BH-2	STANDARD	SL-4	180
BH-3	STANDARD	SL-5	205
BH-3	STANDARD	SL-6	170
BH-4	STANDARD	SL-7	183
BH-4	STANDARD	SL-8	197

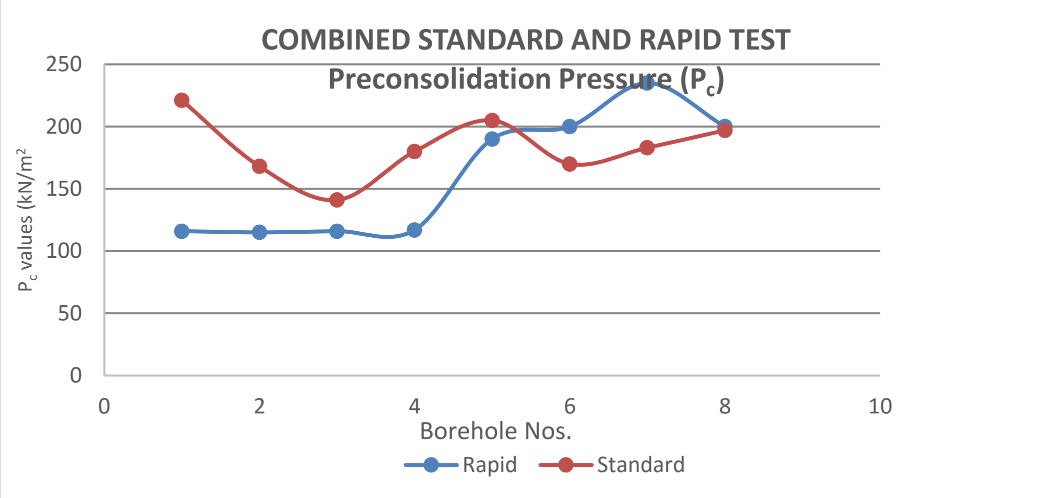

Figure 4.5: P_c plots for Combined Standard and Rapid load Tests

From Table 4.5, the Preconsolidation Pressure (Pc) values were plotted against the Boreholes number for all the tested samples. From Figure 4.5, it was observed that the values for the Pc for the rapid loading tested samples were observed to be lower than those of the standard loading by an average of 15.4%. This shows that when soils are subjected to rapid loading, the Preconsolidation pressure decreases because of the rapid loading.

Table 4.6: Results for 90% Consolidation (t90)

Borehole No.	Loading Type	Sample No.	t90 (Min.)
BH-1	RAPID	RL-1	6.4
BH-1	RAPID	RL-2	5.8
BH-2	RAPID	RL-3	5.8
BH-2	RAPID	RL-4	5.6
BH-3	RAPID	RL-5	7.9
BH-3	RAPID	RL-6	7.9
BH-4	RAPID	RL-7	5.9
BH-4	RAPID	RL-8	6.7
BH-1	STANDARD	SL-1	5.8
BH-1	STANDARD	SL-2	5.8
BH-2	STANDARD	SL-3	9.3
BH-2	STANDARD	SL-4	8.4
BH-3	STANDARD	SL-5	9.9
BH-3	STANDARD	SL-6	9.9
BH-4	STANDARD	SL-7	6.4
BH-4	STANDARD	SL-8	10.2

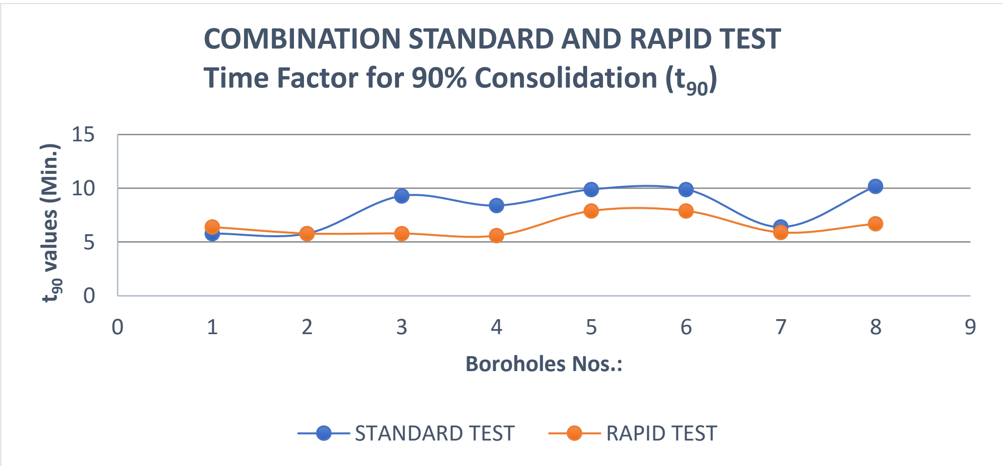

Figure 4.6: t_{90} plots for Combined Standard and Rapid load Tests

From Table 4.6, the time Factor for 90% consolidation to occur (t90) values were plotted against the Boreholes number for all the tested samples. From figure 4.6, it was observed that the t90 values for the rapid loading tested samples were found to be lower than those of the standard loading by 32.6%. This shows that when soil is loaded rapidly, the time required for 90% consolidation to occur is reduced due to the effect of the rapid loading.

Table 4.7: Results for Settlement

Borehole No.	Loading Type	Sample No.	mv (x10^-1 m2/MN)	Delta sigma (kN/m2)	H (m)	Settlement (mm)
BH-1	RAPID	RL-1	1.40	172	2	48.2
BH-1	RAPID	RL-2	1.40	172	2	48.2
BH-2	RAPID	RL-3	1.40	172	2	48.2
BH-2	RAPID	RL-4	1.87	172	2	64.3
BH-3	RAPID	RL-5	2.92	172	2	100.4
BH-3	RAPID	RL-6	1.40	172	2	48.2
BH-4	RAPID	RL-7	1.98	172	2	68.1
BH-4	RAPID	RL-8	3.00	172	2	103.2
BH-1	STANDARD	SL-1	3.00	172	2	103.2
BH-1	STANDARD	SL-2	1.32	172	2	45.4
BH-2	STANDARD	SL-3	1.03	172	2	35.4
BH-2	STANDARD	SL-4	1.03	172	2	35.4
BH-3	STANDARD	SL-5	1.05	172	2	36.1
BH-3	STANDARD	SL-6	2.92	172	2	100.4
BH-4	STANDARD	SL-7	1.05	172	2	36.1
BH-4	STANDARD	SL-8	1.05	172	2	36.1

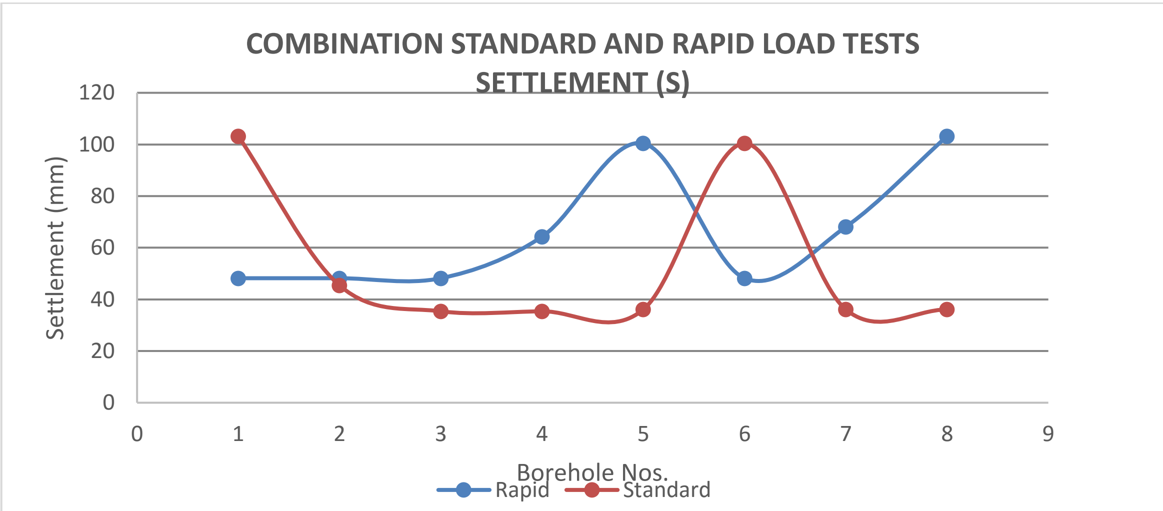

Figure 4.7: Settlement plots for Combined Standard and Rapid load Tests

From Table 4.7 and Figure 4.7, the settlement values were plotted against the Boreholes number for all the tested samples. The settlement observed for the rapid loading tested samples were found to be higher than those of the standard loading by 23.5%. This shows that when soils are subjected to rapid loading conditions, they experience higher settlements because of the rapid loading.

4. CONCLUSION

Below are the results of the investigation and it is possible to draw a number of conclusions:

1. The consolidation (C_v) values for the rapid loading conditions were lower by 37.8%.
2. There was an increase of 34.8% in the coefficient of compressibility(m_v) values for the rapid loading compared to the standard loading.
3. The values for compression index (C_c) were found to be higher in the rapidly loaded samples by 77.2% as compared to the standard loading
4. An average reduction of 33.8% was observed in the recompression index (C_s) values for the rapid loading conditions
5. There was an average reduction of 15.4% in the Preconsolidation pressures (P_c) of the rapid loading tests as compared to the standard loading tests
6. There was an average reduction of 32.6% in the time factor for 90% consolidation (t_{90}) values

for the rapid loading tests compared to those of the standard loading.

7. The settlements for the rapid load test samples were found to be higher by 23.5% compared to those of the standard loading tests.

From the above findings, it can be deduced that the loading pattern has a significant effect on the settlement and compressibility properties of soils.

5. RECOMMENDATIONS

Based on the findings, below are some recommendations for future work:

1. Undisturbed samples should be used as they would give more accurate results
2. Reloading samples to achieve a better graphical representation and consequently more accurate results.
3. Measurement of pore pressure should be included to ascertain accurate effective stresses during the period of testing.

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REFERENCES

- Akpila S.B., (2019) "Basic soil Mechanics", Ist Ed. Greatprints, Nigeria.
- Gupta, A., Gupta, N., Dola, M. M., Hossain, P. D., Islam, M. A., Badhon, F. F. & Imtiaz, T. (2021). "Properties and Behaviour of Soil Online Lab Manual", Mavs Open Press Hill Co. Inc. New York.
- Jonathan, K, Craig R.F. (2012), "Craig's Soil Mechanics", 7th Ed. Spon Press New York.
- Joseph, E. Bowles; P.E.; S.E.; (1997), "Foundation Analysis and Design" 5th Ed. McGraw-Hill University, pp. 1-116.
- Juan, B. M. (2004), "Rate Effects of Rapid Loading in Clay Soils", Thesis for PhD. University
- Murthy V.N.S., (2003), "Geotechnical Engineering- Principles and practices of Soil Mechanics and Foundation Engineering". Marcel Dekker Inc. New York.
- Murthy, V.N.S., (2017) "Textbook of Soil Mechanics and Foundation Engineering", CBS Publishers and Distributors, India.
- Braja M. Das, (2019) "Advance Soil Mechanics", 5th Ed. Taylor & Francis Inc.
- Handy, R. L., (2020), "Geotechnical Engineering: Soil and Foundation Principles and Practice' 1st Ed., McGraw Hill Foundation.
- Handy R.L., (2020) 'Foundation Engineering: Geotechnical Principles and Practical Applications' 1st Ed. McGraw-Hill Education
- Hang H. Y. (1990), "Foundation Engineering Handbook", Springer New York, N.Y
- Braja M. Das, Nagaratnan S. (2015) "Introduction to Geotechnical Engineering", 2nd Ed. Cengage Learning.
- William. K, Robert D. (2002), "An Introduction to Geotechnical Engineering", Prentice Hall, Eaglewood Cliffs, New Jersey.
- Robert D. (2002), "An Introduction to Geotechnical Engineering", Prentice Hall, Eaglewood Cliffs, New Jersey.
- Arora, K.R., (2008) "Soil Mechanics and Foundation Engineering", 7th Ed. Standard Publisher Distribution.
- Jean-louis, B., (2013) "Geotechnical Engineering Unsaturated and Saturated Soils", 2nd Ed. Wiley.
- Willey N., Kenny T.C., Chan H.T., (2021) "Principles of Geotechnical Engineering", 10th Ed.Cengage Learning.
- Powel, G., (2018), ''Geotechnical Engineering and Soil Science'', Larsen & Keller Education.
- Sirdharan, H.B. Nagaraj, N. Srinivas (1999), ''Rapid_method_of_consolidation_testing'', Retrieved from: https://doi.org/10.1139/t98-107
- Wikipadia, ''Soil Consolidation'', Retrieved from https://en.wikipedia.org/wiki/Soil_consolidation
- ASTM STANDARD D4318-17e1 (2017). ''Standard Test Methods for Liquid Limit, Plastic''
- ASTM D2435/ D2435M-11(2020). ''Standard Test Methods for One-Dimensional Consolidation properties of soils using incremental loading''