Analysis of oedometer and rowe cell consolidation compared to experimental testing

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Abstract. Consolidation settlement in clay soils can be predicted by analyzing the consolidation parameters. Consolidation parameters were obtained from the results of a laboratory consolidation test using an oedometer and rowe cell. The rowe cell can measure pore water pressure, soil saturation, and back pressure as a simulation of field condition while the Oedometer cannot. However, there are significant differences between the results of the analysis with the consolidation settlement occurred in the field caused by drainage conditions, the micro characteristics of the soil structure, and the thickness of the soil layer. Therefore, it is necessary to validate the results of settlement in oedometer and rowe cell consolidation analysis with the value of settlement of experimental results. The method used is a laboratory consolidation test using an oedometer and rowe cell as well as a laboratory-scale experimental consolidation test. The results obtained 79% of differences between experimental and oedometer, while rowe cell had a difference of 37% from experimental. Based on this, analysis using rowe cell consolidation parameters can predict a settlement in consolidation in the field more accurately than oedometer, because it has a smaller difference in value.

1. Introduction

Considering the problem of settlement and stabilization in such soft clay soil, that is important to calculate accurate consolidation factors for efficient design and construction, and estimate consolidation is the most important consideration in the field in determining the timing of the final consolidation [1]. Natural soft clays exhibit significant time-dependent deformations under both laboratory and in-situ conditions after the primary consolidation due to the viscosity [2]. The consolidation of soft clay soil can be predicted by analyzing the parameters of the consolidation test results in the laboratory. This test is carried out to determine the amount and level of decrease in volume experienced by finite lateral soil when experiencing different vertical pressures [3,4]. The data obtained can also be used to determine the coefficient of consolidation of the soil.

There are 2 (two) types of test equipment that can be used, oedometer and rowe cell. The standard oedometer test is a classical laboratory test used to determine consolidation parameters of a saturated soil specimen [5]. However, the high compressibility and heterogeneous soil constituent materials, low permeability make various factors must be considered in the design of laboratory testing. That is due to the limitations of the tools in accommodating the testing process. Rowe cell can measure soil saturation and back pressure as a simulation of conditions in the field [6]. The pore water pressure can be controlled
by a constant pressure source through the top drain, and pore water pressure measurements can be made at small ceramics flush mounted in the base plate and connected to pressure transducers in rowe cell [7]. Significant differences between the results of the analysis and the consolidation settlement occurring in the field can also occur. The consolidation settlement that occurs in the field is influenced by drainage conditions, the thickness of the soft soil layer, and microstructure characteristics of the soil so that validation is needed between the results of the analysis with the conditions in the field. The horizontal coefficients determined by CPTU carried out in the field generally correspond to those carried out by the rowe cell test [8], this shows that the results of rowe cell test have the same results in the field based on the CPTU test. This study discusses the consolidation parameters of the oedometer or rowe cell test results, which better describe the conditions in the field.

1.1. Consolidation test
The soil sample is inserted into the metal ring; the top and bottom of the soil sample are limited by the pore stone. The load is applied over the soil sample within 24 hours with the specimen always submerged in water. The periodic addition of load is applied to soil samples. Load used: 0.25; 0.50; 1; 2; 4; 8; 16 kg/cm². Deformation and time recorded are then plotted on a semi-logarithmic chart. The results obtained from the test are the consolidation parameters the compression index (Cc), which are used to analyze the consolidation settlement. The oedometer can be seen in Figure 1 and rowe cell in Figure 2.

![Figure 1. Oedometer.](image-url)
Rowe cell is used to overcome the disadvantages of conventional consolidation devices that cannot be used on low-stability and non-uniform soil. Soil samples were tested by a hydraulic system with water pressure as a diaphragm pressure. The advantage of Rowe cell over oedometer is the minimal effect of vibration test equipment, negligible deformation of the loading system, control of various sample drainage conditions, measurement of pore water pressure, measurement of volume of water released from the sample, saturation of samples under back pressure conditions, back pressure application for simulate field in situ conditions, control loading conditions, and variations in load conditions between equal strain and free strain [9].

1.2. Experimental test
Consolidation settlement can be estimated using the Boussinesq theory approach based on the limited assumptions of the soil model. Therefore, field testing with a trial embankment test is an alternative to determine the decline that is close to field conditions, but usually expensive and time-consuming. Thus, experimental tests in the laboratory are relatively cheap and easy and can be considered to some extent as a valid alternative. Although these tests tend to underestimate the characteristics of soft clay consolidation, they still produce valuable information about the geotechnical properties of soils in a reasonable time frame [10].

2. Method
The soil samples used in this research were soft clay soils from the Gedebage area, Bandung City. Oedometer testing is guided by ASTM D-2435-11 while Rowe cell according to British standards [11]. Each test uses three samples of the same size. Consolidation settlement analysis using the oedometer and Rowe cell test results using Equation 1.

\[
S_C = \sum \left[ \frac{C_C}{1 + e_0} \cdot H \cdot \log \left( \frac{P_o + \Delta P}{P_o} \right) \right]
\]  

(1)

Experimental testing uses a laboratory model scale with a steel box measuring 1000 mm × 1000 mm × 1000 mm. The soil material used previously was dried and filtered using No. filter 4, then the water content is adjusted to the conditions in the field. Load media uses a concrete plate measuring 200 mm × 200 mm, which is pressed using OPT hydraulic pump. The experimental testing scheme can be seen in Figure 3.

Figure 2. Rowe cell.
The parameters from the oedometer and Rowe cell consolidation test were then carried out a consolidation settlement analysis for each load according to experimental testing. The results of the analysis and experimental tests were made in the form of a graph between settlement and pressure. Based on the graph, the oedometer or Rowe cell line has the closest distance to the experimental line. The difference in distance was analyzed by calculating the error percentage value. Error is diversity (variability) caused by the inability of experimental material or experimental objects to behave similarly in these experiments. The expected error value is the smallest value. This explains the consolidation parameters that are the same as the conditions in the field.

3. Results and discussion

3.1. Consolidation results
The results obtained from the consolidation test are the compression index ($C_c$) obtained from the e-log $P$ graph. The e-log $P$ graph for the oedometer can be seen in Figure 4 and Rowe cell in Figure 5.

Figure 3. Experimental testing scheme.

Figure 4. e-log $P$ oedometer graph.

Figure 5. e-log $P$ Rowe cell graph.
The compression index for the oedometer and rowe cell can be seen in Table 1.

### Table 1. Compression index

|                | Oedometer | Rowe cell |
|----------------|-----------|-----------|
| Sample         | C<sub>C</sub> | Sample | C<sub>C</sub> |
| Sample 1       | 0.465     | Sample A | 0.126       |
| Sample 2       | 0.498     | Sample B | 0.106       |
| Sample 3       | 0.399     | Sample C | 0.120       |
| Average        | 0.454     | Average  | 0.117       |

3.2. *Experimental test results*

The experimental test results can be seen in Table 2.

### Table 2. Experimental test results.

| Pressure (kN/m<sup>2</sup>) | Settlement (m) |
|-----------------------------|----------------|
| 12.24                       | 0.0026         |
| 24.48                       | 0.0059         |
| 36.72                       | 0.0156         |
| 48.96                       | 0.0256         |
| 61.20                       | 0.0367         |
| 73.44                       | 0.0446         |
| 85.68                       | 0.0497         |

3.3. *Consolidation settlement results*

The results of the consolidation settlement based on the oedometer and rowe cell consolidation parameters are obtained based on Equation 1, where the variable adjusts to experimental testing. The results of the consolidation settlement in oedometer, rowe cell, and experimental test can be seen in Table 3.

### Table 3. The results of the consolidation settlement in oedometer, rowe cell, and experimental test.

| Pressure (kN/m<sup>2</sup>) | Experimental Settlement (m) | Oedometer Settlement (m) | Rowe cell Settlement (m) |
|-----------------------------|-----------------------------|--------------------------|--------------------------|
| 12.24                       | 0.0026                      | 0.0636                   | 0.0178                   |
| 24.48                       | 0.0059                      | 0.0884                   | 0.0254                   |
| 36.72                       | 0.0156                      | 0.1046                   | 0.0307                   |
| 48.96                       | 0.0256                      | 0.1167                   | 0.0349                   |
| 61.20                       | 0.0367                      | 0.1266                   | 0.0386                   |
| 73.44                       | 0.0446                      | 0.1349                   | 0.0418                   |
| 85.68                       | 0.0497                      | 0.1423                   | 0.0448                   |

The consolidated settlement values in Table 3 are illustrated in graphical form (Figure 6). The experimental line is used as a reference. The difference in the distance on the graph was analyzed by calculating the error percentage value. The results obtained are differences between experimental tests with an oedometer of 79% while rowe cell has a difference of 37%.
Figure 6. The results of the consolidation settlement in oedometer, rowe cell, and experimental test.

4. Conclusion
Consolidation settlement analysis using rowe cell parameters can predict a consolidation settlement in the field more accurately than an oedometer because it has a smaller error percentage value.

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