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# CASE STUDY OF REPLACEMENT METHOD ON ROAD EMBANKMENT OVER A DEEP SOFT SOIL

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***ABSTRACT***

*The remove-and-replace method is one method used to overcome soft soil problems. This research aims to determine the effect of replacement depth on the amount of settlement and the value of the safety factor of the embankment. The research was carried out by comparing the initial conditions with replacement depths of 0.5, 1, 1.5, and 2 meters. Analysis was carried out using the finite element method with the help of PLAXIS 2D software. From the analysis results, it was found that the largest decrease in settlement value for 2-meter replacement was 22.7% for DB-2 and 16.1% for DB-13. The 2-meter replacement also results in increased safety factor values for the DB-2 and DB-13.*

***Keywords:*** *remove and replace, settlement, factor of safety, finite element method, road embankment*

## 1. INTRODUCTION

Construction development in Indonesia is starting to develop a lot, one of which is in the industrial sector. Currently, many industrial areas are being developed around coastal areas because the location has direct access to the port. However, unfortunately, many coastal areas, especially on the north coast of Java, have very soft soil conditions. The soft soil in this coastal area is because the coastal area is mostly an area of sediment. The soft soil problem in this area requires improvement so that construction can be done properly.

The most classic method for dealing with soft soil problems is the remove-and-replace method. This method is widely used because the method is quite simple, by replacing bad material with better material. However, in deep soft soil conditions, it is certainly not possible to replace all materials considering the costs that will be required will be very high. The literature states that generally material replacement is quite effective up to a depth of 4 meters. This type of soil improvement can increase the bearing capacity of the soil and reduce the thickness of compressible soil but must carry out correct design analysis (Badan Standardisasi Nasional, 2017).

Recently, numerical methods have gained popularity for predicting settlements due to their application on non-homogeneous anisotropic elastic materials using finite elements. These methods can handle complex nonlinear stress-strain behaviors. Engineers often place confidence in finite element findings because of their strength and flexibility, but it's essential to recognize that inherent idealizations and assumptions exist within this approach. High-quality data input significantly impacts the accuracy of predictions, emphasizing the importance of evaluating experimental constraints to ensure reliable data for numerical analysis.

In this research, an analysis was carried out regarding the influence of the depth of soil replacement on the settlement value and slope safety factors that occur..

## 2. ANALYSIS AND DISCUSSION

### Finite Element Methode

Contemporary engineers and researchers commonly employ Finite Element Method (FEM) for embankment design. FEM is a numerical technique used to analyze and design various engineering problems, both practical and research-oriented. It proves particularly valuable for complex geometries, diverse loadings, and material properties where analytical solutions are elusive. Within FEM, three types of finite elements are prevalent: one-dimensional (line), two-dimensional (plane), and three-dimensional (solid). Among these, the two-dimensional approach is favored by many researchers when studying embankment stability. Noteworthy software tools for geotechnical analysis, testing, and design include Plaxis (E.M. Da Silva, 2017), Abaqus (Y. Zhuang, 2016), and Fast Lagrangian Analysis of Continua (FLAC) (Parsa-Pajouh A, 2014). While FLAC is less commonly used for road embankment studies, Plaxis remains popular due to its user-friendly soil modeling capabilities, allowing engineers to address simple problems within complex strata. Furthermore, Plaxis can handle a wide range of geotechnical engineering scenarios, including pile design, ground foundation, retaining walls, slope stability, and dam analysis.

### Soil Profile Models

Based on the results of the soil tests that have been carried out, it is known that the condition of the soil layer in this area is soft soil with a thickness of 14 m from the ground surface as shown in Figure 1 and Figure 2.

From the soil test results, it was found that for zone I the top layer to a depth of 8.00 m is soil containing sand, silt, and clay with the dominant material being clay to silt (CLAY to SILT) and has a very soft to soft consistency. The depth of hard soil obtained by the Cone Penetration test is between -17.60 m to -27.40 m based on the existing elevation. For zone II, the soil test results showed that the top layer to a depth of 10.00 m is soil containing sand, silt, and clay with a dominant material of clay (CLAY) and has a very soft-to-soft consistency. The depth of hard soil obtained by Cone Penetration Test data is between -16.60 m to -27.00 m based on existing elevation.

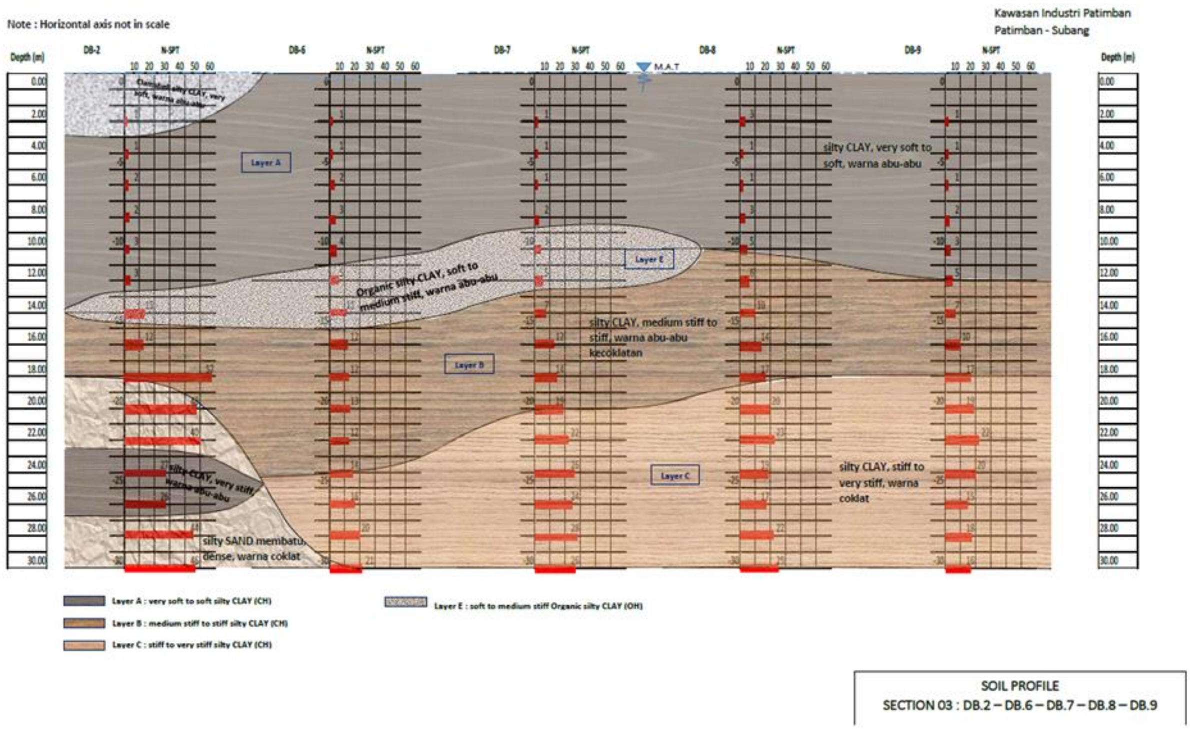


Figure 1. Soil profile section 03

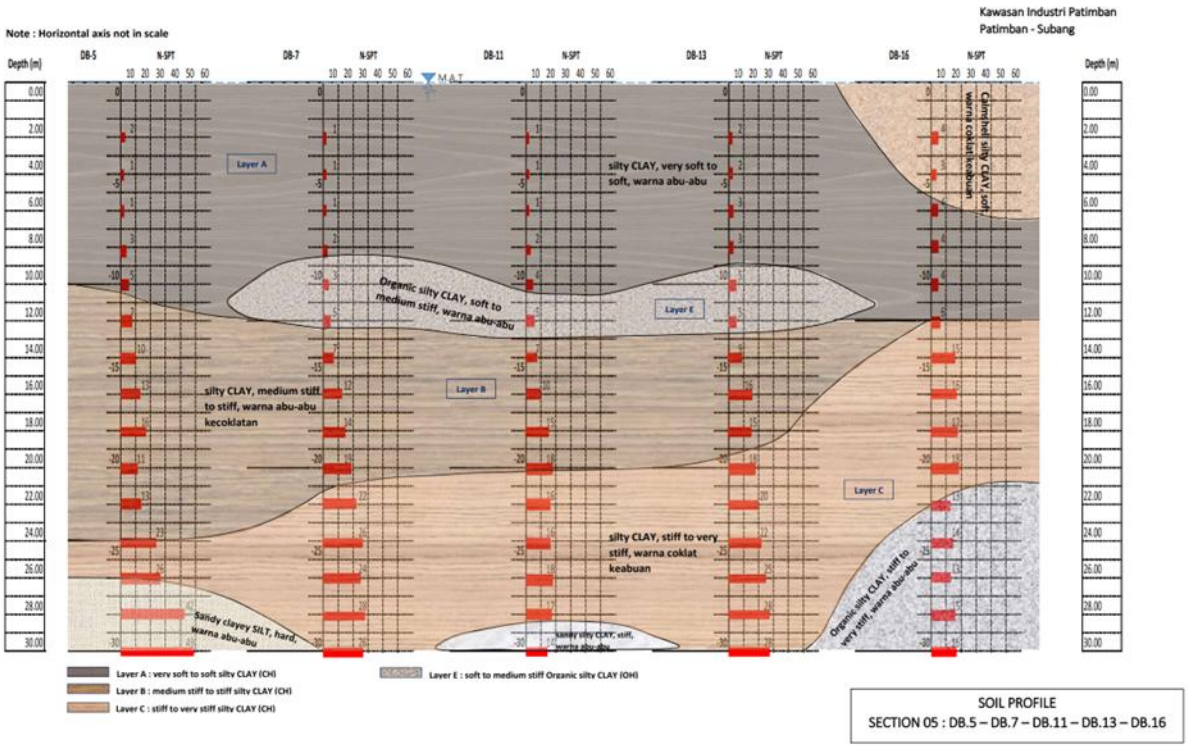


Figure 2. Soil Profile Section 5

## Geotechnical Parameter

From the results of the soil report, it is stated that there are 2 zones in this area, namely zone 1 and zone 2. In this research, 2 drill hole points were taken, namely DB2 and DB 13 to represent each of these zones. The soil parameters used in this analysis were obtained from the soil test laboratory report and the correlation of the N-SPT values from the test results. Soil parameters used in this analysis are presented in Table 1 and Table 2.

For embankment materials and replacement materials, parameters from previous studies (Hamonangan & Syahputra, 2023) are used which are shown in Table 3.

## 3. DESIGN CRITERIA

### Load

According to Panduan Geoteknik 4 (Departemen Permukiman dan Prasarana Wilayah, 2002), load traffic for arterial roads with primary road function is 15 kN/m2.

### Settlement

Settlement limit for road embankment general case is 100 mm (Kementerian Pekerjaan Umum & Perumahan Rakyat - Direktorat Jenderal Bina Marga, 2017)

### Safety factor

Safety factor minimum for road embankment 1.5 (Badan Standardisasi Nasional, 2017)

### Model

After the soil parameters are obtained, modeling is then carried out using PLAXIS 2D version 22. The modeling results that will be reviewed are the amount of settlement and the value of the safety factor for each soil model.

Table 1. Soil parameter DB-2

| DB 2 (MAT 0 m) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Depth (m) | | | Layer | Material Model | Drainage type | N-SPT | $\gamma_{unsat}$ (kN/m$^3$) | $\gamma_{sat}$ (kN/m$^3$) | E (kN/m$^2$) | v | Cu (kN/m$^2$) | c' (kN/m$^2$) | ϕ' (°) | $R_{inter}$ |
| 1 | 0 | - | 12 | Silty CLAY | Mohr-Coulomb | Undrained | 2 | 14 | 16 | 2800 | 0.4 | 14,00 | - | - | 0,8 |
| 2 | 12 | - | 16 | Silty CLAY | | Undrained | 12 | 15 | 17 | 16800 | 0.35 | 84,00 | - | - | 0.8 |
| 3 | 16 | - | 18 | Sandy SILT | | Drained | 57 | 17 | 19 | 18900 | 0.3 | - | 1 | 36 | 0,9 |
| 4 | 18 | - | 22 | Silty SAND | | Drained | 44 | 17 | 19 | 15000 | 0.3 | - | 1 | 38 | 0,9 |
| 5 | 22 | - | 26 | Silty CLAY | | Undrained | 26 | 16 | 18 | 36400 | 0.3 | 182,00 | - | - | 0,8 |
| 6 | 26 | - | 30 | Silty SAND | | Undrained | 45 | 17 | 19 | 63000 | 0.3 | 315,00 | - | - | 0,8 |

Table 2. Soil parameter DB-13

| DB 13 (MAT 0 m) | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No | Depth (m) | | | Layer | Material Model | Drainage type | N-SPT | $\gamma_{unsat}$ (kN/m$^3$) | $\gamma_{sat}$ (kN/m$^3$) | E (kN/m$^2$) | v | Cu (kN/m$^2$) | c' (kN/m$^2$) | ϕ' (°) | $R_{inter}$ |
| 1 | 0 | - | 9 | Silty CLAY | Mohr-Coulomb | Undrained | 3 | 14 | 16 | 4200 | 0.4 | 21,00 | - | - | 0,8 |
| 2 | 9 | - | 12 | Silty CLAY | | Undrained | 5 | 14 | 16 | 7000 | 0.4 | 35,00 | - | - | 0,8 |
| 3 | 12 | - | 16 | Silty CLAY | | Undrained | 15 | 15 | 17 | 21000 | 0.35 | 105,00 | - | - | 0,8 |
| 4 | 16 | - | 24 | Silty CLAY | | Undrained | 20 | 16 | 18 | 28000 | 0.3 | 140,00 | - | - | 0,8 |
| 5 | 24 | - | 30 | Silty CLAY | | Undrained | 26 | 16 | 18 | 36400 | 0.3 | 182,00 | - | - | 0,8 |

Table 3. Embankment and soil replacement parameter (Hamonangan & Syahputra, 2023)

| Soil Type | $\gamma_{sat}$/ $\gamma_{unsat}$ kN/m$^3$ | E' reff kPa | $\upsilon_{ur}$ - | c' ref kN/m$^2$ | Φ' deg | $k_x = k_y$ m/day |
|---|---|---|---|---|---|---|
| Fill | 18/17 | 50000 | 0.25 | 10 | 25 | 0.02272 |
| Selected Borrow | 18/17 | 50000 | 0.28 | 5 | 30 | 1.063 |

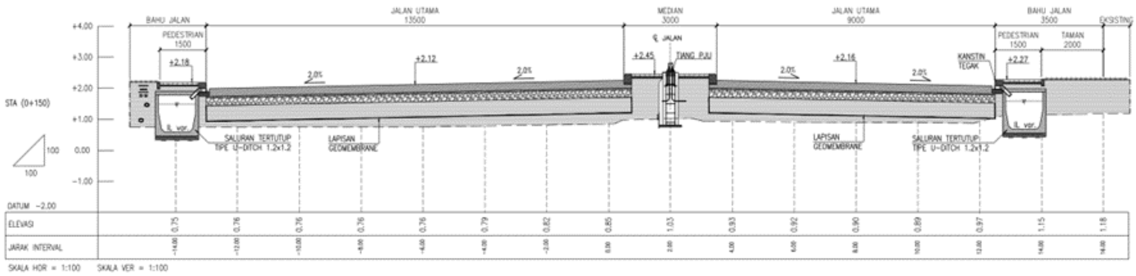

Figure 3. Cross Section Road Embankment

Modeling in the PLAXIS program refers to the cross-section image shown in Figure 3. Each layer is adjusted to the soil investigation results obtained in the soil test. Owing to the symmetry of the problem, only one-half needs to be modeled. 15 noded plain strain elements have been used for discretizing both the embankment as well as the foundation material.

Images of the subgrade and embankment modeling in the Plaxis 2D finite element program can be seen in Figure 4 and Figure 5.

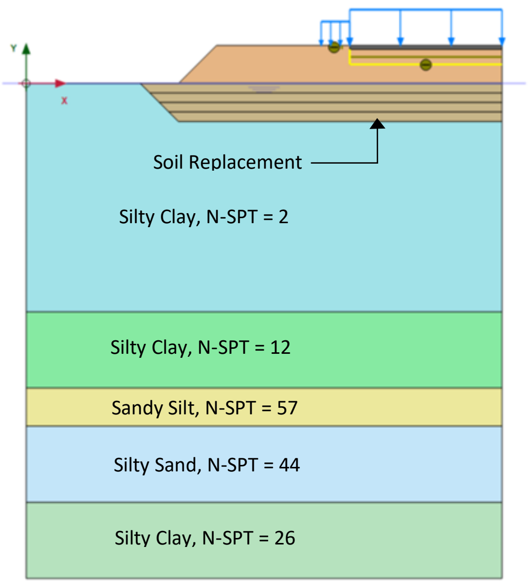


Figure 4. Model DB-2

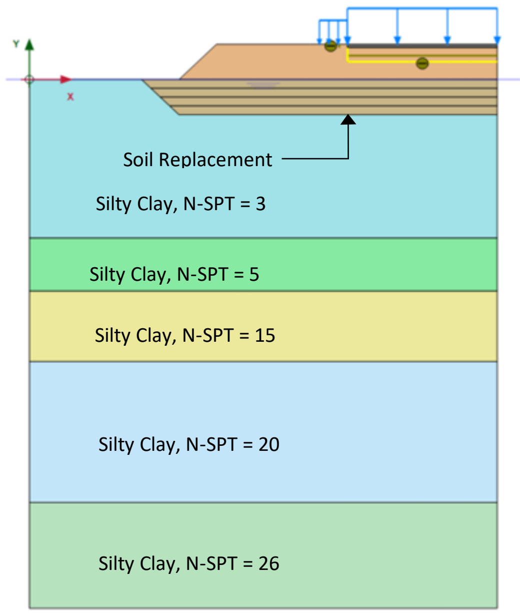


Figure 5. Model DB-13

## 4. RESULT

### Results of Vertical Settlement Analysis

After evaluating the overall settlement, it became evident that the failure mechanism is associated with the distribution of excess pore pressure. Following the completion of the embankment and pavement construction, settlement significantly increased at both the pavement surface and embankment. This phenomenon occurs due to the dissipation of excess pore pressure within the soft soil layer, leading to consolidation. Notably, as shown in Figure 6 and Figure 7, in the case of replacement 2 meters, the maximum vertical settlements for DB-2 and DB-13 were 72,1 and 29,2 mm, respectively—making them the least compared to other replacement depths.

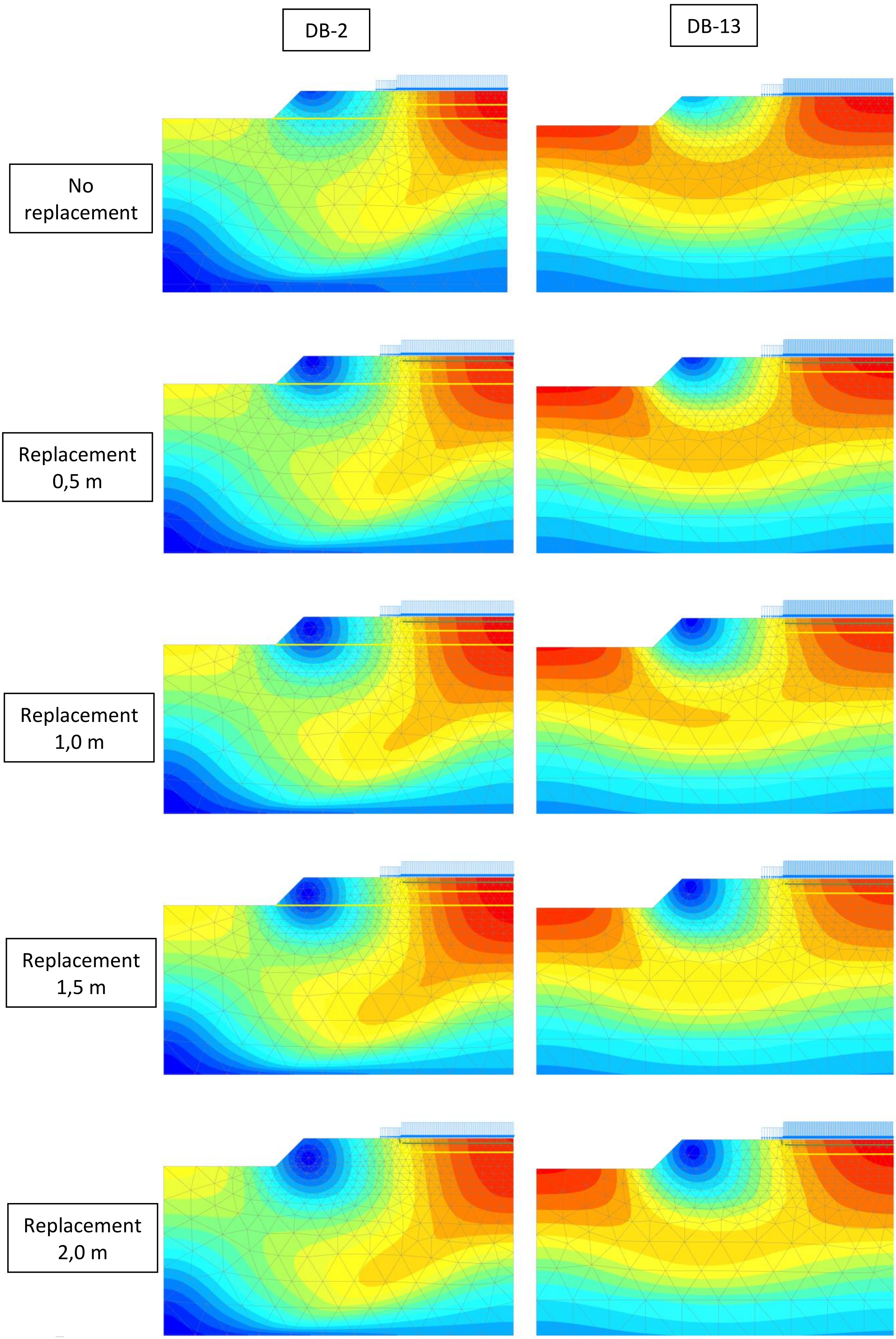


Figure 6. Output of maximum total displacement with different replacement depth

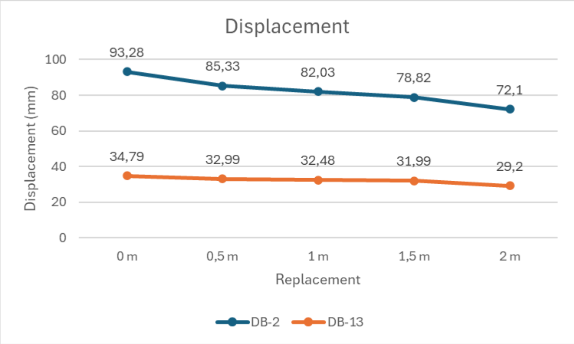


Figure 7. Variation of maximum vertical displacement with different replacement depth

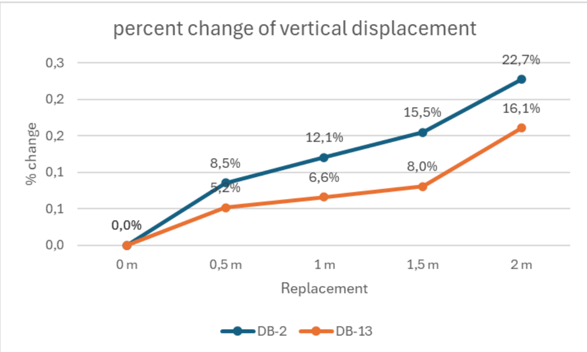


Figure 8. Variation of % change in vertical displacement with different replacement depth

### Results of Safety Factor Analysis

Figure 1 shows a comparison of a factor of safety values computed from the phi/c-reduction calculation option available in PLAXIS for the different embankment fill materials.

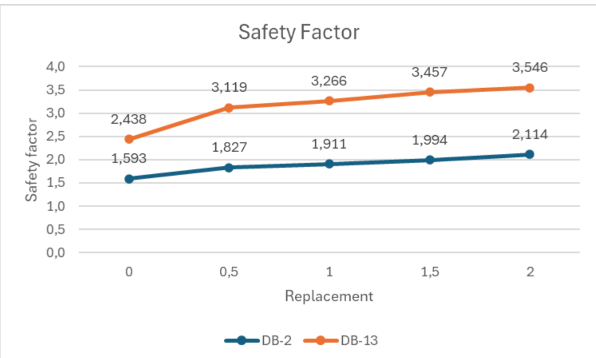


Figure 1. The factor of Safety values for different replacement depth

It can be observed from the above figure that deeper replacement depth generally gives a higher factor of safety compared to others.

## 5. CONCLUSIONS

From the results of the discussion above, it can be concluded as follows:

a. The least value of maximum vertical displacement in replacement is 2 meters for both DB-2 and DB-13. Displacement on DB-2 was found to be 72.1 mm resulting in a 22,7% decrement from embankment without replacement (93,28 mm). Displacement on DB-13 was found to be 29,2 mm resulting in a 16.1% decrement from embankment without replacement (34,79 mm).
b. The maximum FOS against slope failure was observed in the case of replacement 2 meters (2,114 for DB-2 and 3,546 for DB-13)
c. The results of the analysis show that the replacement of soil can reduce settlement in locations with soft soils and can increase the safety factor value of the embankment.

## REFERENCES

[1] Badan Standardisasi Nasional. (2017). *SNI 8460:2017 Persyaratan perancangan geoteknik*.

[2] Departemen Permukiman dan Prasarana Wilayah. (2002). *Panduan Geoteknik 4 Desain dan Konstruksi Timbunan Jalan pada Tanah Lunak*.

[3] E.M. Da Silva, J. J.-B. (2017). The effect of geotextile reinforcement and prefabricated vertical drains on the stability and settlement of embankments. *Geotextiles and Geomembranes*, 447-461.

[4] Hamonangan, E. K., & Syahputra, M. Y. (2023). Perbandingan Hasil Analisis Finite Element Untuk Stabilitas Dan Penurunan Timbunan Dengan Beberapa Soil Model Di Lokasi Rencana Pembangunan Jalan Tol Subang. *Jurnal HPJI (Himpunan*

*Pengembangan Jalan Indonesia) Vol. 9 No. 1, 1–8.*

[5] Kementerian Pekerjaan Umum & Perumahan Rakyat - Direktorat Jenderal Bina Marga. (2017). *Manual Desain Perkerasan Jalan*.

[6] Parsa-Pajouh A, F. B. (2014). Trial Embankment Analysis to Predict Smear Zone Characteristics Induced by Prefabricated Vertical Drain Installation. *Geotechnical and Geological Engineering*, 1187-1210.

[7] Y. Zhuang, K. Y. (2016). Finite-Element Analysis on the Effect of Subsoil in Reinforced Piled Embankments and Comparison with Theoretical Method Predictions. International Journal of Geomechanics.