COLLAPSE POTENTIAL ASSESSMENT OF ORGANIC AND CLAY SOIL IN THE KHULNA REGION: IMPLICATIONS FOR CONSTRUCTION STABILITY

Maria Islam Rattry[1], Md. Humayun Kabir[2], Abhishek Sarkar*[3] and Tanjil Ahammed Robin[4]

[1] *Graduate, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: mariaislamrattry@gmail.com*
[2] *Associate Professor, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: mhkabir@ce.kuet.ac.bd*
[3] *Postgraduate Student, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: sarkar1701019@gmail.com*
[4] *Undergraduate Student, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh, e-mail: tanjilahammedrobin@gmail.com*

***Corresponding Author**

ABSTRACT

Collapsible soil refers to soil that experiences a substantial and sudden reduction in volume upon wetting, leading to the disintegration of its structure and significant settlements. The Khulna region is known for its soil containing a higher organic content and clay, making it essential to assess the collapse potential of these soils. This study aims to determine the collapse potential of both organic and clay soil to understand their behaviour upon wetting. The organic soil sample used in the test contains approximately 20% organic matter. Atterberg limit tests are conducted for both soil samples, revealing that the organic soil has a liquid limit of around 168% and a plastic limit of about 81%, resulting in a plasticity index of approximately 87%. On the other hand, clay soil has a liquid limit of around 41%, a plastic limit of about 18%, and a plasticity index of about 23%. Single oedometer tests are performed on both soil samples to assess the collapse potential. The results show that the collapse potential for the organic soil is approximately 1.17%, indicating slight collapsibility. In contrast, the collapse potential for the clay soil is about 0.77%, suggesting that it does not exhibit significant collapsibility. Considering all the evaluated values of the organic and clay soil, it can be concluded that for the organic soil, the value is higher. However, though it will experience slight settlements upon sudden wetting, which is the same as the other soil. By understanding the collapse potential of these soil types, engineers and builders can make informed decisions and implement appropriate construction techniques to ensure the stability and longevity of structures in the Khulna region.

Keywords: *Collapsible Soil, Collapse Potential, Organic Soil, Clay Soil, Void Ratio-Pressure Relationship.*

1. INTRODUCTION

Soils often exhibit a reduction in volume when submerged in water. This occurrence is termed "collapsed settlement" of the soil, as it correlates with the collapse of soil particles. Ignoring this collapsibility in the soil during foundation design can jeopardize structural safety, potentially leading to complete failure.

Various methods, including soil improvement techniques, can be implemented to address the collapse potential issue. The choice of method hinges on both its effectiveness in enhancing soil quality against collapse and its cost-efficiency compared to alternative processes.

The failure of structures often stems from abrupt soil collapses or soil collapsibility. Consequently, assessing the collapse potential of soil before construction is imperative, and enhancing soil quality against collapse, if necessary, is equally critical.

Khulna, situated in southeastern Bangladesh near the mangrove forest of Sundarbans, harbours organic matter within the soil layer ranging from 5 to 25 feet beneath the surface. This presence of organic matter poses challenges for geotechnical engineers in devising economical foundations. Due to this organic component, special attention must be paid to soil and its engineering parameters.

Furthermore, organic-rich soil tends to have diminished bearing capacity, heightening the risk of settlement. Preventive measures necessitate a comprehensive understanding of the geotechnical characteristics, particularly those tied to organic soil (Sharma et. al., 2017).

Another challenge afflicting Khulna is its heightened susceptibility to climate change effects, notably frequent waterlogging due to heavy rainfall during the monsoon season and unpredictable, intense rainfall in non-monsoon periods. Annually, the city encounters 1808.5 mm of rainfall (almost 80% of which occurs during the monsoon). Intense rainfall can induce inundation, potentially disrupting soil particle bonds and ultimately resulting in sudden soil collapses. Abrupt collapse of the soil is one of the major concerns. To ensure the safety and viability of structures in the Khulna region, it is crucial to assess the collapse potential of organic-rich soil, given its established problematic nature (.

The research undertaken in Khulna aims to address challenges associated with organic and clay soils. The study's overarching goals encompass evaluating the collapse potential of these soils, determining their rates of consolidation, and conducting a comparative analysis to discern their respective behaviours. By achieving these objectives, the study seeks to enhance our understanding of soil behaviour in the region, thereby contributing valuable insights for informed geotechnical and construction practices.

This study primarily focuses on evaluating the collapse potential of local soil characterized by organic and clayey attributes. Initially, essential soil index properties, such as moisture content, specific gravity, and Atterberg limits (liquid limit, plastic limit), are established. Subsequently, the soil's collapse potential is assessed using the oedometer test (Sharma et. al., 2017). The comprehensive scope of this research encompasses quantifying post-load settlement, determining consolidation rates, analysing void ratios at distinct loading phases, evaluating void ratio-pressure relationships under various loading conditions, and calculating the collapse potential of the soils. These endeavours collectively deepen our understanding of the local soil's collapse behaviour, providing crucial insights for informed geotechnical practices and construction methodologies.

However, it's important to note that laboratory testing may not perfectly replicate actual field conditions, potentially leading to slight discrepancies between the two. Furthermore, the collection and transportation process introduce the possibility of minor variations between laboratory soil and real-world conditions. Additionally, human errors in laboratory work may marginally impact overall results (Ayeldeen et. al., 2017).

2. METHODOLOGY

In this study, the primary materials required were organic soil and clay soil. To obtain these materials, organic soil was gathered from Boroitola and Khulna City Bypass, while clay soil was sourced from the Khulna University of Engineering & Technology (KUET) campus (Riyad e. al., 2023). Once collected, the soils were transported to the laboratory, where their index properties were measured. Subsequently, the soils underwent single oedometer tests and Atterberg Limit tests to assess their additional properties.

2.1 Site Information and Sample Collection

The research necessitated the acquisition of organic and clay soils, which were obtained from a designated site. Initially, a thorough site investigation was conducted to gain insights into the formation and development of organic and clay soils. Organic soil was procured from Boroitola and Khulna City Bypass, while clay soil samples were extracted from the KUET campus.

During the site visit, several influential factors were observed, including temperature, humidity, rainfall, and the presence of abundant vegetation, which collectively influence the soil's characteristics. These site conditions provided preliminary insights into physical properties such as colour, texture, profile, and groundwater conditions.

The organic soil exhibited a colour range from black to dark brown and emitted an unpleasant odour. Its texture resembled spongy matter and demonstrated high compressibility. The organic content within the soil was approximately 20%.

Sampling was carried out at Boroitola, Khulna City Bypass, and the KUET campus using the Shelby tube method to minimize disturbance during collection, as shown in Figure 1.

2.2 Laboratory Experiments

Following the collection of soil samples, an array of tests was conducted to comprehensively assess the soil's physical, index, and engineering properties. These tests aimed to provide insights into the soil's behaviour under conditions of sudden collapse. Identification of a high collapse potential value would signal problematic soil behaviour, necessitating the implementation of corrective measures to enhance its stability.

Primarily focused on organic and clay soils, this section centred on evaluating the propensity of the soil samples to undergo collapse. The laboratory work for determining soil properties was segmented into two distinct parts.

The initial segment encompassed tests typically associated with the physical and index properties of soil, including parameters such as moisture content, specific gravity, organic content, and plasticity attributes (liquid limit, plastic limit, and plasticity index) (Mahmud et.al., 2008).

The subsequent segment involved the execution of a single oedometer test (consolidation test) designed to ascertain the soil's susceptibility to collapse. This pivotal test provided insights into the soil's behaviour and potential for undergoing sudden collapse.

2.3 Physical And Index Properties of Soil

To establish the physical and index properties of the soil, specific tests were conducted on the acquired soil samples (Hassan et. al., 2017). These tests encompassed the determination of moisture content, organic content, Atterberg limits (liquid limit, plastic limit, plasticity index), and specific gravity (Mitchell et. al., 2005).

2.3.1 Initial Moisture Content

Soil moisture content measurement holds significant importance, as it directly influences various engineering aspects of soil, including compressibility, settlement, workability, and strength. It is a standard procedure in laboratory testing to ascertain the quantity of water present in a given soil sample concerning its dry mass. The moisture content of the soil sample collected adhered to the guidelines outlined in ASTM D-2216-90 (ASTM Standards vol.4.08). In accordance with the stipulated standard, the process for determining soil moisture content is as follows.

A soil sample devoid of any moisture loss, was collected from the designated site. An immaculate, dry container was initially weighed, and this measurement was duly recorded. Subsequently, a representative sample of moist soil was placed into the container, and the combined mass of the moist soil and container was determined. The soil was then subjected to drying in an oven at a constant temperature of 105°C until it reached a stable mass. Post-drying, the combined mass of the soil and the dry container was recorded. Utilizing the values recorded above, the moisture content was calculated using the following formula:

$$Moisture\ Content, w(\%) = \frac{M_w}{M_s} \times 100 \tag{1}$$

Where M_w represents the mass of water within the soil sample and M_w is the mass of the soil solids. The resultant moisture content is expressed as a percentage.

2.3.2 Organic Content

The assessment of organic content in soil is typically conducted to discern the presence and quantity of organic matter. Organic soils are often identifiable by their distinct characteristics, such as colour and odour. The presence of organic matter significantly impacts diverse soil properties, including shear strength, soil structure, water-holding capacity, nutrient contributions, biological activity, and rates of water and air infiltration. Consequently, quantifying the organic content in a soil sample is of paramount importance for soil classification.

The determination of organic content adhered to the testing procedure outlined in ASTM 2974, which prescribes the Standard Test Methods for Moisture, Ash, and Organic Matter of Peats and Organic Soils. The organic content is typically expressed as a percentage, representing the ratio of the mass of organic matter within a given sample to the mass of the corresponding soil solids.

2.3.3 Specific Gravity

Specific gravity, a dimensionless metric, signifies the ratio of a substance's density to the density of water under specific temperature and pressure conditions (Saravanan et. al., 2013). Its calculation is pivotal, as it contributes to the computation of void ratio in the oedometer test and is essential for hydrometer analysis, as shown in Figure 2.

The specific gravity of soil was determined in accordance with the ASTM D 854 standard, which prescribes the procedure for determining the Specific Gravity of Soil Solids.

Following the standard, the equation utilized was:

$$G_s = \frac{30\alpha}{30 - W_{bs} + W_{bw}} \tag{2}$$

Here, α represents the ratio of the density of water at the test temperature, W_{bs} stands for the mass of the pycnometer plus water and W_{bw} denotes the mass of the pycnometer along with soil and water (Mansour et. al., 2008).

2.3.4 Grain Size Analysis

The grain size analysis method is employed to gain insights into the distribution of soil particle sizes, focusing on the range from the No. 200 (0.075mm) sieve down to approximately 0.01mm. This analytical approach plays a crucial role in classifying specific soil types.

The methodology draws upon Stokes' Law, establishing a relationship between the velocity of descent of spheres within a fluid, the sphere's diameter, the respective densities of both the sphere and the fluid, as well as the fluid's viscosity. This analysis is conducted on materials that have successfully passed through the No. 200 sieve in mechanical analysis. To adhere to standardized practices, the grain size analysis test is conducted in accordance with ASTM D 421 and D 422.

2.3.5 Atterberg Limit Test

The Atterberg limit test facilitates the determination of a soil's liquid limit and plastic limit. These limits are pivotal for soil identification, and classification, and for establishing correlations with strength properties. The term "liquid limit" refers to the moisture content below which the soil exhibits plastic behaviour, effectively transitioning towards a viscous fluid state. A specialized device, the liquid limit device with a grooving tool, is employed for this test. The standard protocol adhered to for liquid limit determination is ASTM D 4218 (Liquid Limit, Plastic Limit, and Plasticity Index of Soils).

Distilled water is utilized for testing, and the specified blow rate is set at 120 blows per minute. The liquid limit represents the moisture content that leads to a standard groove closure of 12.7mm (1/2 inch) for 25 blows within the liquid limit machine.

The liquid limit value is attained through multiple trial tests. A semi-log graph paper is utilized to plot moisture content versus the number of blows. By analysing the graph, the moisture content corresponding to 25 blows is identified, yielding the liquid limit of the soil.

Conversely, the "plastic limit" signifies the moisture content below which the soil ceases to exhibit plastic behaviour. Alternatively, it can be defined as the moisture content at which a soil thread crumbles when its diameter is approximately 1/8 inch or 3.2 mm, as stipulated by the standard.

In the plastic limit test, two threads are prepared in the laboratory, adhering as closely as possible to the 3.2mm diameter specified by the standard. The threads are manually inspected, and the values obtained from two samples are averaged to determine the plastic limit of the soil sample.

Once the liquid limit and plastic limit values are obtained, the plasticity index is calculated by subtracting the plastic limit value from the liquid limit value. This comprehensive analysis aids in characterizing the soil's plasticity and behaviour.

2.4 Single Oedometer Test

The assessment of soil collapse or the variation in soil volume resulting from sudden inundation is achieved through a single oedometer test, as shown in Figure 3. This method involves subjecting soil samples to controlled loading to measure their response to imposed stresses. In this context, two primary types of oedometer tests exist, including the Single Oedometer Test and the Double Oedometer Test.

To investigate the occurrence of soil collapse, a single oedometer test was performed on both organic and clay soil samples. The procedure strictly adhered to the guidelines outlined in ASTM D 2435, which details the Test Method for One-Dimensional Consolidation Properties of Soils. The procedural steps are outlined below.

The dimensions of the consolidation ring (diameter and height) were initially measured. The soil sample was carefully placed within the ring, and the combined mass of the ring and the wet soil was recorded. To minimize changes in the specimen's water content due to evaporation, the specimen ring, filter paper, and porous stone were promptly assembled around the wet soil.

Incremental loading was applied in a specific order to achieve the desired vertical stress. The load increments were set at 5, 12, 25, 50, 100, 200, and 400, following the standard's specifications. The dial readings were recorded before each load increment. The time interval between each load increment before saturating the soil sample with water represented the duration for primary consolidation, typically averaging around three hours.

The initial stress applied before loading was set at 200 kPa, at which point the collapse potential was determined. After applying a 200 kPa load to the soil, the sample underwent loading for 24-hour duration. Dial readings were taken after this period. Water was introduced into the sample to saturate it. After adding water, the sample was left to sit for another 24 hours, and the corresponding dial reading was recorded. Additional stress was incrementally applied to the soil specimen, following the requirements outlined in Test Method D 2435, to establish the stress vs. deformation curve.

After recording all dial readings over time, a graph was plotted for each load increment. From the graphical representation, the rate of consolidation at each loading increment was determined, and the collapse potential value was also obtained.

Figure 1: Soil Sampling in Shelby Tube

Figure 2: Hydrometer Analysis

Figure 3: Oedometer Test

3. RESULTS AND DISCUSSIONS

Following the soil sample collection, a detailed assessment of the soil's index properties was conducted to facilitate its classification. This encompassed the determination of initial moisture content, organic content, hydrometer analysis, specific gravity, and Atterberg limits, including liquid limit, plastic limit, and plasticity index. Additionally, a single oedometer test was executed on both organic and clay soil samples, primarily focusing on the evaluation of collapse potential. This section presents the comprehensive results of these analyses, contributing to an overarching understanding of the soil's characteristics.

3.1 Classification

The classification of the examined soil types is based on their characteristics. Table 1 provides a summary of the physical properties of the examined soil types, including specific gravity, natural water content, Atterberg limits (liquid limit, plastic limit, plasticity index), organic content, and their corresponding USCS classifications. These properties offer valuable insights into the behaviour and classification of each soil type, aiding in their engineering evaluation and potential applications.

Table 1: Physical Properties of Soil

Soil Properties	**Soil**			
	Clay Soil Type-1	**Clay Soil Type-2**	**Organic Soil Type-1**	**Organic Soil Type-2**
Specific Gravity, G_s	2.7	2.73	2.3	1.96
Natural Water	30	34	87	81
D_{10}	0.002	0.002	0.01	0.0036
D_{30}	0.004	0.047	0.035	0.0046
D_{60}	0.0245	0.0335	0.12	0.041
#200 Sieve Passing	More Than 50%	More Than 50%	More Than 50%	Less Than 50%
Liquid Limit, LL	41	39	168	148
Plastic Limit, PL	18	21	87	78
Plasticity Index, PI	23	18	81	70
Organic Content (%)	-	-	20	18
$\frac{LL - oven\ dried}{LL\ not\ dried}$	-	-	<0.75	<0.75
Soil Type	CL	CL	OH	OH
Soil Name	Lean Clay	Lean Clay	Organic Clay with High Plasticity	Organic Clay with High Plasticity

3.2 Oedometer Test Data

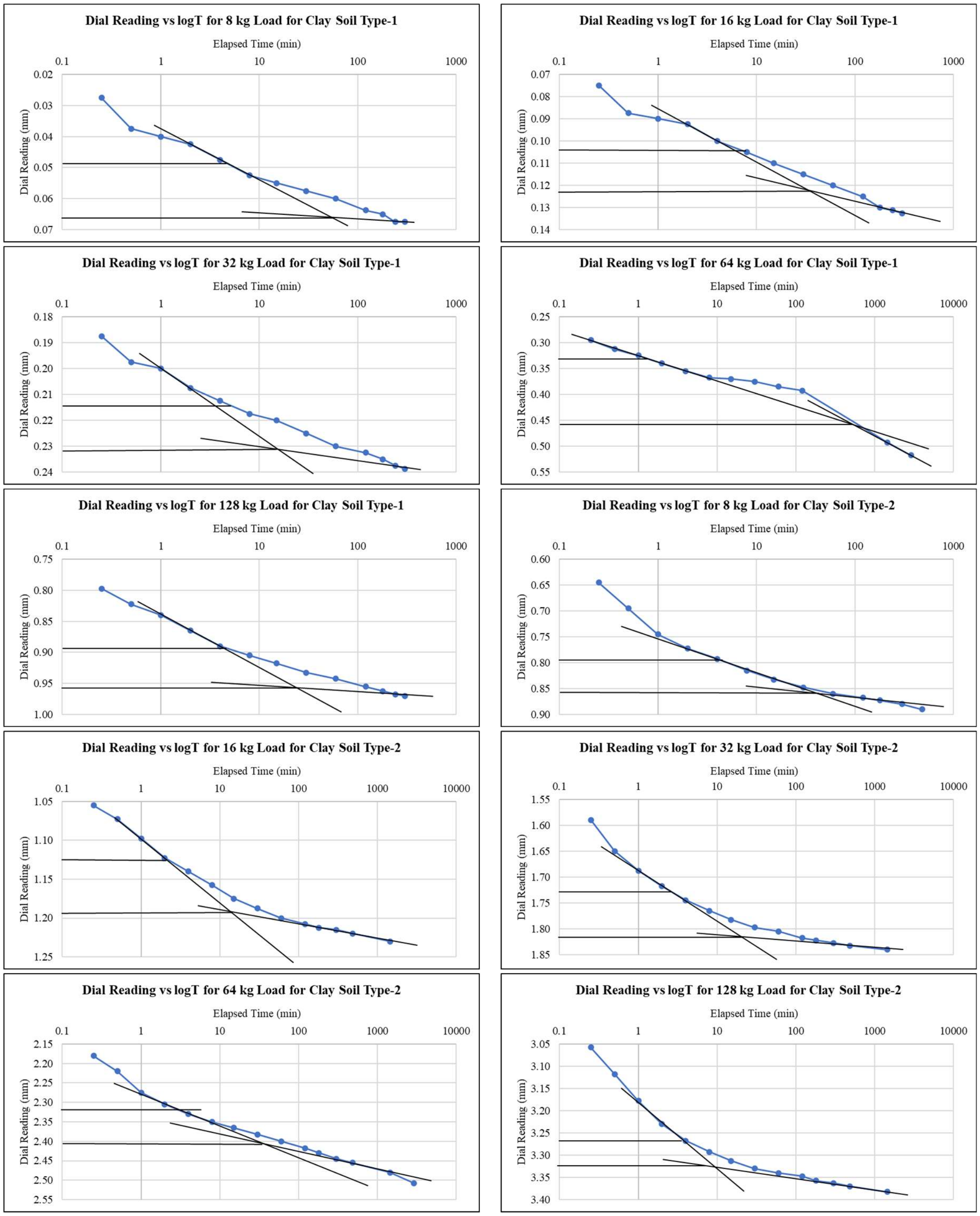
The Oedometer Test Data is presented in Table 2.

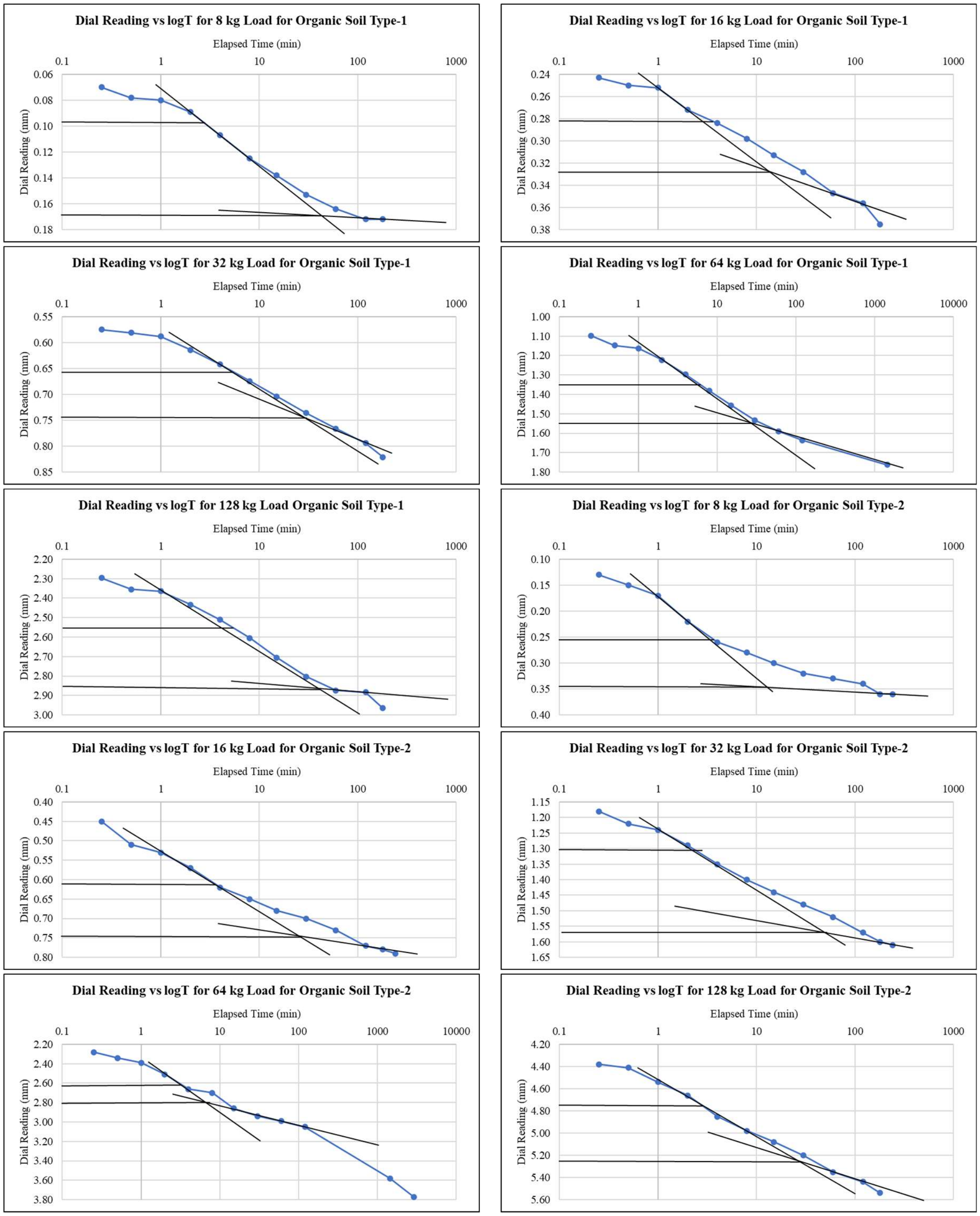
Table 2: Oedometer Test Data

Soil Type		**Loading Type**	t_{50} **(min)**	**Void Ratio, e**	**Strain, ε**	C_v (mm^2/min)
Clay Soil	**Clay Soil Type-1**	**For 8 kg Load**	5.5	0.90	0.003	5.80
		For 16 kg Load	6	0.89	0.005	5.25
		For 32 kg Load	6.3	0.89	0.009	4.99
		For 64 kg Load	6	0.86	0.019	4.64
		For 128 kg Load	6	0.83	0.038	4.10
	Clay Soil Type-2	**For 8 kg Load**	5	0.94	0.036	5.96
		For 16 kg Load	6	0.92	0.048	4.82
		For 32 kg Load	6	0.87	0.072	4.59
		For 64 kg Load	6	0.82	0.098	4.36
		For 128 kg Load	6	0.75	0.133	4.02
Organic Soil	**Organic Soil Type-1**	**For 8 kg Load**	3	2.03	0.007	5.25
		For 16 kg Load	6	2.00	0.017	3.45
		For 32 kg Load	5	1.95	0.032	3.76
		For 64 kg Load	5	1.84	0.070	4.75
		For 128 kg Load	6	1.68	0.121	4.95
	Organic Soil Type-2	**For 8 kg Load**	4	1.96	0.014	5.18
		For 16 kg Load	4.5	1.91	0.031	5.56
		For 32 kg Load	4.5	1.81	0.065	5.06
		For 64 kg Load	4.5	1.58	0.121	5.08

For 128 kg Load	4	1.35	0.219	5.18

The Graphs derived from the Single Oedometer Test Data are shown in Figure 1.





Dial Reading vs logT for 8 kg Load for Organic Soil Type-1

Dial Reading vs logT for 16 kg Load for Organic Soil Type-1

Dial Reading vs logT for 32 kg Load for Organic Soil Type-1

Dial Reading vs logT for 64 kg Load for Organic Soil Type-1

Dial Reading vs logT for 128 kg Load Organic Soil Type-1

Dial Reading vs logT for 8 kg Load for Organic Soil Type-2

Dial Reading vs logT for 16 kg Load for Organic Soil Type-2

Dial Reading vs logT for 32 kg Load for Organic Soil Type-2

Dial Reading vs logT for 64 kg Load for Organic Soil Type-2

Dial Reading vs logT for 128 kg Load for Organic Soil Type-2

Figure 4: Single Oedometer Test Data

3.3 Comparison of Results

3.3.1 Rate of Consolidation

After calculating the rate of consolidation values for all four soil samples, these values are plotted against pressure in the following figures.

In this graph, the rate of consolidation of the first organic soil sample is represented by the ash-coloured line. The yellow line represents the second organic sample's rate of consolidation. The blue line corresponds to the second clay soil sample, and the red line represents the first clay soil sample.

A higher rate of consolidation indicates that the soil will compress more rapidly, leading to a quicker attainment of stable settlement compared to soils with a lower rate of consolidation. From a practical standpoint, a higher rate of consolidation could be advantageous for construction projects as it could reduce the time required for the soil to reach stability, potentially expediting construction schedules and lowering associated costs. However, it's important to recognize that a higher rate of consolidation might also suggest greater compressibility of the soil, making it more susceptible to future settlement, which could pose long-term stability and performance concerns for the construction.

The analysis reveals that the organic soil samples have a higher rate of consolidation, implying that they will compress more rapidly than the clay samples. While this might offer short-term benefits, it could lead to long-term issues.

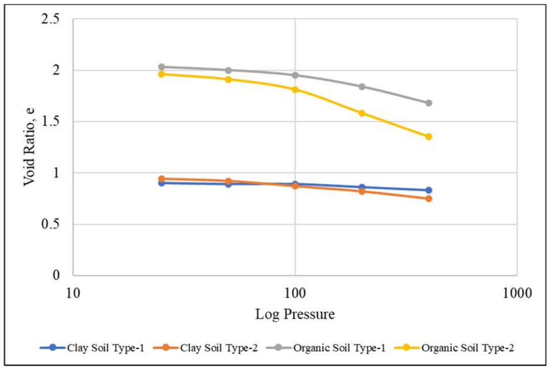


Figure 5: Plotting of Void Ratio (e) vs Log Pressure for Different Types of Soil

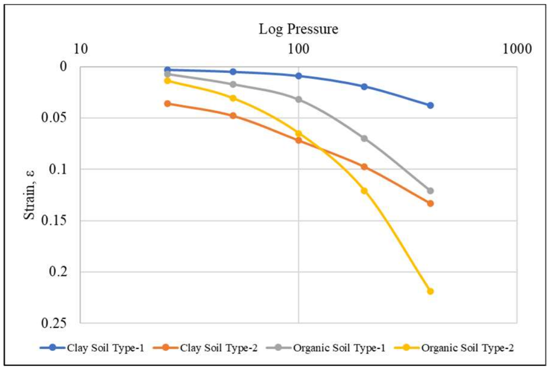


Figure 6: Plotting of Strain (ε) vs Log Pressure for Different Types of Soil

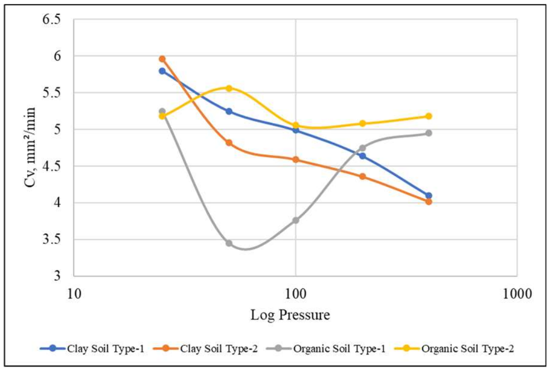


Figure 7: Plotting of C_v (mm^2/min) vs Log Pressure for Different Types of Soil

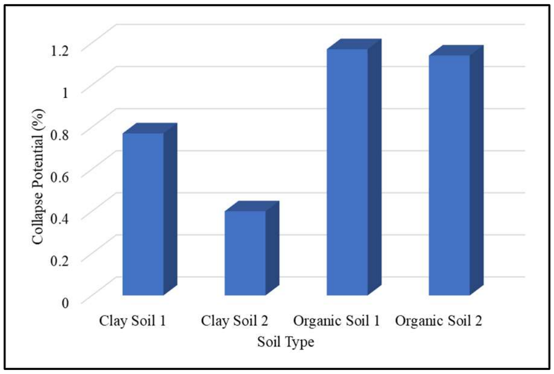


Figure 8: Comparison of Collapse Potential for Different Types of Soil

3.3.2 Oedometer Test

According to Jennings and Knight's standard (1975), collapse potential ranges and their associated severities are defined in Table 3.

Table 3: Jennings and Knight Standard (1975)

Collapse Potential (%)	Severity of Disorders
0-1%	Without risk
1-5%	Moderate trouble

5-10%	Trouble
10-20%	Severe Trouble
>20%	Very Severe Trouble

Based on the test results, the collapse potential of the four soil samples was determined, and their corresponding severities are presented in Table 4.

Table 4: Collapse Potential of Soil Samples and Severity Disorders

Soil Samples	Collapse Potential (%)	Severity of Disorder
Clay Soil 1	0.77	Without risk
Clay Soil 2	0.40	Without risk
Organic Soil 1	1.17	Moderate trouble
Organic Soil 2	1.14	Moderate trouble

For the first clay soil sample, the collapse potential was found to be 0.77, indicating that it falls within the "Without risk" range. Similarly, the second clay soil sample exhibited a collapse potential of 0.40, also classified as "Without risk." On the other hand, the collapse potential values for the organic soil samples were 1.17 and 1.14, both falling within the "Moderate trouble" range.

These results suggest that the clay soil samples have a lower risk of collapse upon sudden inundation, while the organic soil samples pose a slightly higher risk of moderate trouble in terms of collapse potential.

4. CONCLUSION

This study examines the collapse potential of soil samples, specifically focusing on organic and clay types. The key findings are as follows: the organic soil samples exhibit higher liquid limit and plasticity index values compared to clay soil samples, indicating greater compressibility and lower shear strength. Additionally, organic soil types are more prone to consistency changes with slight variations in water content. The analysis reveals that organic soil samples have a faster rate of consolidation, implying quicker compression compared to clay samples. While the collapse potential for the first clay soil sample is determined to be 0.77 (within the range of 0-1, indicating no problem), the second clay sample has a lower value of 0.40, also not posing a collapse risk. However, for the organic samples, with values of 1.17 and 1.14 (within the range of 1-2, indicating slight problematic nature), there is a possibility of sudden collapse, necessitating precautionary measures before construction. The high values for the two organic samples indicate problematic soil conditions that may collapse upon inundation, requiring measures such as compaction or soil improvement techniques before construction.

REFERENCES

Ayeldeen, M., Negm, A., El-Sawwaf, M., & Kitazume, M. (2017). Enhancing mechanical behaviors of collapsible soil using two biopolymers. *Journal of rock mechanics and geotechnical engineering*, *9*(2), 329-339.

Benchouk, A., Abou-Bekr, N., & Taibi, S. (2013). Potential collapse for a clay soil. *International Journal of Emerging Technology and Advanced Engineering*, *3*(10), 43-47.

Houston, S. L., Houston, W. N., & Lawrence, C. A. (2002). Collapsible soil engineering in highway infrastructure development. *Journal of Transportation Engineering*, *128*(3), 295-300.

Hutter, K., Svendsen, B., & Rickenmann, D. (1994). Debris flow modeling: A review. *Continuum mechanics and thermodynamics*, 8, 1-35.

Lemos, M. A. D. C., Guimarães, L. M., & Cavalcante, A. L. B. (2021). Experimental evaluation of the classical and alternative consolidation theories in predicting the volumetric change of contaminated and non-contaminated soil. *Soils and Rocks*, *44*.

Liu, H., Chen, G., Shen, S (2019). Experimental Study on the Collapse Potential of Loess Under Simulated Rainfall. *Journal of Rock Mechanics and Geotechnical Engineering*, 766-776.

Mahamud, M. A., Alamgir, M., & Hossain, M. J. (2008). Laboratory Investigation on the Behaviour of Improved Organic Soil of Khulna Region.

Mansour, Z. M., Chik, Z., & Taha, M. R. (2008). On the procedures of soil collapse potential evaluation. *Journal of Applied Sciences*, *8*(23), 4434-4439.

Mitchell, J. K., & Soga, K. (2005). *Fundamentals of soil behavior* (Vol. 3, p. USA). New York: John Wiley & Sons.

Rabbee, T., & Rafizul, I. M. (2012). Strength and compressibility characteristics of reconstituted organic soil at Khulna region of Bangladesh. *International Journal of Engineering and Technology*, *2*(10), 1672-1681.

Santagata, M., Bobet, A., Johnston, C. T., & Hwang, J. (2008). One-dimensional compression behavior of a soil with high organic matter content. *Journal of geotechnical and geoenvironmental engineering*, 134(1), 1-13.

Sarkar, S. K., Rahman, M. A., Esraz-Ul-Zannat, M., & Islam, M. F. (2021). Simulation-based modeling of urban waterlogging in Khulna City. *Journal of Water and Climate Change*, *12*(2), 566-579.

Shalaby, S. S. (2014). The assessment of the collapse potential of fills during inundation using plate load tests. *Life Sci. J*, *11*(8), 1001-1006.

Sharma, R. S.; Chander, K (2017). Influence of Fibers on the Collapse Potential of Black Cotton Soil. *Journal of Materials in Civil Engineering*.

Wan Hassan, W. H., Rashid, A. S. A., Latifi, N., Horpibulsuk, S., & Borhamdin, S. (2017). Strength and morphological characteristics of organic soil stabilized with magnesium chloride. *Quarterly Journal of Engineering Geology and Hydrogeology*, *50*(4), 454-459.