IMPACT OF REPEATED LOADING ON THE SECONDARY COMPRESSION INDEX OF ALLUVIAL CLAY SOIL IN KHULNA REGION

Md Asif Hosnain*[1], Md. Rokonuzzaman[2]

[1] *Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: mdasifhosnain@gmail.com*
[2] *Professor, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: rokon@ce.kuet.ac.bd*

***Corresponding Author**

ABSTRACT

Secondary compression, a fundamental characteristic of clay soil, plays a crucial role in estimating total settlement. The secondary compression index is indispensable for this purpose, given its association with the time-dependent creep behavior of secondary compression. Numerous studies have highlighted the influence of loading patterns on secondary compression. This research specifically explores the repercussions of two types of repeated loading on the secondary compression index. The investigation employs one-dimensional consolidation tests in the laboratory, considering various load increment ratios. Findings indicate that repeated loading leads to a significant reduction in secondary compression. Besides, the research also shows that with the increment of load increment ratio, the secondary compression index also increase and the analysis shows that for static loading condition, the increment is linear and for repeated loading the increment is polynomial which indicates, if the Load Increment Ratio exceeds a certain limit, the secondary compression will decrease due to excessive creep at the loading unloading cycle. This work indicates that for higher Load Increment Ratio under repeated loading condition, the secondary compression settlement of the soil decreases. The study also indicates that with varying Load Increment Ratio under different loading condition doesn't affect the compression index of clay soil. That gives a insight that compression index isn't affected by the factors like Load Increment Ratio and Loading Pattern.

Keywords: *Secondary Compression Index, Repeated Loading, Clay Soil, One Dimensional Consolidation Test*

1. INTRODUCTION

In the field of civil engineering, meeting serviceability criteria is imperative alongside addressing structural failure. In the Khulna region, instances abound where structures succumb to failure attributed to excessive settlement. A critical concern in this context is the protracted nature of secondary compression settlement, persisting indefinitely over time. The challenge lies in accurately predicting this continuation settlement during the design phase, as its unforeseen occurrence can significantly impact the structural integrity throughout its service life. Unlike primary consolidation secondary compression continues for infinite time (Mesri & Vardhanabhuti, 2005). As a result when soil is weak against secondary compression it has to be estimated with accuracy for ensuring safety of the structure.

Notably, the Khulna region is characterized by numerous storage houses and oil tanks, structures that exhibit a notably low self-weight relative to the substantial loads they bear over their lifespan. Complicating matters further, these structures undergo loading and unloading cycles at varying intervals. Consequently, the calculation of settlement for such structures becomes intricate, deviating from the conventional approach due to the unique challenges posed by secondary compression settlement. This research endeavors to shed light on the influence of loading and unloading behaviors on the secondary compression settlement of structures in the Khulna region.

The pioneering work of Taylor and Merchant in 1940 laid the foundation for the computation of secondary compression settlement in soil. However, their model was designed to operate effectively only under conditions of incremental stress. Unfortunately, when soil experiences cyclic loading and unloading, this model falls short in accurately predicting soil settlement. Recognizing this limitation, subsequent researchers sought to develop a more robust model capable of computing secondary compression settlement under repeated loading scenarios.

The study by Seed and Chan in 1958 highlighted the multifaceted challenges posed by repeated loading in clay soil, particularly when serving as the subgrade for flexible pavement. Notably, sustained loading and unloading over brief durations were identified as factors significantly diminishing the soil's load-bearing capacity, leading to failures across varying moisture content and conditions (Seed & Chan, 1958). Building on this, Seed et al. (1960) demonstrated that the strength of clay soil could be enhanced through repeated loading, introducing the concept of soil "memory" following stress application. It was observed that if stress increments remained within the soil's memory threshold, settlement was mitigated. Both studies underscored the critical role of soil stress history.

Moreover, Luo's investigation in 1973 delved into the impact of cyclic loading on the engineering properties of clay, adding valuable insights to the existing body of knowledge (Luo, 1973). Despite these contributions, none of the aforementioned researchers specifically focused on the phenomenon of secondary compression settlement in clay soil. The intricacies of predicting secondary compression settlement are underscored by Mesri and Vardhanabhuti's assertion in 2005 that this type of settlement persists indefinitely, presenting a unique challenge in geotechnical engineering research (Mesri & Vardhanabhuti, 2005).

The correlation between the secondary compression index and primary compression index has been a subject of interest in geotechnical engineering. Mesri and Castro (1987) noted that the C_α/C_c ratio, representing the secondary compression index to primary compression index, remains relatively constant for typical soils. This relationship is derived under static loading conditions, where there are no loading and unloading cycles.

Fujiwara et al. (1985) conducted a study on the consolidation behavior of alluvial clay under repeated loading, specifically focusing on the impact of repeated loads on an oil tank in alluvial clay soil in Kanda. The research revealed that the settlement under repeated loading, after 100% consolidation, exceeded the settlement under static loading. This outcome suggested an excess of secondary compression under repeated loading. To gain a deeper understanding of clay's secondary compression behavior, Fujiwara conducted further research.

In a subsequent study, Fujiwara et al. (1987) demonstrated that clay soil exhibits greater settlement under repeated loading due to secondary compression. Notably, Fujiwara employed a modified oedometer that allowed for gradual load application to simulate the field loading system of an oil tank. Additionally, the loading and unloading cycle was maintained for 16 hours, well beyond the time required for completing primary consolidation. This approach indicated that Fujiwara deliberately permitted a certain amount of secondary compression to occur in each loading cycle, mirroring the loading and unloading conditions experienced by an oil tank (Fujiwara et al., 1987). But, study from (Yin, 1999) has showed that soil undergoes creep or secondary compression settlement even in primary consolidation stage. This indicates that under repeated loading condition soil may undergo creep in repeated loading cycle's primary consolidation stages. As a result, finally the secondary compression will be less after the cyclic loading. For evaluating this prediction, this work focuses on the evaluation of the impact of the repeated loading on the secondary compression of clay soil.

This study builds upon Fujiwara's methodology from 1987, with certain modifications aimed at enhancing our comprehension of the secondary compression behaviour exhibited by the clay soil in the Khulna region under conditions of repeated loading.

For different loading condition, the study focuses on establishing some mathematical relationship which will allow to predict secondary compression index (C_α) under different load increment ratio. This relationship will allow to determine the secondary compression index for clay soil by performing simple one dimensional consolidation test at the laboratory with the known value of compression index (C_c).

2. METHODOLOGY

The research commenced by collecting undisturbed soil samples, followed by a meticulous analysis of their physical parameters in the laboratory. Subsequently, a conventional one-dimensional consolidation test was conducted to ascertain the preconsolidation pressure, crucial for establishing the target stress. Building on this foundation, a series of nine additional one-dimensional consolidation tests were systematically executed, with variations in loading conditions and load increment ratios. Ultimately, the data derived from these tests were employed to determine both the secondary compression index and primary compression index. Then a regression analysis was performed to predicting the C_α/C_c ratio under different Load Incremental Ratio in a particular range.

2.1 Collection of Soil Sample

Soil samples were obtained from the KUET campus, extracted from a depth of 5 feet below the ground surface. To ensure the collection of undisturbed soil samples, a cubic box measuring 1 foot by 1 foot by 1 foot was employed. The box was carefully inserted into the soil by excavating an open pit with a depth of 5 feet. The sample collection method is called shallow pit excavation method (Lima et al., 2005). Collecting soil samples in a box preserves the inherent structure and composition of the soil, ensuring accurate analysis of its properties. This approach is especially beneficial for investigations into the soil's physical, chemical, and biological characteristics.
After the sample collection, the box was closed with polyethene wrapping and kept in a cold place in the laboratory so that sufficient moisture loss didn't take place.

2.2 Soil's Physical Parameters Determination

The investigation commenced with the determination of essential physical parameters crucial for soil identification, along with the execution of the one-dimensional consolidation test. These parameters encompass specific gravity, liquid limit, plastic limit, field moisture content, and organic content.

Table 1: physical parameters of soil

Test name	Test Result
Specific Gravity, Gs	2.71
Liquid Limit, LL (%)	65
Plastic Limit, PL (%)	26
Plasticity Index, PI	39
Field Moisture Content, w(%)	42
Organic Content (%)	7.6

2.3 Soil Classification

The soil classification adhered to the Unified Soil Classification System, following the guidelines outlined in ASTM D2487-17. Utilizing the physical properties derived from the soil sample, the classification according to the USCS identified the soil as fat clay or expansive clay, designated by the group symbol CH.

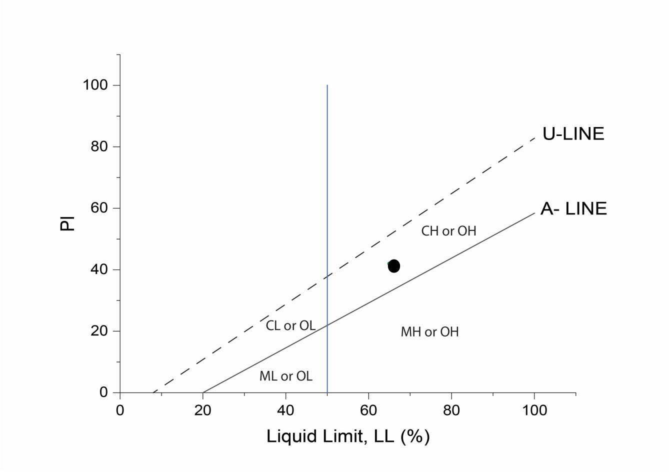

Figure 1: Soil Classification according to Unified Soil Classification System

2.4 One Dimensional Consolidation Test

In the methodology, the primary objective was to ascertain the preconsolidation pressure, crucial for calculating the "Target Stress." The estimation of preconsolidation pressure relied on the e vs. log (effective stress) plot derived from the one-dimensional consolidation test. The Log-Log method, as recommended by Oikawa (1987), was selected for its suitability in determining preconsolidation pressure.

To minimize sample disturbance, the collected undisturbed soil sample underwent precise cutting using a wire saw. The field stress of the soil was determined utilizing sample collection data, providing valuable insights into the soil's consolidation condition in the field.

All consolidation tests adhered to the ASTM D2435-96 standard. The initial one-dimensional consolidation test maintained a Load Increment Ratio (LIR) of 1. The test procedure and calculation was similar to the one dimensional consolidation test of Terzaghi.K and the equation proposed by his one dimensional consolidation model was used to calculate the void ratio for different stress applied to the soil. The following equation from Terzaghi et al. (1925) was used for establishing a standard curve for the soil

$$e_0 - e = C_c log_{10}(\frac{P + \Delta P}{P})$$

where, e_0=initial void ratio,

e= void ratio at P+ΔP stress

P= initial stress before inducing stress
ΔP= incremental stress
C_c= compression coefficient

The preconsolidation pressure was established utilizing the Log-Log method, chosen due to the limited data points available before reaching the preconsolidation pressure. The Casagrande method was intentionally avoided for this reason. The approach for determining preconsolidation pressure closely followed the method outlined by Jose et al. (1989), known for its effectiveness in determining the preconsolidation pressure of clay.

Table 2: One Dimensional Consolidation Test Result

Preconsolidation Pressure	78KPa
Compression Index, C_c	0.3
Recompression Index, C_r	0.045
OCR	3.4

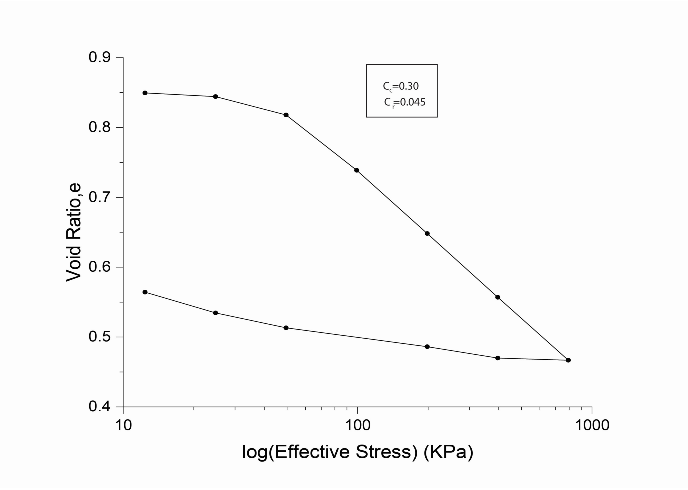

Figure 2: Compression Index and Recompression Index Determination

The curve depicting void ratio against log effective stress exhibited a distinctly straight segment after the preconsolidation pressure, signifying that the soil sample remained undisturbed. This observation validates the successful fulfillment of the objective behind collecting undisturbed soil samples.

2.5 Repeated One Dimensional Consolidation Test

A target stress was selected above the preconsolidation pressure of the soil in the field. Following the selection of the target stress, a series of repeated one-dimensional consolidation tests were conducted to determine the secondary compression index at the designated stress level. The experimental design adopted for these tests was inspired by the work of Fujiwara et al. (1985) and was subsequently modified to align with the specific requirements of the laboratory.

In this study, the repeated loading pattern drew inspiration from the research conducted by Fujiwara et al. (1987) to investigate the impact of repeated loading on the secondary compression index C_α. However, certain adjustments were implemented to tailor the system to the laboratory apparatus's specifications. Additionally, the loading and unloading durations were extended compared to Fujiwara's experiment to allow for an adequate amount of secondary compression settlement.

The research incorporated three distinct loading conditions: static loading, one-way loading, and two-way loading. Static loading entailed the sustained application of a constant load over an extended period without any unloading. One-way loading involved applying a load solely in one direction, while two-way loading applied a load in two opposing directions. By subjecting the soil to these loading conditions, the study aimed to analyze and compare the secondary compression settlement behavior of local clay in Khulna city under different loading scenarios, particularly in contrast to static loading conditions.

In this research study, the determination of the secondary compression index, Cα is conducted under the P+ΔP load across three distinct loading conditions. For the static load, characterized by a loading pattern akin to a one-dimensional consolidation test, there is no loading or unloading phase. Conversely, for one-way and two-way loading, loading and unloading precede the application of the P+ΔP load. In one-way loading, these phases occur exclusively in the forward direction, while in two-way loading, they transpire in both forward and backward directions.

The target load in the repeated consolidation test, denoted as P+ΔP, generates a stress referred to as the target stress. A crucial criterion in selecting the target stress was ensuring it exceeded the preconsolidation pressure of the soil sample. Rigorous attention was given to ensuring that all stress induced during loading surpassed the soil's preconsolidation pressure. For this research, the meticulously chosen target stress was set at 400 KPa.

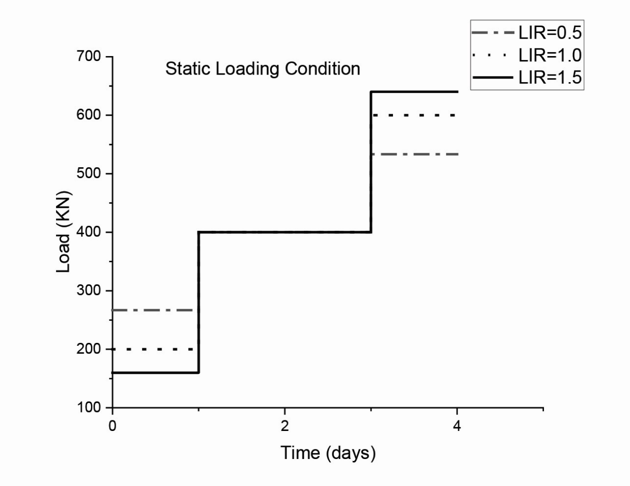

Figure 3: Static Loading Condition

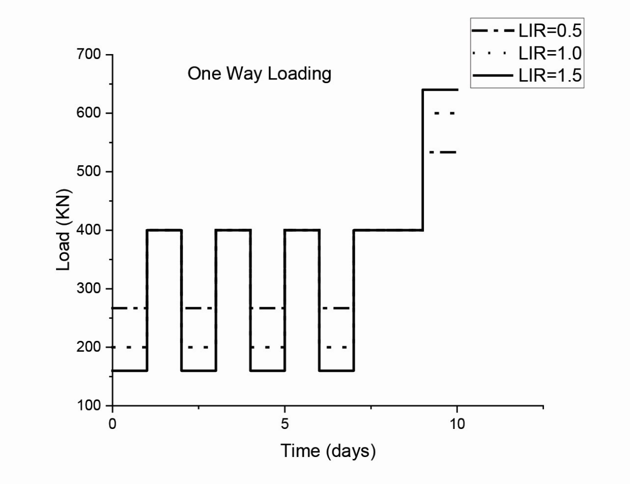

Figure 4: One Way Loading Condition

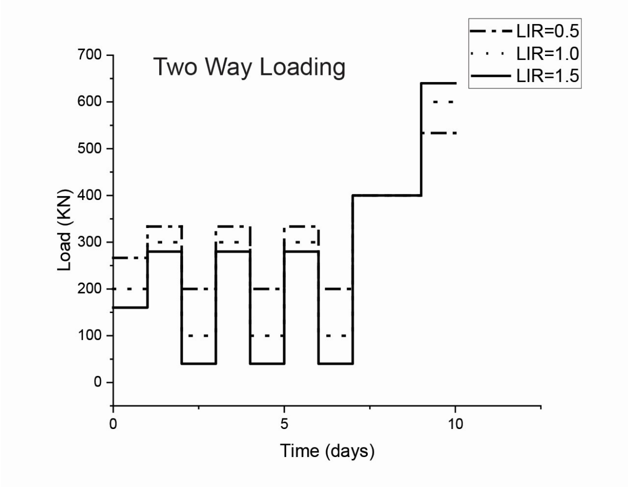

Figure 5: Two Way Loading Condition

3. RESULTS AND DISCUSSION:

From the static and repeated consolidation test following results are obtained.

Table 4: Test Results from Static and Repeated Consolidation Test

LIR	Loading Condition	C_c	C_α	C_α/C_c
0.5	Static	0.29	0.00732	0.025241
	One Way	0.27	0.00149	0.005519
	Two Way	0.29	0.00512	0.017655
1.0	Static	0.28	0.0075	0.026786
	One Way	0.26	0.00155	0.005962
	Two Way	0.33	0.00583	0.017667
1.5	Static	0.29	0.00764	0.026345
	One Way	0.25	0.00156	0.00624
	Two Way	0.28	0.00589	0.021036

The outcomes of this research shed light on the intricate behavior of clayey soil when subjected to prolonged and repeated loading, extending beyond the typical duration for primary consolidation completion. The discernible decrease in the secondary compression index, a key parameter indicative of soil settlement, suggests that the impact of extended repeated loading on secondary compression is relatively modest. This nuanced understanding is further enriched by the study's differentiation between one-way and two-way loading scenarios, revealing a significantly lower secondary compression index in the former. This distinction implies that the manner in which stress is applied and subsequently removed has a substantial influence on the soil's behavior, particularly in terms of secondary compression.

The practical implications of these findings are of substantial importance, proposing a potential strategy for mitigating secondary compression in real-world applications through the implementation of preloading techniques. Despite secondary compression often being overlooked in practice, especially when primary consolidation appears to extend beyond the expected service life of a structure, this research emphasizes the significance of considering secondary compression, particularly in scenarios involving thin, soft clay layers. The study's recommendation, particularly relevant for regions like Khulna with prevalent clayey soil exhibiting these characteristics, suggests that for the construction of structures such as storage houses or oil tankers, repeated loading may serve as a beneficial measure in reducing the likelihood of secondary compression settlement.

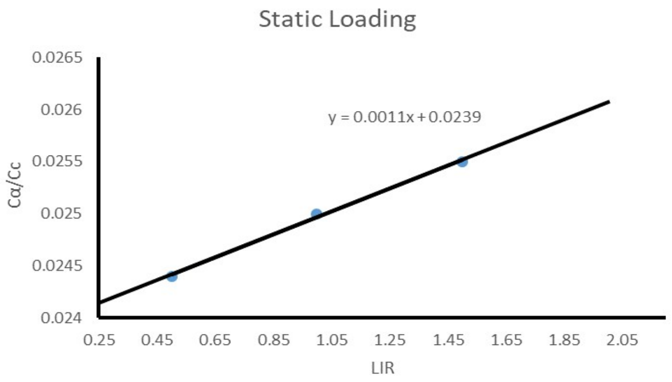

Figure 6: Correlation for Static Loading

In the context of static loading, the study explores the consistency of the C_α/C_c ratio across various load incremental ratios. Under static loading conditions, a linear relationship is identified for predicting the secondary compression index at different Load Increment Ratios (LIR) which is

$$\frac{C_\alpha}{C_c} = 0.0011(LIR) + 0.0239 \qquad 0.25 \le LIR \le 2.0$$

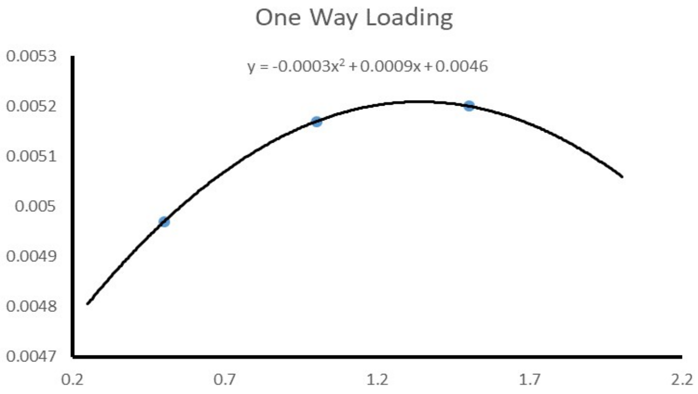

Figure 7: Correlation for One Way Loading

For repeated loading scenarios, polynomial relationships are established between LIR and Cα. Specifically, for one-way loading conditions, the relationship is as follows

$$\frac{C_\alpha}{C_c} = -0.0003(LIR)^2 + 0.0009(LIR) + 0.0046 \qquad 0.25 \le LIR \le 2.0$$

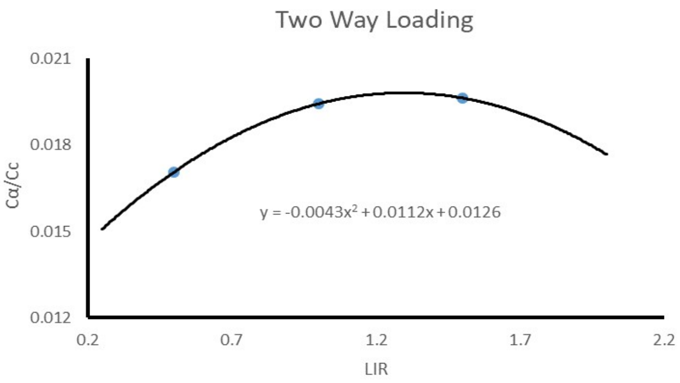

Figure 8: Correlation for Two Way Loading

For two way loading condition the relationship is

$$\frac{C_\alpha}{C_c} = -0.0043(LIR)^2 + 0.0112(LIR) + 0.0126 \qquad 0.25 \leq LIR \leq 2.0$$

where, C_α= secondary compression index,
C_c= compression index,
LIR= Load Increment Ratio

In case of repeated loading, the polynomial curves indicate normal belt shape that actually indicates that after a optimum LIR the secondary compression index will decrease with the increasing incremental load. This indicates that soil's creep behavior in secondary compression actually decrease after sustaning a certain amount of load. In this case, the excess load increment causes the creep settlment in the time of primary consolidation and as a result after completing the primary consolidation, creep settlement becomes less which causes less secondary compression settlement.

This aligns with prior research findings and underscores the robustness of this ratio under different loading conditions. Moreover, the upward trend observed in the secondary compression index (C_α) with increasing load increment ratios provides valuable insights. It suggests that a strategic reduction in incremental loads over clayey soil could be pivotal in mitigating secondary compression. This insight advocates for a meticulous approach to construction, emphasizing the benefits of employing smaller incremental loads to minimize the potential for settlement due to secondary compression—a crucial consideration in the practical execution of construction projects. For the validation of the experiments performed in the work, all void ratio vs effective stress curve contains a standard curve established from the equation of Terzaghi et al. (1925) and most of the curves that are established from laboratory analysis are falling close to that standard curve.

Another key finding is the constancy of the compression index (C_c) of clayey soil, irrespective of loading conditions. This observation implies that altering loading conditions does not exert a significant influence on the primary consolidation of clayey soil. As a result, the research underscores the need for alternative strategies when addressing primary consolidation concerns, emphasizing that changes in loading conditions alone may not suffice in mitigating the primary compression settlement of clayey soil. This nuanced understanding contributes to the broader knowledge base in geotechnical engineering, providing valuable insights for practitioners and researchers alike.

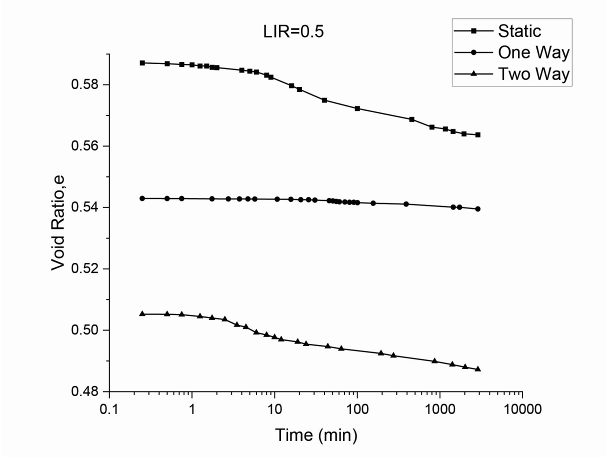

Figure 9: Void Ratio vs log(Time) curve for LIR=0.5

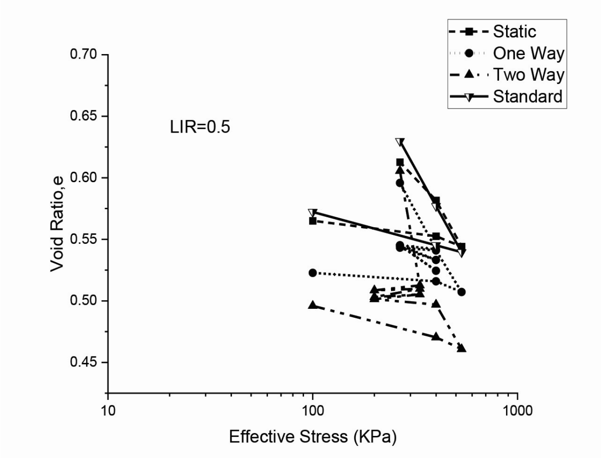

Figure 10: Void Ratio vs log(Effective Stress) curve for LIR=0.5

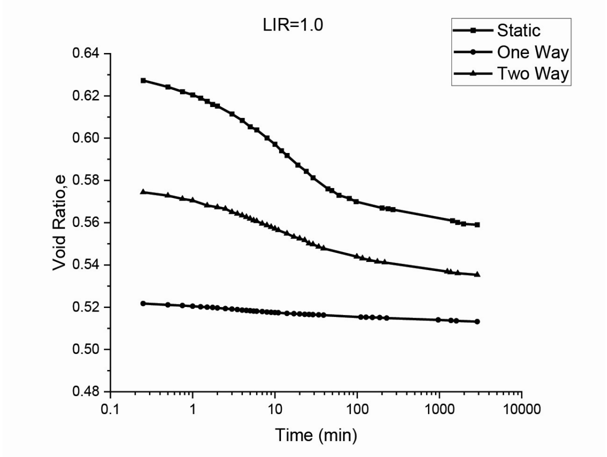

Figure 11: Void Ratio vs log(Time) curve for LIR=1.0

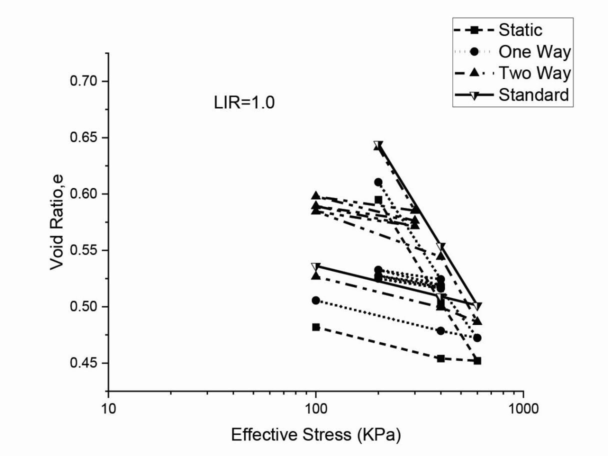

Figure 12: Void Ratio vs log(Effective Stress) curve for LIR=1.0

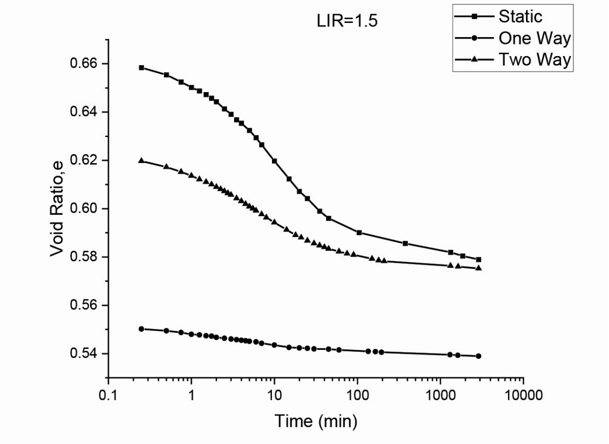

Figure 13: Void Ratio vs log(Time) curve for LIR=1.5

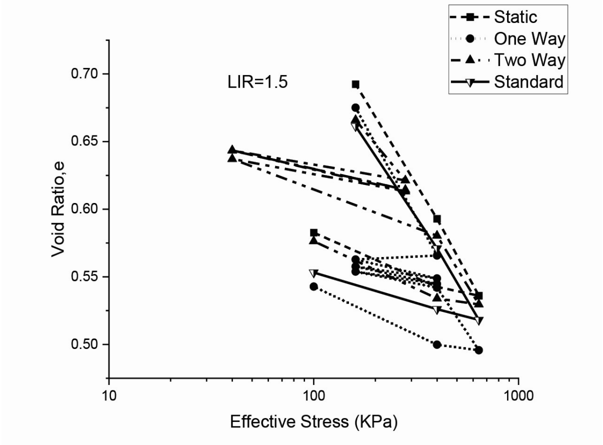

Figure 14: Void Ratio vs log(Effective Stress) curve for LIR=1.5

4. CONCLUSIONS

In this paper the impact of static and repeated loading on the primary and secondary compression behavior of local clay soil in Khulna city is observed through laboratory testing under various Load Incremental Ratio. Then, a corelation is established to find out how Load Increment Ratio will affect the secondary compression under static and repeated loading. In conclusion the following findings are obtained-

i) Compression coefficient, C_c remains almost constant for all loading conditions.

ii) Secondary compression index, C_α increases with increasing load incremental ratio. For static loading this increment is linear and for repeated loading this increment is polynomial. As a result, if the load increment ratio exceeds the optimum value then secondary compression of soil will start to decrease. So, a large load increment can be utilized to reduce secondary compression through repeated loading.

iii) Secondary compression index, C_α is less for the repeated loading compared to static loading which ensures the safety that structures facing long term repeated loading over a clay soil will be less vulnerable to secondary compression settlement compared to strcucture under normal static loading.

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