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Finite Element Analysis of Embankment Deformation on Soft Soil with Soft Soil Model

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ABSTRACT
A common problem when a construction is built on soft soil is the low carrying capacity of the soil and the magnitude of the decline that occurs. One method that can be used to increase the carrying capacity is to use geotextile. To find out geotextile performance, it is generally done directly with a full-scale heap or one to one in the field. The field data is then analyzed with the help of finite element method (FEM) to obtain FEM parameters and further analysis with the help of computers. This study aims to analyze the data of the results of research conducted with numerical methods using a model that is suitable for soft soil models, namely soft soil models. The description to be analyzed is the deformation of the pile.
The design of the study to be carried out is to collect secondary data such as pile models, decreases, and horizontal deformation. Then determine the soil parameters to be used in soft soil modeling. From the results of the parameters that have been obtained, modeling will be done using PLAXIS 2D by running on PLAXIS 2D to calculate deformation. From the results of this running process obtained the final result is to compare the results of field tests and numerical analysis.
Based on the curve on the vertical displacement of the results in the field, the decrease that occurs is increasing with the increase in the load of the heap. Although it produced almost thesame final decline, the soft soil model was closer to a decline in the field throughout the downturn process time compared to the Mohr Coulomb model. In addition despite thedifference in magnitude, horizontal displacements under geotextiles are seen to produce the same behavior between numerical results and observations in the field. While above the geotextile, the movement looks much different which may be due to the restraint of the inclinometer pipe on the geotextile.
Keywords: *Embankment slope ; Deformation ; Soft soil models.*

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I. INTRODUCTION

Background

A common problem when a construction is built on soft soil is the low carrying capacity of the soil and the magnitude of the decline that occurs. One method that can be used to increase the carrying capacity is to use geotextiles. (Arsyad et al., 2020; Bergado et al., 2002; Chu et al., 2012; Hinchberger & Rowe, 2003; Mohan & Nair, 2005; Moraci et al., 2014; Panayides et al., 2012; Panigrahi & Pradhan, 2019; Rowe & Soderman, 1985; Siavoshnia et al., 2010).

To find out geotextile performance, it is generally done directly with a full-scale heap or one to one in the field. The field data is then analyzed with the help of finite element method (FEM) to obtain FEM parameters and further analysis with thehelp of computers.

Arsyad et al., (2020) conducted a full-scale heap test on soft land in Tapin Regency, South Kalimantan. There are twotypes of heaps with different materials and the number of different geotextile layers applied to the hoard. In the study, finite element analysis used the Plaxis program with mohr coulomb material model. The result was that the total heap was almost the same between FEM and measurements in the field. It's just that the second graphof the analysis of his behavior is not close. This may be due to the use of the Mohr Coulomb model is not suitable for soft soils with low over consolidation (<2) and is more suitable using soft soil models (Bergado et al., 2002).

This study aims to analyze the data of the results of research conducted (Arsyadet al., 2020) with numerical methods usinga model that is suitable for soft soil models, namely soft soil models. Because soft soil model parameters are rarely obtained from laboratory test results, the data must be analyzed first to get a paramater soft soil model. There are three descriptions that will be analyzed, namely decline, horizontal deformation, and slope safety factors.

Problem Formula

Based on the existing background, can be formulated problems that will be examined, among others:

1. Soil parameters of soft soil model suitable for heap model.
2. How to adjust between the results of field decline tests with FEM analysis with soft soil models.
3. How to adjust between the results of the horizontal deformation test of the field with the analysis with the soft soil model.
4. Slope safety factor of heap results of analysis with soft soil model.

Research objectives

The purpose of this study, among others:

1. Determine the parameters of the soft soilmodel for analysis with Plaxis
2. Analyze the suitability of the declinetest results in the field with FEManalysis with soft soil models.
3. Analyze the adjusting between the results of the horizontal deformation test of the field with the analysis with the soft soil model.
4. Analyze slope safety factors with soft soil model material.

II. LIBRARY REVIEW

Characteristics of Soft Soil

In geotechnical engineering the terms 'soft' and 'very soft' are specifically definedfor clay with strong shear as indicated in Table II.1 and as an indication of the strength of the clays the field identification procedures in Table II.2 provide some clues (Indonesian Geotechinical Materials and Construction Project, 2001).

Table II.1 Definition of Shear Strength Soft Clay (Proyek Indonesian *Geotechinical Material and construction*, 2001)

Consistency	Shear Strength (kN/m2)
Soft	12,5 - 25
Very Soft	< 12,5

Table II.2 Shear Strength of Unrained Slides of Soft Clay Soils (Proyek Indonesian *Geotechinical Material and construction*, 2001)

Consistency	Field Indications
Soft	It can be formed easily with the fingers.
Soft	Out between the fingers ifVery squeezed in fist

In geotechnical engineering, soil classification is distinguished based on its organic levels seen in Table II.3.

Table II.3 Types of Soil Based on Organic Levels (Proyek Indonesian *Geotechinical Material and construction*, 2001)

Land Group	Organic Content
Clay	< 25%
Organic Clay	25% - 75%
Peat	< 75%

Consolidation Theory

Consolidation is the process of decreasing the volume or decreasing of pore cavities from low-unsaturated soil due to loading. This process occurs if the low-pore saturated soil is encumbered, then the pressure of the soil pore waterincreases, as a result of which the water flows over the soil with low pore water pressure followed by soil subsidence. Due to low soil permeability, this processrequires time The consolidation process onthe ground can be observed with the installation of a piezometer. The magnitude of the decrease can be measured from the reference point set (Hardiyatmo, 2002).

Consolidated Test

One-dimensional consolidation tests in the laboratory are carried out with an Oedometer or consoleidometer. Schematic images of this tool are seen in Figure II.1. Examples of soils representing soil elements that are easily compressed in the soil layers investigated, are carefully inserted into the iron ring. The top andbottom of the test object are bounded by a porous stone. The P load is applied over the test object, and the drop is measured bya dial gauge.

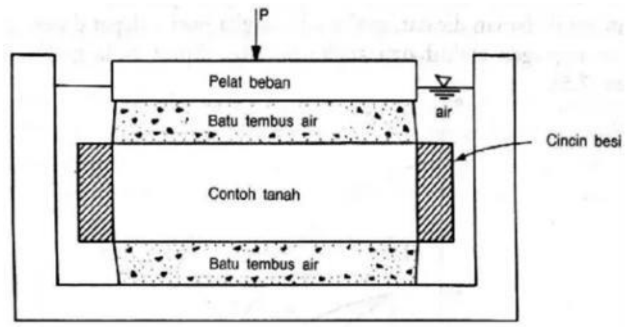


Fig. II.1 Schematic Consolidated Test Tool (Hardiyatmo,2002)

Data Achievement

Vermeer, (2002) suggests in the publication plaxis 2D empiricalrelationships in the following equations:

$\lambda^* \approx 0,3I_p$ and Equation (2.1)

$\lambda^* \approx 0,2(W_L - 0,1)$ Equation (2.2)In general, the ratio limit is as follows:

$\frac{\lambda^*}{\kappa^*} = 2,5 - 7$ Equation (2.3)

The soil layer beneath the ocean canbe considered fully saturated and thepresence of a water head can be ignored because the nature of the soil depends onlyon the effective voltage.

$\sigma' = \sigma - u$ Equation (2.4)Where the total voltage can be expressed as:

$\sigma = \rho_w g a + \rho_m g a$ Equation (2.5)

Where a is the height of the phreatic line above the seafloor, ρ_w is the mass of the water type, ρ_m is the total density of the soil layer. Pore water pressure can be expressed as follows:

$u = \rho_w g(a+b)$ Equation (2.6)

Where b is the depth below the seafloor to any voltage point P by entering equationamaan (2.5) and (2.6) the final function that states the effective voltage in terms of effective unit weight can be written in the following equations

$\sigma' = \rho_w g a + \rho_m g a - [\rho_w g(a+b)] = \rho' g b$ Equation (2.7)

Safety Factors on the Slopes

The slope safety factors requiredfor the stability analysis of the ground slopes are shown in Table II.3 based on consideration of the cost and consequences of slope failure to the degree of uncertainty of the analysis conditions. As for rock slopes, the required safety factors are shown in Table II.4 taking into account the permanent or temporary conditions of the rock slopes to be planned.

Table II.3 Safety Factor Value for Soil Slopes (SNI 8460:2017)

The costs and consequences of slope failure	Level of uncertainty analytical conditions	
	Low[a]	High[b]
The cost of repairs is comparable to the additional cost of designing more conservative slopes.	1,25	1,5
Repair costs outweigh the extra costs of designing more conservative slopes	1,5	2,0 or more

[a] The degree of uncertainty of analytical conditions is categorized as low, if geological conditions can be understood, soil conditions are uniform, soil investigations are consistent, complete and logical to conditions in the field.

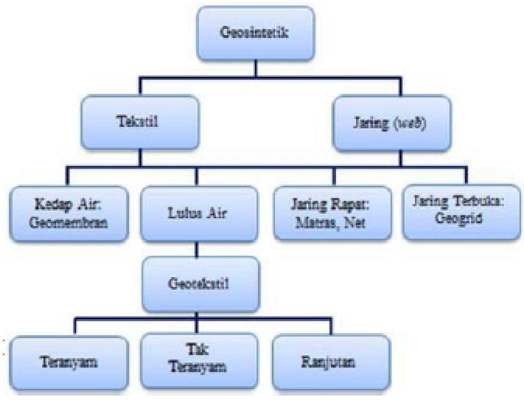
[b] The degree of uncertainty of analytical conditions is categorized as high, if geological conditions are very complex, soil conditions vary, and soil investigations are inconsistent and unreliable.

Table II.4 Safety Factor Value Recommendations For Rock Slopes (SNI 8460:2017)

Slope conditions Rock	Factor value recommendation security
Permanent condition	1,5
Temporary conditions	1,3

Classification of Geosynthetics

Fig. II.2 It shows a geosynthetic grouping that begins with a grouping based on physical form, the nature of water graduation and the manufacturing process. The classification is described briefly below (Bina Marga, 2009).



Geosynthetic Function as a Pile Strengthening

Basically, geosynthetic layers act as materials that strengthen or accelerate the process of soft soil consolidation. The first function is always intended to increase the security factor of the pile on a temporary basis . The trick is to speed up construction time or strengthen the slope of the slope (Bina Marga, 2009).

Mechanism of Pile Collapse in Soft Soil

Fig. II.3 The following notices the on

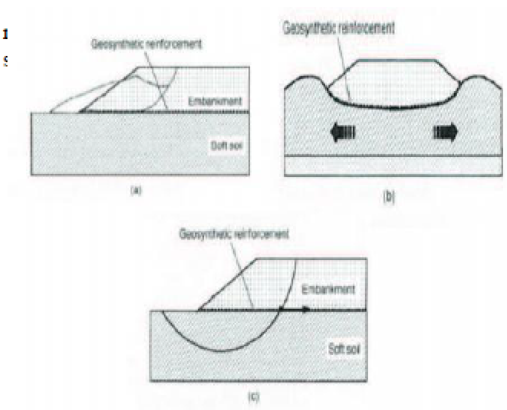


Fig. II.3 Mechanism of Pile Collapse onSoft Soil (Bina Marga, 2009)

Heap Stability Analysis

Before starting the analysis, first sketch the geometry of the pile complete with the dimensions of the pile that is high (H), length (L), lower width (B), width of the top / peak of the pile (W) and slope slope (b / H). For more details, you can refer to the example in Fig. II.4 (Bina Marga, 2009).

***Finite Element Method* (FEM) at Plaxis 2D**

Some steps that must be implemented before using Plaxis for the completion of aproject, namely:

1. Construction sketches equipped with specific coordinate points
2. Data such as soil layer data, groundwater level, load, and material data used.Permodelan Perilaku Tanah

***Mohr Coulomb* Model**

In mohr coulomb material modeling model (MC model) there are 7 parameters that need to be included, namely *young modulus* (E), *poisson's ratio*(v), sliding angle (φ), cohesi (c), , , kx andy (Gracia, 2018).

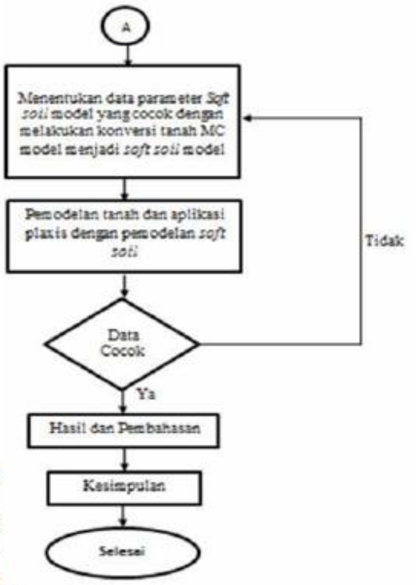
***Cam Clay* Model (*Soft Soil* Model)** γ γ_{unsat}

In soft soil material modeling the model requires parameters to be included, namely the compression index. (λ), index expansion (k), cohesi (c), sliding angle(φ), and dilational angle (Gracia, 2018).

RESEARCH METHODS

Procedures & Methods of Implementation

Fig. III.1 *Flow-Chart*



Heap Mode

There materials ar layers applie Fig. III.3 (A:

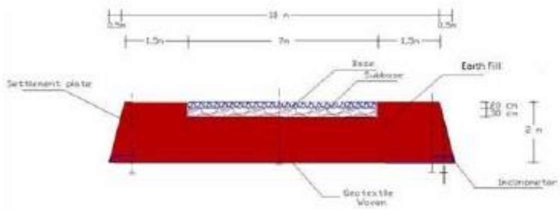


Fig. III.3 Embankment with Earth fill (Arsyad et al., 2020)

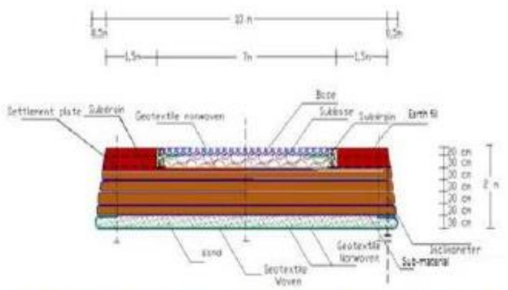


Fig. III.4 Embankment with Sub-material(Arsyad et al., 2020)

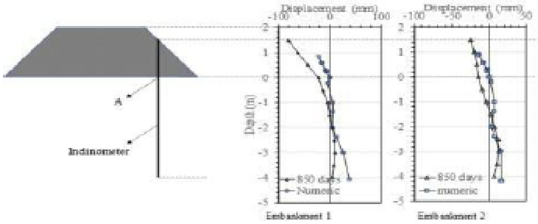


Fig. III.6 Horizontal Displacement Results with Inclinometer Measurement (Arsyad etal., 2020)

RESULTS AND DISCUSSION

Soil Data

The results of the research obtained based on laboratory testing Soil Mechanics University of Lambung Mangkurat location point is in the Regency Tapin, Overseas City, South Kalimantan Province. Land data used is HB 2 below ata depth of 0.5 m – 7.5 m.

Validation of Consolidation Test Results in the Laboratory

Soil data taken from the field was tested in the laboratory fo get the parameters used in the Plaxis model. Validation especially for data related to the consolidation test. The parameters obtained from IV.1 Relationship between log p and Pore Rate (Laboratory Testing e-log relationship curve p. Figure IV.1 shows an example of test results consolidation at a depth of 0.5-1.0 m. Where cc is the slopeof the unloading curve (line b).

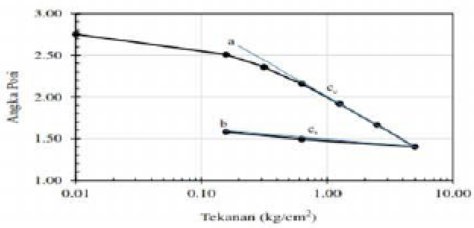


Figure IV.1 Relationship between log p and Pore Rate (Laboratory Testing Soil Mechanics, University of LambungMangkurat)

One of the important parameters in soilcompression analysis is determination of preconsolidation pressure. Figure IV.2 shows the determination preconsolidation pressure suggested by Cassagrande (Das, 2008). The graph shows that the preconsolidation pressure is 0.25 kg/cm2 or around 25 kPa

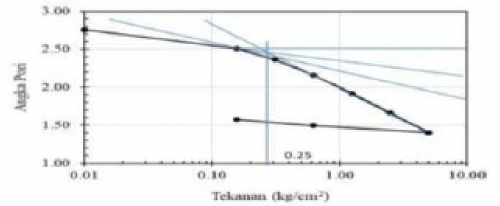


Figure IV.2 Determination of Preconsolidation Pressure by the Cassagrande Method

The parameters mentioned above can not be directly used for perform an analysis using the soft soil model in Plaxis. Therefore In addition, the soil parameters for the soft soil model are determined from the data source and then validated using Plaxis. Soft soil parameters determined from consolidated data are ÿ and k. Where the two parameters are obtained from the slope ln p relationship curve with e as shown in Figure IV.3.

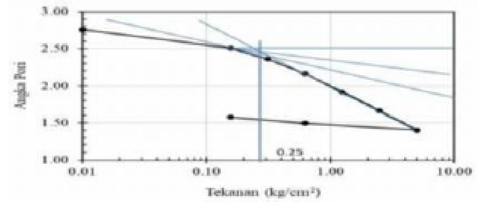


Figure IV.3 Determination of Parametersand

The results of the analysis of the values of ÿ, k, and preconsolidation pressure are summarized in Table IV.3. Seen in the table, the amount of Po (pressure over burden) or the pressure caused by the pressure of the soil above it is getting higher with the deeper the sample (z). The sample is also considered submerged in water so that the unit weight of the soil used is the effective unit weight (') i.e. (sat- w). The table also summarizes data and k with magnitude between 0.071-0.113 and 0.010-0.015 respectively. While PC data obtained from the results of the analysis using the Cassagrande method where The value of Pc is greater than Poon the surface soil. This can caused bylowering of the groundwater level increasein the effective stress over burden of the soil. The data obtained in Table IV.2 is validated with input it into Plaxis and compare the results of laboratory tests withPlaxis analysis results. The axisymmetric model of the consolidation test was carriedout with Plaxis as shown in Figure IV.4. Samples with a diameter of 6.4 cm were applied to 3.2 cm. The sample is flankedby two porous rocks which are stiff and porous. At the top, given the same pressurethat was applied to the sample at laboratories, starting from 15.6, 31.3, 62.51, 125, 250, 500 kN/m2 and followed by unloading 61.51 and 15.6 kN/m2 each for one day.

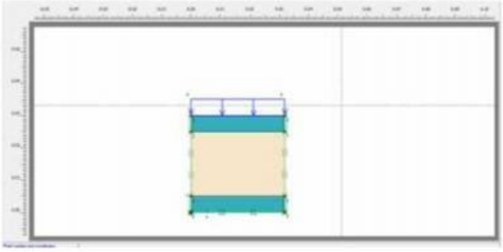


Figure IV.4 Consolidation Test Model with Numerical Methods

The data is then input as shown in Table IV.3 with Enter material sets.

Table IV.3 Parameter Results of Soft SoilModel Analysis

No	Kedalaman (m)	γ (kN/m³)	Po' (kN/m²)	λ	k	Pc (kN/m²)
1	0-1	14,62	2.31	0.099	0.013	25
2	1-2	15,50	8.25	0.071	0.010	15
3	2-3	14,13	10.325	0.090	0.009	25
4	3-6	14,81	21.645	0.076	0.013	30
5	6-7	14,32	28.08	0.087	0.017	25
6	7-8	13,83	28.725	0.113	0.015	25
7	8-9	13,83	32.555	0.113	0.015	25
8	9-10,5	13,83	37.3425	0.113	0.015	25

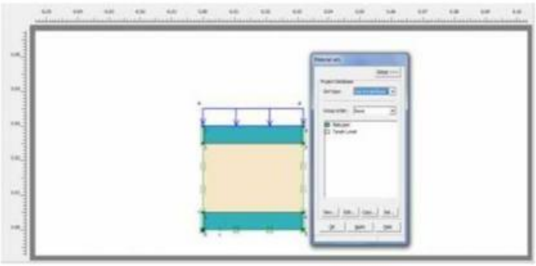


Figure IV.5 Input Material Properties

The difference in input parameters between the Mohr-Coulomb model and soft soil is POP (pre-overburden pressure) data is required. The POP size is input on initial condition process in Ko condition. Pc parameters (POP) are inputted with select the layer to be filled as shown in Figure IV.7 Step then according to anothermodel procedure followed by the process calculations.

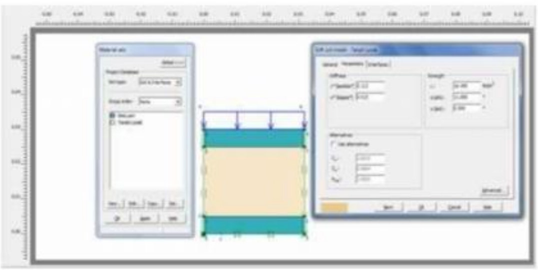


Figure IV.6 Input Parameters of the softsoil model

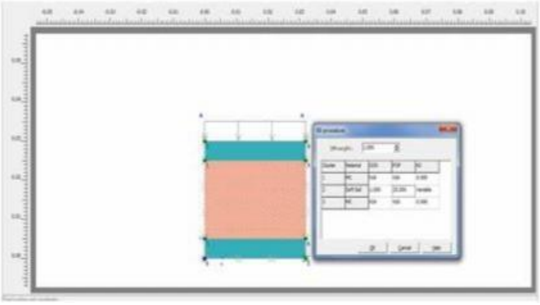


Figure IV.7 Input Pre-OverburdenPressure (POP)

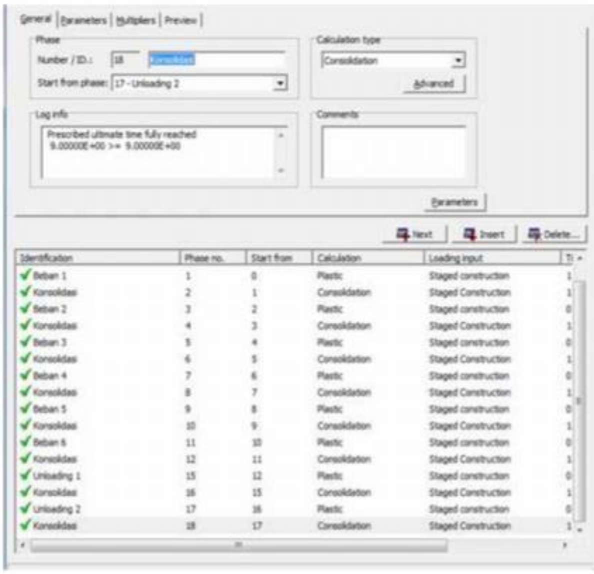


Figure IV.8 Process of Loading Steps

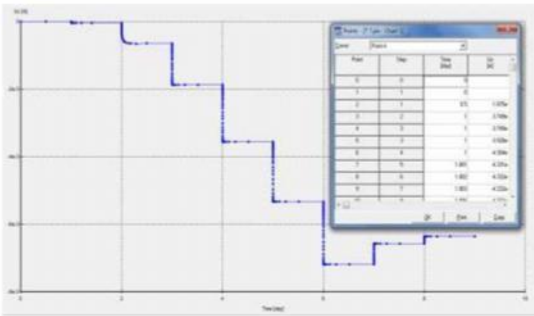


Figure IV.9 Derivation Data for eachLoading and Unloading Step in the Test Consolidation

Data from numerical analysis results are then plotted onto a graph ln p and e relationship as shown in Figure IV.10 to Figure IV.15. Seen in the figure, the results of the analysis using numerical approach to the results obtained in the consolidation test in the laboratory. This shows the suitability of the soft soil model soil data obtained against the test data laboratory and can be used for fieldembankment analysis carried out using the data in Table IV.3

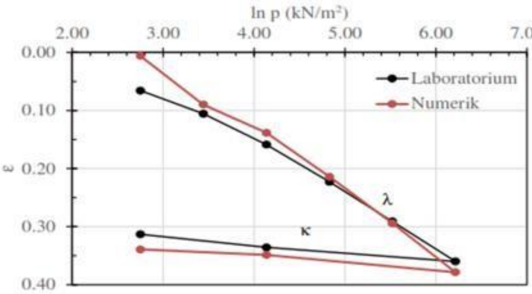


Figure IV.10 Relationship ln p and eSample Depth 0.5-1.0 m

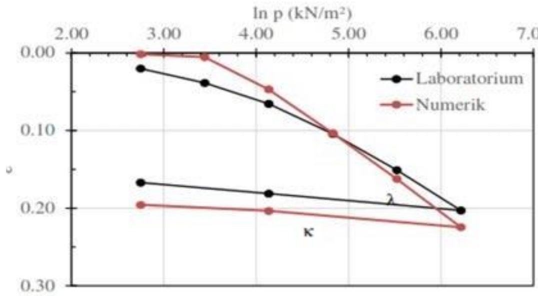


Figure IV.11 Relationship ln p and esample depth 1.5-2.0 m

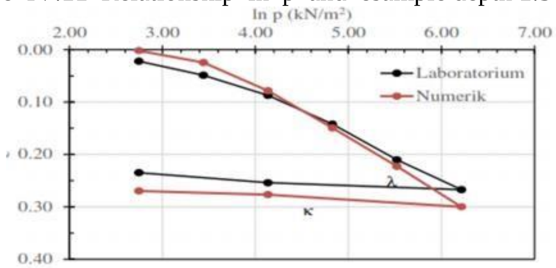


Figure IV.12 Relationship ln p and esample depth 2.5-3.0 m

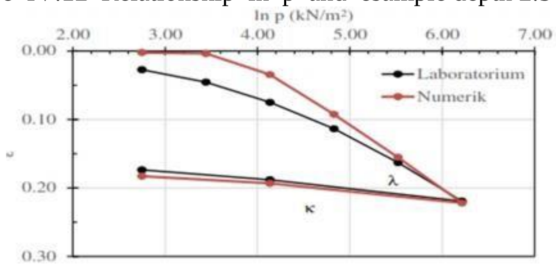


Figure IV.13 Relationship ln p and esample depth 3.0-3.5 m

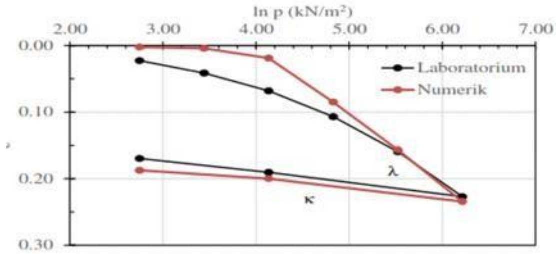


Figure IV.14 Relationship ln p and esample depth 6.0-6.5 m

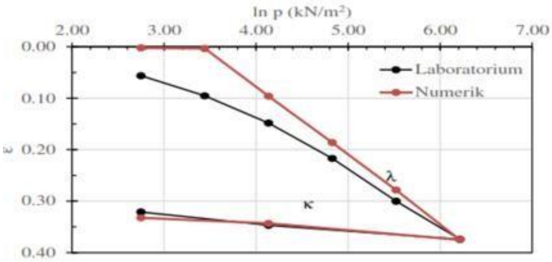


Figure IV.15 Relationship ln p and esample depth 7.0-7.5 m

Numerical Analysis of Stockpiles withthe Soft Soil Model
Decline

Several modeling steps using the Plaxisprogram for settlement of decline, namely:

1. Creating a geometric model

The consolidation test model is processed with the axisymmetric model,model designed consolidation ½ D of the original diameter. For subsoil made accordingly with soil data obtained in the field and in the laboratory. The load given in the consolidation test is appliedevenly in units of kN/m2 namely 15.6; 31.3; 62.51; 125; 250; and 500 kN/m2 .

Followed by unloading 61.51 and 15.6 kN/m2 each for one day. Images can be viewed in Figure IV.4.

2. Input material properties

The material model used in this thesis is the Soft Soil model, on In this model, the parameters used can be seen in Table IV.1. Input example Material data can be seen in Figure IV.5 andFigure IV.6. If you have inputting material on the geometry model thenthe next step is generate mesh, where the mesh will include all points and lines which is in the geometry that has been arranged, so that all layers of soil and load is taken into account.

3. Initial conditions

At this stage the pore water pressure and the initial effective stress will also participate calculated. In the pore water pressure section, it is sufficient to enter the depthgroundwater level and for the initial effective stress POP data (pre-overburden pressure) is inputted to K0- procedure. Pc (POP) parameters are input by selecting layer to be filled as shown in Figure IV.7.

4. Calculations

At this stage, the required loading and consolidation will be inputted for thesis purposes. For loading and unloading usecalculation type Plastic, and for consolidation using calculation type Consolidation (Figure IV.8). After doing the calculation and produce checklist is green on load and consolidation, then the results of the reduction can be obtainedfrom the Output and Curvesfeatures. In Figure IV.9 you can seethe results calculation from the Curves feature.

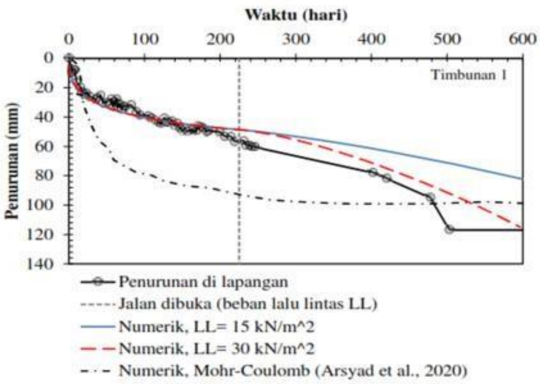


Figure IV.16 Settlement due to Embankment 1: Field Observation Results and 48 Numerical Analysis

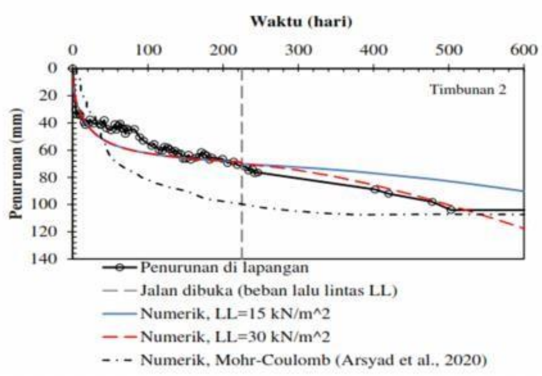


Figure IV.17 Settlement due to Embankment 2: Field Observation Results and Numerical Analysis

In Figure IV.16 and Figure IV.17, it can beseen that the magnitude of the final decline

Both models, both Mohr-Coulomb and soft soil, produce significant decreases Thesame. It's just that, the soft soil model is closer to the decline behavior in throughout the descent process. One of the advantages of the soft soil model is that it can application of preconsolidation pressure so that when the load is applied smaller than the pre-consolidation pressure, the decrease that occurs is smaller When the load exceeds the preconsolidation pressure, settlement begins looks bigger.

Horizontal Displacement

To obtain horizontal movement data, deformation output is used as shown inFigure IV.18 Data retrieved using functions the cut (A-A') corresponds to theposition of the inclinometer in the deepfield this case is located on a slope as shown in Figure IV.18.

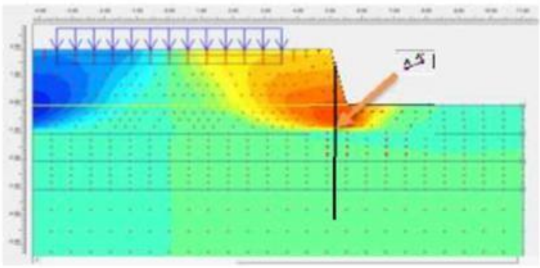


Figure IV.18 Output Horizontal Movementof Plaxis

From this process, a graph is obtained as shown in Figure IV.19 the detailed datacan be retrieved by using the table functionas shown in Figure IV.20 this data can be copied and moved to other applications forgraphing and comparison with inclinometer data.

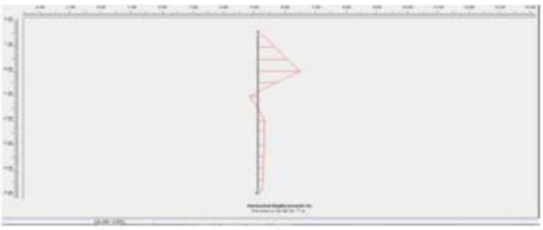


Figure IV.19 A-A' Horizontal DeformationSection Graph

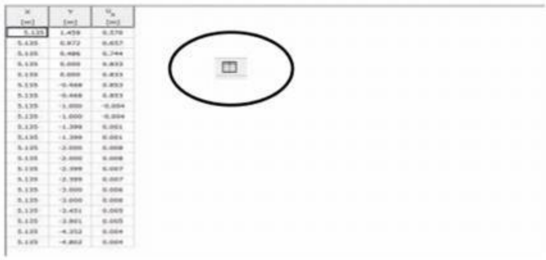


Figure IV.20 Table of Soil Horizontal Deformation Data.

Numerical analysis is shown in Figure IV.21 and Figure IV.22. Both pictures shows the similarity of horizontal movement behavior between measurement results in the field and numeric at the bottom of the heap. Meanwhile, there are differences in the upper part is a smaller horizontal displacement value on the result field measurements compared with numerical results, this is due Due to data limitations, the data collection was simplified. In addition, it is known that the horizontal displacement is getting bigger and negative until towards the subgradeunder the foot of the embankment, this canbe due to influence Passive force on the subgrade due to embankments pushing the subgrade towards in. The occurrence of passive force on the embankment is influenced by time consolidation longenough to allow time for the soil to bepiled up give it a passive style.

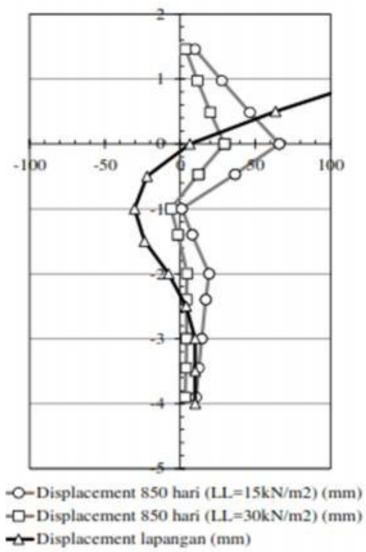


Figure IV.21 Horizontal Displacement on Embankment 1

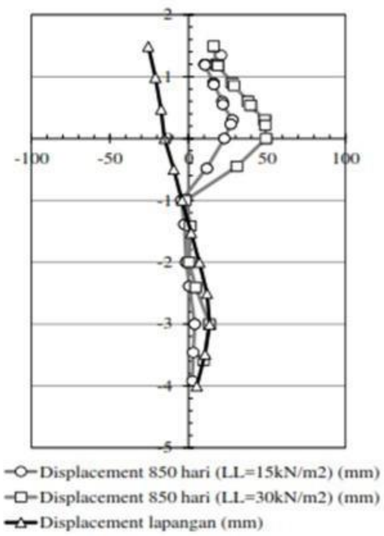


Figure IV.22 Horizontal Displacement onEmbankment 2

III. CLOSING

Conclusion

Based on the results and discussion on Numerical Analysis research EmbankmentDeformation on Soft Soil with Soft Soil Model, then get concluded as follows:

1. Numerical analysis in this study can be used in determining parameters of the soft soil model by conducting test validation consolidation in the laboratory, namely the parameters obtained from the test consolidation like cc and cs of the e-log p relationship curve. Analysis results using numerical with soft soil models close to the resultsobtained on consolidation tests in thelaboratory in the ln p and e relationship graphs.
2. . In the vertical displacement of the results in the field, the decline that occurs is increasingly increases with increasing pile load. Even though it earns almost the same final settlement, the soft soil model is closer to settlement in the field throughout the decline process time compared to the model Mohr Coulomb. One of the advantages of the soft soil model is its presence pre consolidation pressure.
3. Even though they look different in magnitude, the horizontal displacement is below geotextiles appear to produce similar behavior between the numerical results and the field observations. Meanwhile, on top of the geotextile, themovement is visible much different which may be due to the clamping ofthe inclinometer tube on geotextile.

Suggestions

As for suggestions on the research of Numerical Analysis of Embankment Deformation in On Soft Soil with Soft SoilModel, among others:

1. It is necessary to pay attention to the placement of the inclinometer pipe during field observations especially at the foot of the heap.
2. . It is necessary to carry out further research regarding the effect of embankment height against lateral movement and consolidation.

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