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Modeling Studi of Flexural Pavement on Soft Soil Using Plaxis 2d Software

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Abstract: Road construction on soft soils presents significant technical challenges due to the natural properties of the soil such as low bearing capacity, high compressibility and limited shear strength. This study aims to analyze the response of soft clay soil to vertical loads under varying water infiltration conditions using numerical modeling with PLAXIS 2D software. Modeling was performed at a laboratory scale of 1:20 with a soft soil thickness of 57 cm and a 3 cm thick flexible pavement layer. Simulations were conducted under three water addition scenarios: 19%, 36%, and 53%, each with a waiting period of 3 days before a load of 20.4 kg was applied. The simulation results showed that increasing the water content significantly affected the soil deformation (displacement), with vertical settlement values of 0.06128 mm, 0.1342 mm, and 1.039 mm for the 19%, 36%, and 53% scenarios, respectively. Meanwhile, the effective stress values also experienced a limited increase, namely 10.17 kN/m², 11.39 kN/m², and 11.41 kN/m². This finding indicates that although the effective stress increases numerically, saturated conditions due to high infiltration can actually decrease the overall stability of the soil.

Keywords: *PLAXIS 2D, soft clay, effective stress, displacement, water infiltration, flexible pavement.*

1. Introduction

The development of reliable transportation infrastructure is essential in supporting national economic growth [1]. As the need for road networks increases due to population and industrial growth, building roads on various types of soils, including soft soils, is an unavoidable challenge.

Soft soils such as clays and peat cover more than 10% of Indonesia's land area or about 20 million hectares, widely distributed in various coastal areas such as the North Coast of Java, East Coast of Sumatra, and Kalimantan [2]. The main characteristics of soft soils are low shear strength, high compressibility, and limited bearing capacity, which make them unstable as a base for road construction.

Clay soils, in particular, have extreme shrinkage-deflation properties depending on moisture content. When wet, the soil expands and pushes the pavement structure upwards, while when dry, the soil shrinks and causes settlement or cracks in the pavement [3][4][5]. Its low permeability also leads to the accumulation of water under the pavement layer, increasing the risk of damage such as potholes and structural failure. In extreme climates, freeze and thaw cycles exacerbate this damage [6]. Heavy rainfall is also a major factor in soft soil slope avalanches [7].

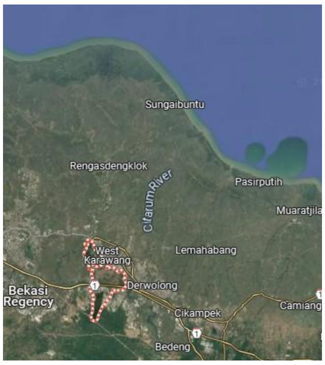
A real case occurred in Karawang Regency, especially after the opening of Karawang New Industry City by China Fortune Land Development in 2019. Rapid industrial growth has put significant pressure on the road network, especially on the Tempuran-Cilamaya section. The recurring failures are thought to be caused by inconsistent material selection and improper geomembrane installation, as well as an inaccurate understanding of soil-pavement interaction.

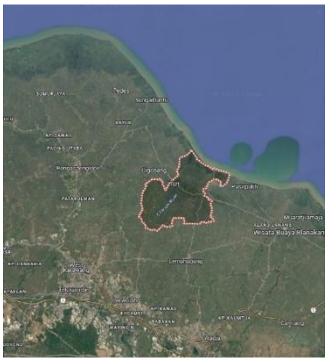
These repeated failures suggest that previous repair approaches have not been effective enough, most likely due to a lack of technical understanding of the interaction behavior between flexible pavements and soft soils. Therefore, there is a need for in-depth research into the response of flexible pavements to variations in moisture content and repetitive loading, particularly in projects that are built in the dry season and start operating in the rainy season. This research is expected to provide constructive and sustainable solutions to the problem of road failures on soft soils.

2. Research Method

2.1. Research location

The research was conducted in Karawang Regency, on the distribution route between Telukjambe Barat and Tempuran Subdistricts, which connects the Karawang New Industry City (KNIC) industrial area in Wanajaya with the Cilamaya Port development site. This route is projected to be the main route for the distribution of industrial goods. Soil sampling locations can be seen in Figures 1.





Telukjambe Sub-district Tempuran Sub-district

Fig. 1. Soft Clay Soil Research Site

2.2. Models Field Data Collection Technique

Soft clay soil sampling was conducted in Karawang Regency using two methods, namely disturbed and undisturbed samples according to ASTM D1587-67 standards. Undisturbed samples were used to test soil physical properties such as moisture content (ASTM D2216), specific gravity (ASTM D854), and density and volume weight (ASTM D193). The disturbed samples were used as subgrade material in laboratory modeling.

2.3. Plaxis Analysis

Utilizing Flexural pavement response was analyzed through 1:20 scale laboratory modeling, as an alternative to direct field testing. In this simulation, the standard vehicle load of 8.16 tons with a wheel contact area of 50 cm was adjusted to 20.4 kg and 2.5 cm in the scale model. The pavement width was converted to 40 cm (from 800 cm for two lanes), with the pavement thickness consisting of 1 cm asphalt, 2 cm base, and 3 cm subbase.

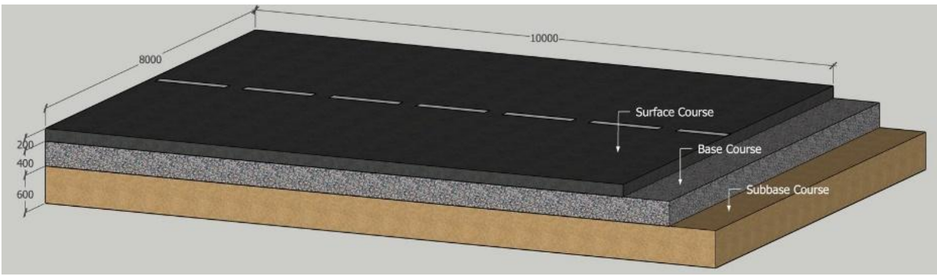


Fig. 2. Flexural Pavement

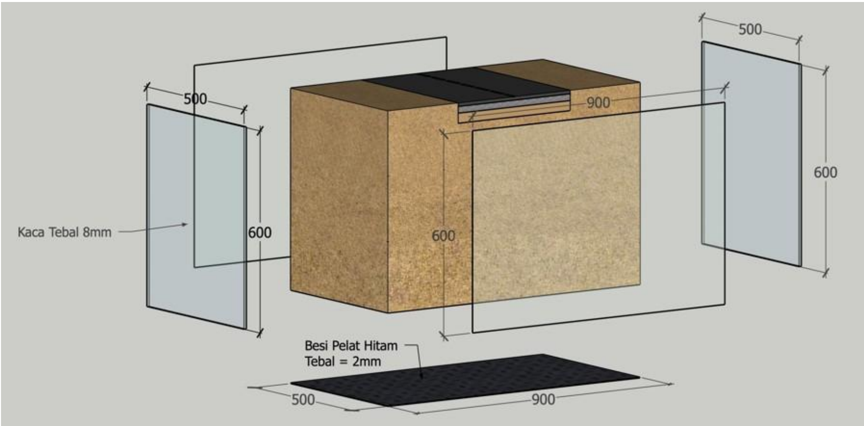


Fig. 3. Sample Dimensions

Modeling was performed using AutoCAD and Plaxis software to assist in stress and deformation analysis of the soil due to variations in moisture content. Tests were conducted with gradual addition of moisture content: 19%, 36%, and 53%, with a three-day break between each stage. Prior to the load test, calibration of the loading device was carried out to ensure that the actual pressure of 20.4 kg could be achieved precisely.

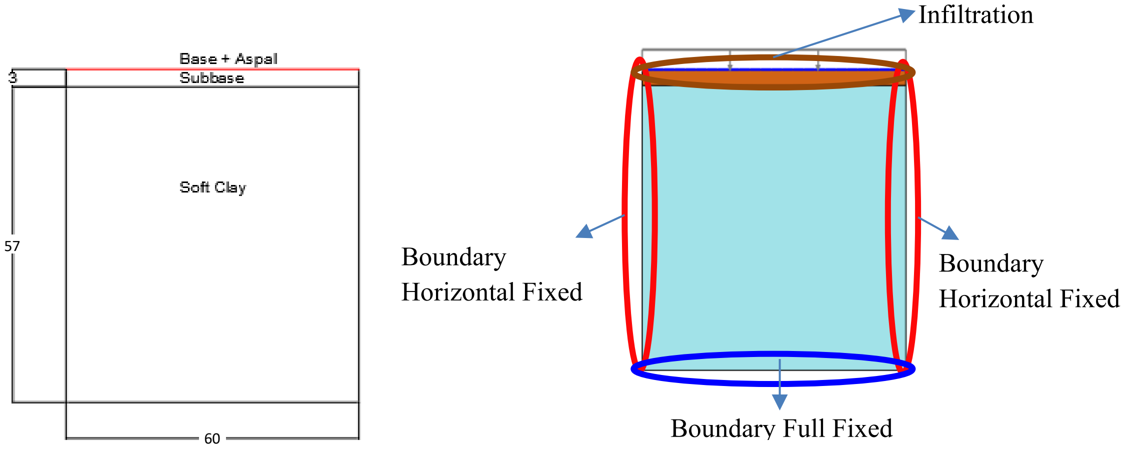
3. Result and Discussion

3.1 Stages of Modeling and Simulation of Clay with Water Addition

Before numerical modeling using PLAXIS software, the first step is to create a geometric plan drawing using AutoCAD. The purpose of this stage is to ensure accurate model dimensions and facilitate the geometry input process into PLAXIS. The left figure shows the initial design of the model with horizontal dimensions of 50 cm × 60 cm, consisting of a 57 cm thick soft clay layer and a 3 cm thick flexible pavement layer on top. After the geometric design was completed, the AutoCAD modeling files were imported and utilized in the numerical modeling process in PLAXIS 2D, as shown in the figure on the right.

In PLAXIS modeling, several boundary conditions were used to reflect the field conditions more realistically. A horizontal fixity boundary is applied on the left and right sides of the model to prevent lateral movement of the soil, while a full fixity boundary is applied at the bottom of the model to prevent soil movement in all directions (both vertical and horizontal), so that the lower foundation is assumed to be an undisturbed layer (bedrock or very stiff layer).

To simulate the addition of water to the soil surface, an infiltration method approach is used, where water flow is assumed to enter from the top and move vertically downward. This infiltration process plays an important role in analyzing changes in pore water pressure and effective stress in the soil, and its effect on settlement and deformation of the soil mass. At each stage of water addition, a delay period of 3 days was applied to allow gradual infiltration and redistribution of pore water pressure. After that, the consolidation stage was carried out by applying a vertical load of 20.4 kg, aiming to evaluate the soil consolidation response due to the additional load.



Autocad Modeling

Plaxis Modeling

Fig. 4. Stages of Modeling

3.2 Displacemnt

The vertical and horizontal deformations of the soil that occur during the consolidation process due to water addition and loading. Simulations were conducted in three different scenarios based on the percentage of water addition, namely 19%, 36%, and 53%, with each scenario accompanied by a waiting time of 3 days before a vertical load of 20.4 kg was applied. The purpose of this analysis is to understand the effect of increasing water content on the amount of soil deformation, so that the relationship between the degree of soil saturation and settlement potential can be identified.

1. Displacement at 19% Water Addition
   At the initial stage of the simulation with 19% water addition, the soil infiltrated from the surface vertically downward, affecting the distribution of pore water pressure and effective stress in the soft clay layer. The modeling results showed that a vertical displacement of 0.06128 mm occurred, with the deformation being relatively small and still within the safe threshold for lightweight structures, can be seen in figure 5.

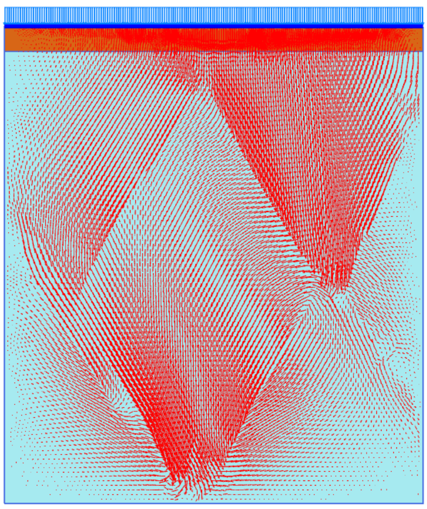


Fig. 5. Displacement at 19% Water Addition

2. Displacement at 36% Water Addition
   In the second scenario, water infiltration was increased to 36%, which caused a more significant increase in pore water pressure. The simulation results show a vertical displacement of 0.1342 mm, which is more than double that of the 19% condition. This decrease indicates a decrease in soil stiffness, with wider and deeper deformation zones, can be seen in figure 6.

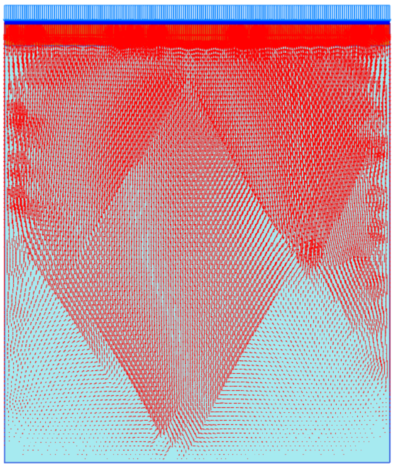


Fig. 6. Displacement at 36% Water Addition

3. Displacement at 53% Water Addition
   The maximum water addition of 53% has the most significant impact on soil deformation behavior. In this scenario, infiltration causes the soil to approach a fully saturated condition, The modeling results show a vertical displacement of 1.039 mm, which is very large compared to the previous two scenarios. This value reflects extreme settlement, as can be seen in Fig. 7.

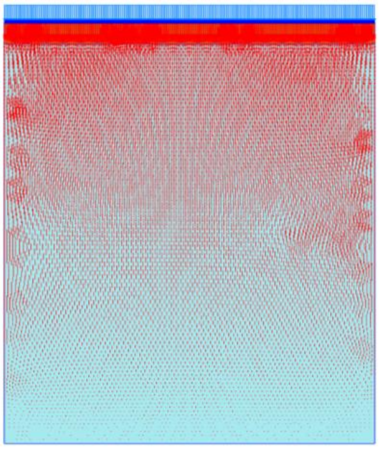


Fig. 7. Displacement at 53% Water Addition

Based on the results of numerical modeling using PLAXIS 2D for the three water addition scenarios, displacement values were obtained, indicating an increase in soil deformation as the water content in the soft clay layer increases. A recapitulation of the displacement results of the three scenarios is shown in Table 1 below:

Table 1. Recapitulation of Displacement against Water Addition

No	Water Addition(%)	Displacement (mm)
1	19	0,06128
2	36	0,1342
3	53	1,039

3.3 Effective Stress

In the simulation using PLAXIS 2D, three infiltration scenarios with variations in water addition of 19%, 36%, and 53% were conducted, aiming to determine how increasing the water content affects the distribution and effective stress values in soft clay layers.

1. Effective Stress at 19% Water Addition
   At 19% water addition, the resulting effective stress value was 10.17 kN/m². although there was a slight increase in pore water pressure due to initial infiltration. The distribution of effective stress is still relatively even, indicating that the soil condition is still stable and has not shown signs of collapse or excessive deformation. can be seen in figure 8.

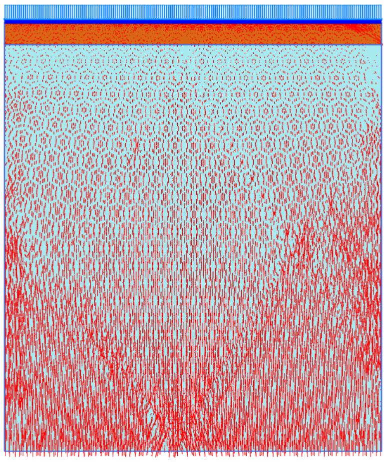


Fig. 8. Effective Stress at 19% Water Addition

2. Effective Stress at 36% Water Addition
   When infiltration increased to 36%, the effective stress value also increased slightly to 11.39 kN/m². This shows that even though the water content increased, the sufficient waiting time (3 days) provided an opportunity for the water to diffuse into the soil pores and provide better stress redistribution.

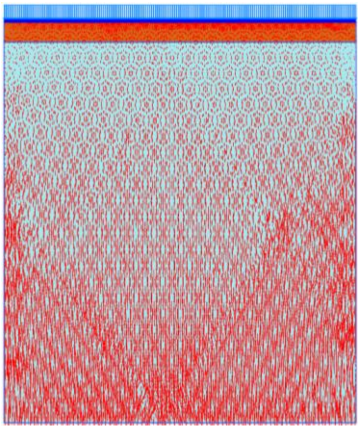


Fig. 9. Effective Stress at 36% Water Addition

3. Effective Stress at 53% Water Addition
   In the maximum infiltration scenario, i.e. 53% water addition, the effective stress reached 11.41 kN/m². This value is only slightly higher than the 36% scenario, but this does not necessarily indicate an increase in soil strength. On the contrary, too high an increase in water content close to saturated conditions can lead to uneven stress redistribution, as well as an increased risk of deformation and potential local instability.

Table 2. Recapitulation of Effective Stress Water Addition

No	Water Addition(%)	Effective Stress (kN/m^2)
1	19	10,17
2	36	11,39
3	53	11,41

From the above results, it can be seen that although the effective stress value increases with the addition of water, the increase in effective stress in high water content conditions indicates that the soil becomes weaker because the soil will be more saturated, it can also be seen in the increase in the graph, where the relationship of effective stress to time is higher.

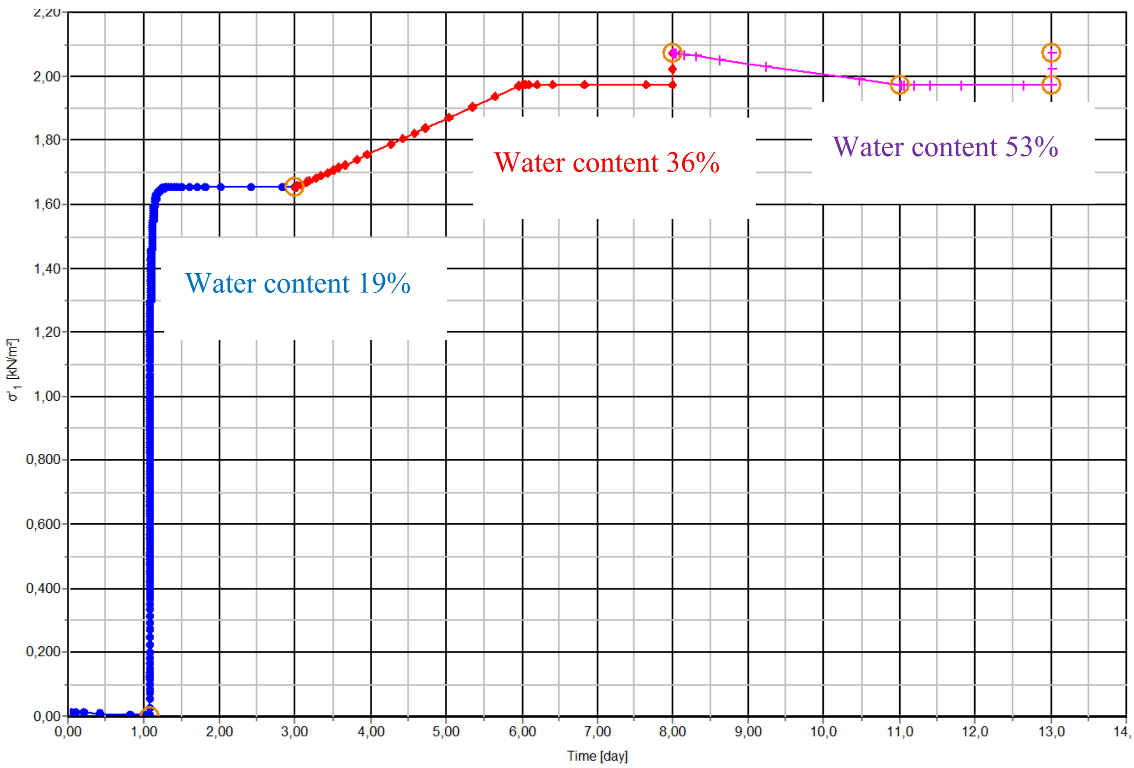


Fig. 10. relationship of effective stress to time

4. Conclusions

Based on the results of numerical modeling using PLAXIS 2D software of flexural pavement structures on soft clay, it can be concluded that increasing the moisture content significantly affects the deformation and stability of the soil. The vertical displacement increases drastically as the moisture content increases, from 0.06128 mm at 19% infiltration to 1.039 mm at 53% infiltration, indicating that the soil becomes increasingly soft and prone to settlement. Meanwhile, the effective stress also experienced a limited increase, from 10.17 kN/m² to 11.41 kN/m², but did not reflect an overall increase in soil strength. On the contrary, the high moisture content near saturated conditions led to uneven stress redistribution and increased the risk of deformation and potential local instability. These results confirm that the higher the water addition, the greater the effective stress, indicating that the soil loses strength.

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