The Settlement Ratio Prediction of Compressible Soil In Area Under Embankment

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Abstract. This paper aims to predicting the ratio of settlement under the toe embankment, outer side of embankment and the centre of embankment. The methods used in this study are the empirical approach to estimate the index compression value (Cc) for compressible clay soil. The magnitude of soil subgrade settlement is carried out using a 1-dimensional compression formula developed by Terzaghi and considers the soil subgrade is an over consolidated clay. This study uses several variables such as the embankment dimension by considering the height and width of embankment and the depth of compressible layer of soil subgrade. Those variable uses to compare the ratio of settlement depend on those variables. The results obtained from this study are the settlement ratio of toe/centre is around 0.23 and the settlement ratio of outside/centre is around 0.84. The empirical formulation of settlement ratio for various condition are described in this study.

Keywords: soil settlement, settlement ratio, settlement under embankment

1. Introduction

Construction of road embankment in java island Indonesia is often carried out on soft soil. In addition, the road embankments with a relatively high elevation are often also committed. This condition can lead to several new problems such as landslide, differential settlement, low bearing capacity and many other. The problems of embankment construction will be discussed in this research is the soil settlement under the embankment. The calculation of soil settlement under the embankment always put an assumption that the settlement in the centre of embankment has same value of settlement in other area under the embankment. While the settlement at the toe of embankment is always considered to have a value of zero. In addition, an area which is several meters from the toe embankment also considered did not happen settlement. In fact, soil compression can occur in areas affected by embankment load and it is not appropriate just under embankment.

The possibility of not-zero value of settlement under the toe embankment and the affected area around the embankment can be seen from stress distribution at that area. Based on the one-dimension formulation of primary consolidation soil settlement by Terzaghi, the increase of stress due to the load on it can influence the settlement. Thus, the compression that occurs right at the toe of the embankment is not worth zero. Research on this subject by using the compressible soil in Surabaya, Indonesia was conducted by [1]. The amount of compression is very important to know whether any of the compression does not adverse impact on stability of the embankment itself and the buildings around the embankment. It is necessary for further analysis to calculate the amount of compression that occurs at the toe of the embankment and at the other areas affected by road embankment.
The consolidation settlement calculations for this study are using the 1-dimensional primary consolidation settlement formula. The magnitude of consolidation settlement under embankment loading is calculated using classical theory of one-dimensional consolidation and the strain-based recompression ratio. The magnitude of vertical stresses and the anticipated increase in stress under embankment loads were calculated in a classical manner from layer thickness, position of ground water table and unit weights using stress distribution based on elastic soil behaviour.

This study was conducted to determine the soil settlement at the toe embankment and the settlement ratio at the outer-side embankment. The amount of ratio is then compared between several variables that is the soil subgrade characteristic and the embankment dimension. This study is a continuation of previous research conducted by [1]. This study was conducted with several empirical approaches to obtain the value of compression index (Cc). Lots of empirical formula for compression index formulation approach has been tested on soft clay soils in some developing countries. The empirical formulations derived from correlate the soil consistency values and soil characteristics which are more easily tested in the laboratory. Some empirical formulation based from Liquid limit value has been tested by [2-4]; based from Plasticity Index has been tested by [5,6] based from Shrinkage Index has been tested by [7].

Other formulas also been tested in other area that Chicago clay, Brazilian clay, Clay Motley from the city of San Paulo and USA clay as well as in Greece based on the value of water content, void ratio and Liquid Limit by [8],[9] conducted tests on clay in the North Atlantic based on the value of plasticity index. Furthermore, dozens of other formulations have also been developed to correlate the characteristic value of void ratio, specific Gravity and water content. Some of these formulations are developed by [8,10-14]. The formula offered to the entire soft clay. This study will use three formulas of compression index that have been developed previously.

The aim of this study is determining the magnitude of soil settlement under the embankment in three location that is the centre of embankment, outside of embankment and in the toe of embankment (Figure 1). The result of those calculation is the settlement ratio of soil subgrade under the toe embankment and under the outer-side embankment with the maximum amount of settlement that occurs at the centre of the embankment. Results of this study was to obtain empirical formula to determine the compression ratio of subgrade under embankment on the various types of soil subgrade with empirical approach and several variations of compressible soil depth and embankment dimension. The simplification of formulation is also described in this study to find the simple way to calculate the ratio settlement in the area under embankment.

![Figure 1](image.png)

**Figure 1.** The illustration of soil subgrade settlement under toe of embankment, out-side area of embankment and centre of embankment (a= settlement under the embankment toe; b= settlement under outside of embankment; c= settlement under the centre of embankment).

2. **Material and method**
Research to obtain a compression ratio of subgrade under the embankment is conducted by some variation of the data for comparisons that is 3 embankment height variations (3 meter; 5 meter and 7 meter); 2 compressible soil subgrade depth variations (10 and 20 meter); 3 wide embankment variation (20, 30 and 40 meter); 3 empirical formula for calculating the compressible index of soil subgrade.
[15,16,13]. This study uses ratio 1:1 for embankment slope. The swelling index to calculate the magnitude of soil settlement is using 1/8 compressible index.

The variations were used to determine the magnitude of the stress increase of soil subgrade due to the embankment load. The calculation of the stress distribution is conducted to determine the magnitude of soil settlement. The calculation of the vertical stress increase is performed by the method of superposition that can be seen in Figure 2 and graph to obtain the factor influence measurement [17].

![Figure 2](image-url.png)

Figure 2. The calculation of vertical stress under embankment load with superposition method.

Empirical formulations to obtain the value of plasticity index (Cc) were used in this study are:

\[
Cc = 0.006 \times LL + 0.13 e_o - 0.13 \\
Cc = 1.15 (e_o - 0.35) \\
Cc = 0.75 (e_o - 0.50)
\]

Where Cc is compression index of soil subgrade; LL is liquid limit and e_o is void ratio. Three empirical formula used above is considered to represent all types of soft clay. The value of Cc is used by the empirical formula above is varied between 0.3 until 1.2. The recapitulation of soil subgrade compression index data used for this study can be seen in Table 1. By using the value of Cc is then performed calculations to determine the amount of compression subgrade beneath the embankment using Terzaghi one dimensional consolidation by assuming the entire soil type are over-consolidated clay (OC) soil by the condition po + \Delta p > pc.

Table 1. The recapitulation of compression index (Cc) and swelling index (Cs) used in this study using 3 empirical formulation mention above

| Compression index (Cc) | Swelling index (Cs) |
|------------------------|---------------------|
| 0.3                    | 0.0375              |
| 0.375                  | 0.046875            |
| 0.45                   | 0.05625             |
| 0.525                  | 0.06525             |
| 0.6                    | 0.075               |
| 0.6325                 | 0.079               |
| 0.7475                 | 0.092               |
| 0.8625                 | 0.108               |
| 0.9775                 | 0.122               |
| 1.0925                 | 0.136               |
| 1.2075                 | 0.150               |
3. Settlement ratio of soil subgrade under embankment

Initial analyses conducted on the settlement ratio of the soil subgrade under the embankment by a height of 3 meters, 5 meters and 7 meter. This initial analysis was performed to compare the settlement ratio that occurs by soil depth variation of compressible soil, embankment wide variations and the variation of the index compression. The result and analysis of the settlement ratio with the variation of Cc can be seen in Figure 3. The results of calculation and analysis of compression soil ratio with the width of embankment can be seen in Figure 4. The analysis result of the compression ratio with the thickness of compressible soil can be seen in Figure 5.

![Figure 3](image1.png)

**Figure 3.** The compression ratio of the soil subgrade settlement at the toe embankment and the side embankment using the variation of soil depth and width embankment

Based on the results that can be seen in Figure 3, it can be concluded some points namely:

1. At soil subgrade under the toe embankment, the more the ground is compressible, the greater the compression ratio. Instead, the soil subgrade compression ratio on the outer side of the embankment,
the more the ground is incompressible; the compression ratio will be smaller. The trend is occurred in all the analysed embankment width variation.

2. The wider the road embankment, the smaller the compression ratio that occurred but the difference is not too significant.

3. There is no significant difference in the magnitude ratio with an increase in Cc.

4. The settlement ratio of the soil subgrade under the embankment toe to the centre of the embankment is in the range of 0.198 to 0.258. While the compression ratio of soil subgrade under the outer-side of embankment to the centre of the embankment is in the range of 0.732 to 0.914.

![Figure 4](image1.png)

**Figure 4.** Graph the relationship between the settlement ratio of the subgrade under the embankment with variation of embankment width, embankment height (H) and depth of compressible soil (D); (left) Settlement ratio of subgrade under toe and centre embankment; (right) Settlement ratio of subgrade under outside and centre embankment.

![Figure 5](image2.png)

**Figure 5.** Chart the relationship between the compression ratio of the subgrade under the embankment and a compressible layer with various embankment dimension.

The analysis results in Figure 4 and Figure 5 show that embankment height, embankment width and compressible soil depth greatly affect the settlement ratio. As well as the results obtained in Figure 3, Figures 4 and 5 also show the same conclusions where the wider the road embankment, the smaller compression ratio. Another result obtained from this figure are the more the compressible depth of soil subgrade, the greater the settlement ratio under the embankment toe and embankment centre. Instead, the soil subgrade compression ratio on the outer side of the embankment, the more the ground is incompressible; the compression ratio will be smaller. To facilitate the analysis of these results, an empirical formula is then made.

4. **The empiric formula of settlement ratio.**

Based on the results of the above analysis, it can be concluded that the compression ratio of subgrade under embankment is influenced by the variations used. Summary of the conclusions in this analysis are as follows:

1. The larger the embankment width, the settlement ratio under embankment toe/centre and embankment outer-side/centre will be smaller.
2. The larger the compressible layer of soil subgrade, the settlement ratio under embankment toe/centre will be greater and settlement ratio under outer side embankment/centre gets smaller.
3. The larger the embankment height, the settlement ratio under embankment toe/centre will be smaller;
settlement ratio under outer side embankment/centre will be greater.

From the analysis above, it can be obtained several empirical formulas that can be used in several variations. Empirical formulation with a variety of variations can be seen in Table 2. There are many empirical formulas to determine the magnitude of the subgrade compression ratio under the embankment shown in Table 2. Therefore, to simplify the use of the formulation, modification is carried out.

Table 2. The empirical formulation of soil subgrade settlement under embankment load with variations used

| $H_{	ext{embankment}}$ (m) | Compressible layer (meter) | Toe/centre | Outer side/centre |
|-----------------------------|-----------------------------|-------------|-------------------|
| 3                           | 10                          | $y = -0.0001x + 0.2117$ | $y = -0.0007x + 0.824$ |
| 3                           | 20                          | $y = -0.0003x + 0.2481$ | $y = -0.002x + 0.8107$ |
| 5                           | 10                          | $y = -0.00007x + 0.2068$ | $y = -0.0006x + 0.8898$ |
| 5                           | 20                          | $y = -0.0003x + 0.2644$ | $y = -0.0016x + 0.9114$ |
| 7                           | 10                          | $y = -0.00005x + 0.9339$ | $y = -0.0005x + 0.9226$ |
| 7                           | 20                          | $y = -0.0003x + 0.2599$ | $y = -0.0018x + 0.8779$ |

Note: $y$ = settlement ratio; $x$ = width of embankment (meter)

In this study, simplification data of subgrade settlement ratio is done to get a ratio value that can be used for all existing variations. Simplification with statistical methods is then done by looking for coefficients variation of the settlement ratio produced in this study. The value of soil subgrade settlement ratio with various variations can be seen in Table 3. From the data in table 3, it is obtained the coefficient variation of soil settlement under the toe of embankment/centre of embankment is 10.7%; the mean value is 0.23 and the standard deviation is 0.024. Furthermore, the coefficient variation of soil settlement under the outer side of the embankment/centre of the embankment is 6.32%; the mean value is 0.84 and the standard deviation is 0.053. With a small coefficient variation of settlement ratio and it is under 20%, it can be concluded that the compression ratio of subgrade under the toe of embankment / centre of embankment is equal to 0.23 and the compression ratio of subgrade at the outer side of embankment/centre of embankment is 0.84 (Figure 6). From the results of this study the value can be used in all variations of soft soil depth and embankment dimension variations.

Table 3. The soil subgrade settlement ratio with various data used in this study

| $H_{	ext{embankment}}$ (m) | Embankment width (m) | Compressible layer (m) | Toe/centre | Outer side/centre |
|-----------------------------|----------------------|------------------------|-------------|-------------------|
| 7                           | 40                   | 10                     | 0.193       | 0.905             |
| 7                           | 40                   | 20                     | 0.249       | 0.850             |
| 7                           | 30                   | 10                     | 0.193       | 0.908             |
| 7                           | 30                   | 20                     | 0.251       | 0.861             |
| 7                           | 20                   | 10                     | 0.194       | 0.914             |
| 7                           | 20                   | 20                     | 0.255       | 0.882             |
| 5                           | 40                   | 10                     | 0.204       | 0.868             |
| 5                           | 40                   | 20                     | 0.252       | 0.808             |
| 5                           | 30                   | 10                     | 0.204       | 0.871             |
| 5                           | 30                   | 20                     | 0.254       | 0.820             |
| 5                           | 20                   | 10                     | 0.205       | 0.880             |
| 5                           | 20                   | 20                     | 0.258       | 0.844             |
| 3                           | 40                   | 10                     | 0.208       | 0.798             |
| 3                           | 40                   | 20                     | 0.236       | 0.732             |
| 3                           | 30                   | 10                     | 0.208       | 0.801             |
| 3                           | 30                   | 20                     | 0.238       | 0.746             |
| 3                           | 20                   | 10                     | 0.210       | 0.811             |
The results of the above research are the same as the road construction code in Japan which states that settlement of the soil subgrade under the embankment toe is 0.2 times the settlement in the centre of the embankment. Whereas, the soil subgrade settlement under the outer side of the embankment is 0.8 times the settlement magnitude in the centre of the embankment. These results indicate that there will also be affected areas of subgrade settlement due to embankment load in the area located a few meters outside the embankment. In a study of the influence area of settlement in the area around the embankment showed that compression can occur up to 6 meters from the embankment toe for 10 meters compressible depth of soil subgrade. The area of settlement will be even greater if the depth of the compressible layer deeper. Settlement still occurred in 8.5 meters from the toe of the embankment for 20 meters of compressible layer. This research also did not consider a lateral movement of the subgrade under the embankment load.

Figure 6. Settlement ratio under embankment

5. Conclusion
Based on the result mentioned above, then obtained some conclusion namely:

- The result analysis in this study indicate that the settlement under the toe embankment is not zero and settlement magnitude in the outer side of embankment is not the same as in the centre of embankment.

- The settlement ratio of soil subgrade under the toe embankment to the centre embankment is 0.23; The settlement ratio of soil subgrade under the outer side of embankment to the centre embankment is 0.84

- The soil subgrade settlement under the toe embankment is not zero it means that the soil settlement in the surrounding area close by the embankment load is also not zero. The recent study obtained the result that the area affected by settlement due to embankment load area almost 9 meters depend on the depth of compressible layer.

Further research needs to be conducted by considering the horizontal displacement of soil subgrade under embankment load. There should also be analysed the settlement ratio of the soil subgrade under embankment when using PVD as a soil improvement.

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