# CRITERIA OF ACCEPTANCE FOR CONSTANT RATE OF STRAIN CONSOLIDATION TEST FOR COHESIVE SOIL


LAM CHEE SIANG

UNIVERSITI TEKNOOGI MALAYSIA

To my beloved mother, father and Boon Yaa

## ACKNOWLEDGEMENT

In the whole process of preparing this thesis, I would like to express my sincere appreciation to my supervisor Assoc. Prof Dr. Khairul Anuar Kassim for his supervision, advice, guidance, and useful comments. Without his continued support and interest, this thesis would not have been the same as presented here. This research is funded by the Intensification Research of Priority Area (IRPA) Grant Coded 74110 lead by Assoc. Prof Dr. Khairul Anuar Kassim. Thanks also for the assistance of technicians in the Geotechnics Laboratory Faculty of Civil Engineering, Universiti Technologi Malaysia (UTM), Skudai.

Beside that, I would like to say thank you to my parents and my girlfriend for their support and encouragement. Their encouragements provide the energy for me to concentrate on my Master study.

Lastly I would like to say thank you also to those party I did not mention above that had help me direct or indirectly in my research works. Although their contributions are just little and simple work, but I am sure that I will meet a lot of difficulties without their contributions.

## ABSTRACT

Constant rate of strain (CRS) consolidation test is a new method of consolidation testing in Malaysia. Although it had been widely used as an alternative for standard consolidation test in other countries such as Sweden and the USA, there is still no standard equipment for it. The selection of the suitable strain rate for the CRS test is still a major hurdle for the geotechnical engineers. The CRS consolidation test has some advantages over the standard consolidation test where the time needed for the test is reduced from two weeks to few hours and the ability to apply high effective pressure at larger sample size. Various guidelines and criteria of acceptance for the CRS consolidation test had been introduced by many researchers. The aim of this research is to establish new criteria of acceptance for the CRS consolidation test. A new developed CRS equipment has been designed and named Rapid Consolidation Equipment (RACE). The equipment was developed using the concept of continuous consolidation test procedure. The criteria of acceptance for the CRS test were based on the normalized strain rate, $\beta$ introduced by Lee (1981) and the ratio of excess pore pressure to applied pressure, ($u_a/\sigma_v$). It was also established that the maximum $\beta$ to achieve acceptable data is 0.1. The research showed that the minimum value for the $\beta$ and $u_a/\sigma_v$ are 0.005 and 0.01 respectively. Another criterion of acceptance for the CRS test which takes into account the clay fraction (CF) effects was also introduced. The clay fraction is used to modify the normalized strain rate $\beta$, into $\beta$/CF. Results show that for soil with clay fraction more than 50%, the maximum $\beta$ / CF is 0.001. The maximum $\beta$ / CF for soil with CF lower than 50% is 0.008.

# ABSTRAK

Ujian pengukuhan berketerikan malar (CRS) merupakan salah satu ujian pengukuhan yang baru di Malaysia. Walaupun ujian pengukuhan ini telah biasa digunakan sebagai ujian pengukuhan utama di luar negara seperti USA dan Sweden, namun masih tiada peralatan yang piawai. Pemilihan kadar terikan yang sesuai untuk ujian pengukuhan berterikan malar (CRS) merupakan salah satu masalah kepada jurutera geoteknik. Ujian CRS mempunyai beberapa kelebihan berbanding dengan ujian oedometer kerana dapat mengurangkan masa ujian pengukuhan daripada dua minggu kepada beberapa jam dan juga boleh dijalankan sehingga tegasan berkesan yang tinggi pada sampel tanah yang lebih besar. Terdapat beberapa kriteria penerimaan dan panduan untuk ujian CRS telah dikemukakan oleh para penyelidik. Tujuan utama bagi penyelidikan ini adalah mencadangkan kriteria penerimaam yang baru untuk ujian pengukuhan berketerikan malar. Satu alat ujikaji CRS yang baru telah direkabentuk dengan menggunakan konsep ujian pengukuhan berterusan yang dikenali sebagai *Rapid Consolidation Equipment* (RACE). Kriteria penerimaan bagi ujian pengukuhan CRS adalah merupakan kadar keterikan ternormal, $\beta$ yang diperkenalkan oleh Lee (1981) dan nisbah tekanan air liang lebihan terhadap tekanan yang dikenakan, ($u_a/\sigma_v$). Maksimum $\beta$ yang memberikan data yang baik daripada ujian pengukuhan berterusan ialah 0.1. Penyelidikan ini menunjukan bahawa nilai minimum bagi kadar keterikan ternormal, $\beta$ dan nisbah tekanan air liang lebihan dan tekanan yang dikenankan, ($u_e/\sigma_v$) adalah 0.005 and 0.01. Satu lagi kriteria penerimaan untuk ujian CRS telah dicadangkan dimana peratus melepasi lingkungan tanah liat (CF) telah diambil kira. Peratus lepasan lingkungan telah digunakan untuk menukarkan kadar keterikan ternormal kepada $\beta$ / CF. Keputusan menunjukkan bahawa $\beta$ / CF maksimum bagi tanah dengan peratus tanah liat melebihi 50% adalah 0.001. Tanah dengan peratus tanah liat kurang daripada 50% memberikan nilai $\beta$ / CF maksimum sebanyak 0.008.

## TABLE OF CONTENTS

# LIST OF TABLES

| TABLE NO. | TITLE | PAGE |
|---|---|---|

# LIST OF FIGURE

| FIGURE NO. | TITLE | PAGE |
|---|---|---|
| 3.5 | Photo of the Constant Rate of Strain Consolidation Test Equipment (Rapid Consolidation Cell Equipment, RACE) | 44 |
| 3.6 | Mechanical Loading Frame for the CRS test | 45 |
| 3.7 | 50 mm Linear Variable Displacement Transducer (LVDT) | 46 |
| 3.8 | 1500 kPa Pressure Transducer | 46 |
| 3.9 | 907 kilogram S- Type Load Cell | 47 |
| 3.10 | MPX 3000 Data Acquisition Unit (ADU) | 48 |
| 3.11 | Main Page of the Winhost Programme for Collecting Data System | 48 |
| 3.12 | Schematic Arrangement of Control System for Constant Rate of Strain Consolidation Tests | 49 |
| 3.13 | Channel Configuration for the Compression and Pressure Calibrated with ADU and Winhost Programme | 51 |
| 3.14 | Channel Configuration Scaling for the Compression and Pressure | 51 |
| 3.15 | Linear Variable Displacement Transducer (LVDT) Calibration Process | 52 |
| 3.16 | Schematic Arrangement for the Load Cell Calibration on Loading Frame | 53 |
| 3.17 | Displacement Calibration Curve for the CRS Testing System | 54 |
| 3.18 | Loading Pressure Calibration Curve for the CRS Testing System | 55 |
| 4.1 | Particle Size Curve for All Soil Sample | 60 |
| 4.2 | Plasticity Chart for Soil Classification | 63 |
| 4.3 | Void Ratio versus Effective Pressure Curve for Kaolin Soil | 65 |
| 4.4 | Void Ratio versus Effective Pressure Curve for Gemas Soil | 65 |
| 4.5 | Void Ratio versus Effective Stress Curve for Air Papan Soil | 66 |
| 4.6 | Void Ratio versus Effective Pressure Curve for Kluang Soil | 66 |

| FIGURE NO. | TITLE | PAGE |
|---|---|---|

| FIGURE NO. | TITLE | PAGE |
|---|---|---|

| FIGURE NO. | TITLE | PAGE |
|---|---|---|

# LIST OF SYMBOLS

| | | |
|---|---|---|
| ADU | - | Data acquisition unit |
| $a_v$ | - | coefficient of compressibility |
| $c_c$ | - | compression index |
| CF | - | clay fraction |
| CH | - | clay of high plasticity soil |
| CI | - | clay of intermediate plasticity |
| CRS | - | constant rate of strain consolidation test |
| $c_v$ | - | coefficient of consolidation |
| $c_{v\,d}$ | - | drained coefficient of consolidation |
| $c_{v\,ud}$ | - | undrained coefficient of consolidation |
| $D$ | - | constrained modulus |
| e | - | void ratio |
| $e_f$ | - | final void ratio |
| $e_i$ | - | initial void ratio |
| $\mathrm{e_o}$ | - | void ratio at start of test |
| $\mathrm{e_1}$ | - | void ratio at starting effective stress |
| $\mathrm{e_2}$ | - | void ratio at ending effective stress |
| $\bar{e}$ | - | average void ratio |
| Gs | - | specific gravity |

| | | |
|---|---|---|
| $h_o$ | - | height at starting test |
| $H$ | - | length of the maximum drainage path |
| $H_i$ | - | initial height |
| $k$ | - | coefficient of permeability |
| LL | - | liquid limit |
| LVDT | - | linear displacement transducer |
| M | - | tangent modulus |
| MI | - | silt of intermediate plasticity |
| $m_f$ | - | final moisture content |
| $m_o$ | - | moisture content |
| $m_v$ | - | coefficient of volume compressibility |
| $n$ | - | porosity |
| $p$ | - | vertical load |
| $p_b$ | - | back pressure |
| $r$ | - | strain rate |
| RACE | - | Rapid Consolidation Equipment |
| $t$ | - | time |
| $T_v$ | - | time factor |
| $t_{90}$ | - | time corresponding to 90% of primary consolidation |
| $u_a$ | - | excess pore pressure |
| $u_b$ | - | initial back pressure |
| $u_u$ | - | pore pressure |
| $\varepsilon$ | - | strain |
| $\varepsilon_{ave}$ | - | average strain |
| $\sigma$ | - | total stress |

| | | |
|---|---|---|
| σ’ | - | effective stress |
| $\sigma'_0$ | - | effective stress for starting range |
| $\sigma'_1$ | - | effective stress for ending range |
| $\sigma_v$ | - | vertical applied pressure |
| $\sigma'_v$ | - | vertical effective stress |
| $\sigma'_{ave}$ | - | average effective stress |
| $\sigma_v'_{(bottom)}$ | - | bottom effective stress |
| $\sigma_v'_{(top)}$ | - | top effective stress |
| $\beta$ | - | Normalized strain rate |
| $\beta_d$ | - | normalized strain rate at drained face |
| $\beta_u$ | - | normalized strain rate at undrained face |
| $\beta$ / CF | - | Normalized strain rate on clay friction |
| $\Delta e$ | - | changes in void ratio |
| ΔH | - | Displacement |
| $\rho d$ | - | dry density |
| $\rho_w$ | - | water density |
| $\delta e$ | - | change in voids ratio |
| $\delta p$ | - | increment pressure |

# LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Since Terzaghi formulated his consolidation theory in 1923, many extensions had been made continuously to solve many of the unrealistic assumptions made in original theory. Today, consolidation theory had reached an advanced development that solutions are available for most practical problems. Some researcher refines Terzaghi's theory by solving a more generalized form of the differential equation of consolidation (Sheahan and Watters, 1997). Others established new governing consolidation equations based on realistic stress-strain-time models to yield compression-time and pore pressure-time relationships (Znidarcic and Schiffman, 1981). Numerous techniques to measure the compressibility of the soil were introduced after the conventional oedometer test is standardized. These new techniques include constant rate of strain consolidation test, constant rate of load consolidation test, constant pore pressure gradient, constant pressure ratio, restricted flow consolidation and back pressure control.

Constant rate of strain consolidation test is one of the new developments suggested by many researchers to suit the market nowadays. Constant rate of strain consolidation test can reduce the time needed for consolidation test using standard oedometer test from almost two weeks time to few hours. The constant rate of strain consolidation test also has been used as the standard consolidation test in Sweden, Norway, The United States and France.

The Criteria acceptance for the constant rate of strain consolidation test is the objective of the research because the CRS is not a standard consolidation test in Malaysia. The results of the constant rate of strain consolidation test (CRS) depends on the strain rate used in CRS test, so it is important to compare the results for the different strain rate of CRS test with the conventional oedometer test. The criteria of acceptance for the CRS test were developed for future improvements on consolidation test.

Previous researcher suggested few criteria to accept the CRS test result upon comparing the CRS test results with the conventional oedometer. These criteria of the acceptance for the CRS test were based on the comparison of void ratio curve (e against effective stress), coefficient of consolidation ($c_v$), normalized strain rate ($\beta$) and ratio of excess pore pressure to applied total stress ($u/\sigma_v$).

## 1.2 Statement of the Problem

Since 1950's, the standard compressibility test has been used to measure the soil compression characteristic is the one-dimensional Compression Test (Oedometer Test) based on Terzaghi theory. This one-dimensional oedometer test is one of the simplest forms of soil loading test which the soil sample is placed in a stiff metal cylinder so that radial strains equal to zero. Porous discs at the top and bottom to provide drainage of excess pore water (Figure 1.1).

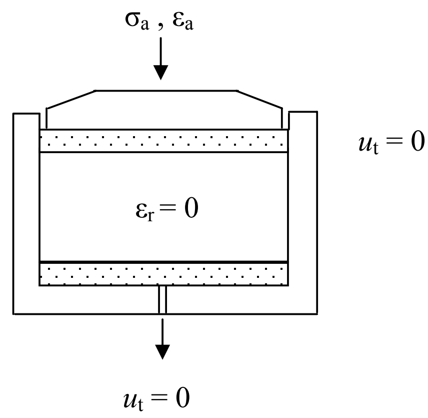


Figure 1.1: Conventional Oedometer.

Conventional oedometer test based on Terzaghi's theory is a step loading tests which took around two weeks for one complete test with loading and unloading stages. The test is also limited to low to medium loading for a sample size of 75 mm diameter. Beside that, pore pressure at the bottom of the soil sample is not usually measured.

Many researchers have introduced other methods to measure the compressibility characteristics of the soil. One of the new developments is the CRS test. Through the CRS test, the testing time for a completed test can be reduced from around two weeks to few hours. The compression test can be conducted until a very high pressure.

The main problem of the CRS test is to determine the proper strain rate used in the test. The selection of the test rate is still a major hurdle in CRS test although many researchers had done various studies on this. Many recommendations had been offered by researchers (Lee, Choa, Lee and Quek, 1993) for the selection of test rate but these recommendations are empirical and vary with clay type.

This research is aimed at finding a criterion on the strain rate used in CRS test for various types of clay obtained in Johor. Modifications on the available strain rate selection method for CRS test is recommended.

## 1.3 Objectives

The following objectives are set forth to achieve the aim of the research:

i. To develop consolidation equipment that could be used to run rapid consolidation using constant rate of strain consolidation method.

ii. To compare the result of the compression characteristic of the soil, coefficient of consolidation ($c_v$) and compression index ($c_c$) obtained from CRS test to the results of conventional oedometer test.

ii. To establish the new criteria of acceptance for Constant Rate of Strain consolidation test.

## 1.4 Scope of the Study

The soil samples for the study are remoulded from disturbed samples obtained from different sites in Malaysia. The interpretation of the research of the study is limited to:

i. Disturbed samples are collected from Kluang, Gemas and Air Papan, Johor (Figure 1.2). Kaolin soil was used as the control sample for the study.

ii. The specimens used for the study is remoulded sample. In the case all the disturbed soil samples were dried and grinded into powder and remoulded from slurry under 100, 200 and 300 kPa pre-consolidation pressure using self made remoulded sampler equipment.

iii Conventional oedometer test and the Constant Rate of Strain consolidation test will be conducted to a maximum of 8.5 kN and 1100 kPa vertical pressure respectively.

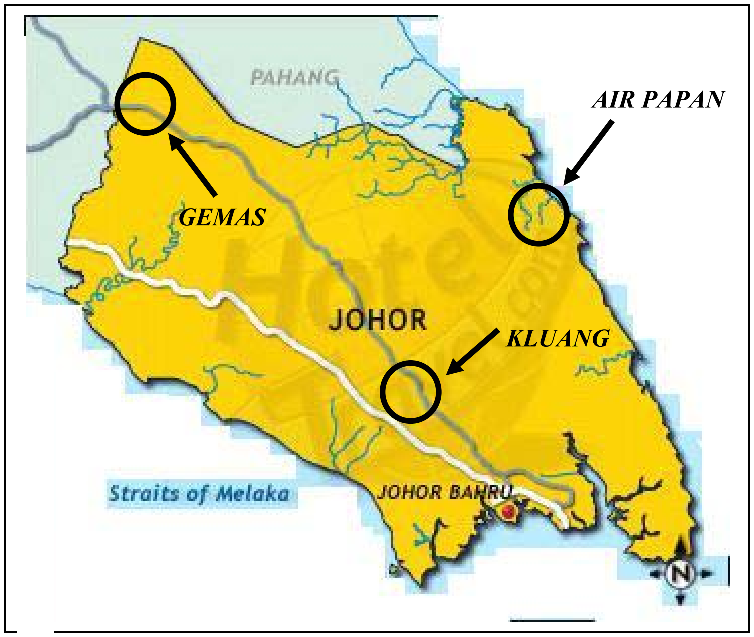


Figure 1.2: Study Area of the Research

## 1.5 Significant of Research

The main purpose of this study is to give recommendations on the testing rate selection which is still a major hurdle in CRS test as well as to establish new criteria of acceptance. Comparisons on the compression characteristics of soil based on oedometer and CRS test were made to establish the criteria of acceptance. With the recommended new criteria on the strain rate selection, geotechnical engineers can easily run the consolidation test for all cohesive soil in a short time. It can reduce the time for construction to wait the results on the soil compressibility characteristics. Beside that, CRS test can achieve higher effective pressure which is the disadvantage of the standard oedometer test. Geotechnical engineers can use this test as the alternative of the on site load test.