# Investigation of Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge

*By* c girsang

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# Investigation of Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge

C. Girsang [1*], P. P. Rahardjo [2], A. Lim [3]

*Civil Engineering Faculty, Paharayangan Catholic University.*

*Email : clintongirsang10@gmail.com .*

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**A B S T R A C T**

Soil as a subgrade foundation under embankment construction often creates problems in terms of stability and settlement. Therefore, it needs improvement by using preloading embankment. This article presents the investigation of pile behavior towards two scenarios of abutment construction using Plaxis 3D, a three-dimensional finite element program. The use of two scenarios of analysis was Method A. The abutment construction phase is conducted without using a preloading embankment, and Method B, where a preloading embankment is constructed before the abutment construction. The case study is located at the Lembak bridge. Compare the analysis results with the measured data. Results showed that Method A and Method B's pile deflection yielded four times and one point six times larger than the measure data, respectively. Hence, it indicates that Method B is recommended for future construction of bridge abutment.

## 1. Introduction

There are a lot of geotechnical problems caused by lateral soil movement. Soil movement itself is caused by various factors such as consolidation, expansive soil, excavation, slope stability issue, embankment, and pile installation with too narrow spacing [1]. Bearing capacity, the foundation must be designed properly to ensure the building avoids problems differential settlement [2][3].The differential settlement will affect the internal forces on structures [4]. The soil movements may, in turn, induce additional stresses and displacement in neighboring abutments pile [5].

The lateral soil movement can cause construction failure, especially on a pile foundation. Pile foundation that receives the lateral load from lateral soil movement is called

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"passive pile". Passive piles have become one of the most common slope stabilization methods in recent years. Estimating lateral loads caused by the movement of an unstable soil; resultant stresses and bending moments developed in the pile shaft have vital importance for an economical and safe design [6]. To determine the pile foundation structure's response, it can do it with the experimental test (loading test) or simulate a mathematical model [7].

Most slope failures occur either during or at the end of construction. Pore water pressure depends on the placement water content of the fill and the rate of construction [8]. Slope failures can also occur without reinforcement on steeps slopes [9]. As the driving load(s) has reached the ultimate slope resistance, the slope begins to move/fail [10]. The Ridgid piles can protect the human construction downslope of the piles [11].

Therefore, this paper will address the correlation between pile behavior and construction stages using a 3-dimensional approach with the help of PLAXIS 3D. Two methods were analyzed: Method A, where the abutment is constructed without any preloading embankment, and Method B, where a preloading embankment is constructed before abutment construction. Embankment loads cause vertical and horizontal displacement [12]. **Figure 1**. illustrates construction stages for Method A, which started from (a) soil – cement mixing, (b) construction of the pile foundation and abutment, and (c) construction of barrier behind the abutment. **Figure 2** illustrates construction stages for Method B, which began from (a) soil – cement mixing, (b) construction of preloading embankment, (c) excavation of the area that will be used for the abutment, (d) construction of the pile foundation and abutment, and (e) additional embankment work behind the abutment to reach planned elevation level.

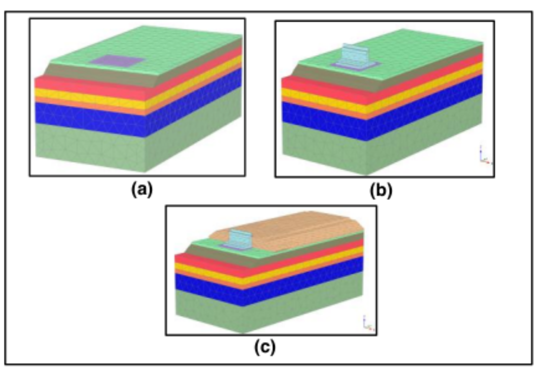


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**Figure 1.** Illustration for Methode A Construction Stage Model


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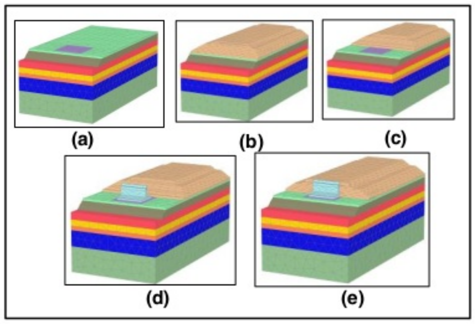


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**Figure 2.** Illustration for Methode B Construction Stage Model

The case study for the analysis is Lembak Bridge, located in East Borneo. The bridge across spanned 50 m and used 80 nos. Driven piles with 60 cm diameter and embedment length of 27 m on the east side. **Figure 3** shows the location of the Lembak River, where the bridge is located.


*Source : Google Earth, 2020*

**Figure 3.** Case Study Location

## 2. Literature Review

The addition of each layer of embankment up to achieving the desired embankment height, it will increase the settlement that occurs on the subgrade [12]. The settlement does not make the soil return to the original position after soil reached its strength, but it will continue to increase with the maximum height embankment.

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The largest settlement soil is in the area below the embankment center. Getting further away from the embankment center, it is getting smaller until the subgrade foundation. The embankment center is an area of great stress due to the applied embankment load and the dam's toe. The load that occurs is getting smaller, so the settlement is getting smaller [12].

## 3. Research Method

The Finite Element Method was used for the case study. The finite element method is a numerical method to provide the differential problem and developed to help solve problems in the solid mechanics model [13][14]. The finite element method divides a complex model into smaller and simpler element meshes in which a solution can be obtained easier [15]. In the conventional subgrade reaction approach, the soil is modeled by spring elements attached to the pile at different depths [16]. The finer the mesh, the better the result will be.

The finite element method nowadays is much easier to be performed since the advancement of computer technology and its software development. One such program was PLAXIS [17][18]. For this research is used PLAXIS 3D [19][20].

PLAXIS 3D is a 3-dimensional finite element analysis program used for various analyses, wherein this study is used for foundation analysis. The program uses simple visual input, allowing users to create complex case models with state-of-the-art output and calculation automatically. Embedded Pile in PLAXIS is a 3-node element with 6 DOF per node (3 translations and 3 rotations) [21]. The embedded pile model is available in the latest version of PLAXIS 3D [22].

## 4. Analysis and Result

### 4.1 General

The case study is modeled and analyzed using PLAXIS 3D version 2013 with the Mohr-Coulomb parameter, where the main parameters are cohesion (c) and friction angle (Φ). **Table 1** and **Table 2** show construction stages to be analyzed for Method A and Method B, respectively. This section contains (concise form) data analysis and interpretation of results. Interpretation of results using theories from articles as used. The descriptions are given theoretical, implicative, and managerial, or practical.

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**Table 1.** Construction Stages for Method A

| No. | Stages Identification | Duration (days) | Calculation |
|---|---|---|---|
| 1 | Land clearing and soil cement mixing | 0 | *Plastic* |
| 2 | Driven Pile Construction | 30 | *Consolidation* |
| 3 | Bridge Abutment Construction | 120 | *Consolidation* |
| 4 | Embankment 1 (El. +11.00) | 5 | *Consolidation* |
| 5 | Embankment 2 (El. +12.00) | 5 | *Consolidation* |
| 6 | Embankment 3 (El. +13.00) | 5 | *Consolidation* |
| 7 | Embankment 4 (El. +14.00) | 5 | *Consolidation* |
| 8 | Embankment 5 (El. +15.00) | 5 | *Consolidation* |
| 9 | Embankment 6 (El. +16.00) | 5 | *Consolidation* |
| 10 | Embankment 7 (El. +17.00) | 5 | *Consolidation* |
| 11 | Embankment 8 (El. +18.00) | 5 | *Consolidation* |
| | *End* | | |

*Source : Thesis on Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge*

**Table 2.** Construction Stages for Method B

| No. | Metode A | Duration (days) | Permodelan |
|---|---|---|---|
| 1 | Land clearing and soil cement mixing | 0 | *Plastic* |
| 2 | Preloading Embankment 1 (El. +11.00) | 5 | *Consolidation* |
| 3 | Preloading Embankment 2 (El. +12.00) | 10 | *Consolidation* |
| 4 | Preloading Embankment 3 (El. +13.00) | 8 | *Consolidation* |
| 5 | Preloading Embankment 4 (El. +14.00) | 9 | *Consolidation* |
| 6 | Preloading Embankment 5 (El. +15.00) | 6 | *Consolidation* |
| 7 | Preloading Embankment 6 (El. +16.00) | 6 | *Consolidation* |
| 8 | Preloading Embankment 7 (El. +17.00) | 6 | *Consolidation* |
| 9 | Wait Time | 79 | *Consolidation* |
| 10 | Preloading Embankment Excavation | 7 | *Consolidation* |
| 11 | Driven Pile Construction | 30 | *Consolidation* |
| 12 | Bridge Abutment Construction | 120 | *Consolidation* |
| 13 | Embankment 1 (El. +11.00) | 5 | *Consolidation* |
| 14 | Embankment 2 (El. +12.00) | 5 | *Consolidation* |

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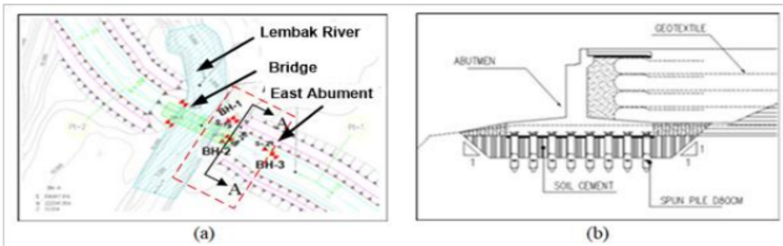
| No. | Metode A | Duration (days) | Permodelan |
|---|---|---|---|
| 15 | Embankment 3 (El. +13.00) | 5 | *Consolidation* |
| 16 | Embankment 4 (El. +14.00) | 5 | *Consolidation* |
| 17 | Embankment 5 (El. +15.00) | 5 | *Consolidation* |
| 18 | Embankment 6 (El. +16.00) | 5 | *Consolidation* |
| 19 | Embankment 7 (El. +17.00) | 5 | *Consolidation* |
| 28 | Embankment 8 (El. +18.00) | 5 | *Consolidation* |
| | *End* | | |

*Source : Thesis on Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge*

## 4.2 Soil Investigation

Three (3) conducted core drilling with Standard Penetration Test (SPT) with a depth of 30 – 40 m and Three (3) Cone Penetration Test (CPT) on the field in 2009. can found the location of the soil investigation points in **Figure 4**. The soil investigation and soil stratigraphy results can be found in **Figure 5** and **Figure 6**, respectively.




*Source : Final Report of Geotechnical Investigation for AB Link Road and Lembak Bridge Bengalon*

**Figure 4.** (a) Soil Investigation Layout; (b) Abutment Cross Section

Based on the data obtained from the soil investigation, the soil is composed as follows:

1. Soil layer from El. +10.00 to +12.00 consists of clay with medium consistency and an average NSPT of 7 blows/30 cm.
2. Soil layer from El. +6.00 to +10.00 consists of soft clay with an average NSPT of 4 blows/30 cm.
3. Soil layer from El. +2.00 to +6.00 consists of sand with medium dense density and average NSPT of 13 blows/30 cm.

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4. Soil layer from El. -2.00 to +2.00 consists of medium clay with an average NSPT of 6 blows/30 cm.
5. Soil layer from El. -2.00 to -4.00 consists of sand with medium dense density and average NSPT of 20 blows/30 cm.
6. Soil layer from El. -4.00 to -12.00 consists of stiff clay with an average NSPT of 9 blows/ 30 cm
7. Soil layer from El. -12.00 to -20.00 consists of sand with medium dense density and an average NSPT of 20 blows/30 cm.

**Figure 5** shows soil layer sand and clay. **Figure 6** shows soil stratigraphy for cross section AA

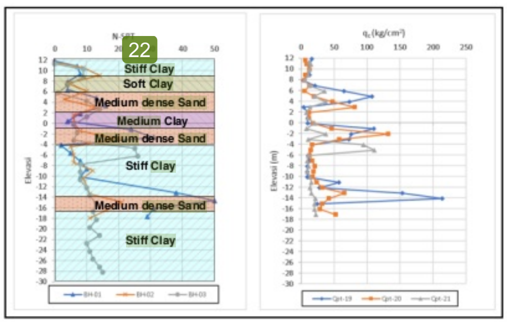


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**Figure 5.** SPT and CPT Graph vs. Elevation

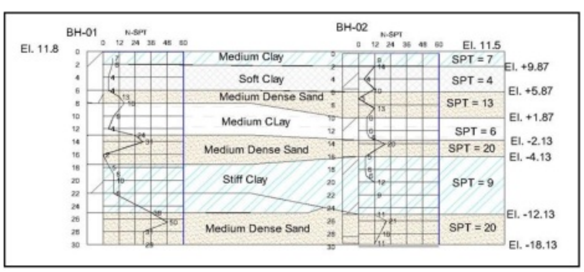


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**Figure 6.** Soil Stratigraphy for Cross Section A-A

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### 4.4 Lab Test Result

Conducted lab testing was on undisturbed soil samples taken during the core drilling. I can found a summary of the lab test in **Table 3**. Based on the water content test (ASTM D2216-98), the water content ranges from 20.3 - 42.2%. From Atterberg limits (ASTM D4318-00), obtained Liquid Limit (LL) value ranging from 46.4 – 89.9 % and Plastic Limit (PL) value ranging from 16.9 – 25.1 %.

**Table 3**. Lab Testing Summary

| Borehole | Depth | Liquid Limit, LL (%) | Plastic Limit, PL (%) | Water Content, $W_n$ (%) | Void Ratio, e | Compresibility Index, Cc |
|---|---|---|---|---|---|---|
| BH-1 | 2.0 – 2.5 | 79.4 | 23.2 | 29.2 | 0.80 | - |
| | 5.0 – 5.5 | 49.2 | 18.2 | 26.1 | 0.70 | 0.26 |
| | 19.8 – 20.50 | 59.1 | 16.9 | 32.1 | 0.80 | 0.50 |
| BH-2 | 2.0 - 2.5 | 79.8 | 23.2 | 26.0 | 0.90 | 0.34 |
| | 5.0 - 5.5 | 46.4 | 21.3 | 20.3 | 0.60 | 0.41 |
| | 12.3 – 13.00 | 68.6 | 25.1 | 41.5 | 1.10 | 0.50 |
| | 18.3 – 19.00 | 59.2 | 22.4 | 36.8 | 1.10 | 0.64 |
| | 21.3 – 22.00 | 55.3 | 21.5 | 27.5 | 0.70 | 0.30 |
| | 24.3 – 25.00 | 52.2 | 22.2 | 30.4 | 0.80 | 0.45 |
| BH-3 | 2.0 – 2.5 | 89.9 | 23.2 | 29.7 | 0.80 | 0.29 |
| | 4.8 - 5.5 | 49.8 | 23.5 | 21.5 | 0.60 | 0.09 |
| | 10.0 – 11.5 | 75.9 | 23.1 | 36.3 | 0.90 | 0.52 |
| | 19.8 – 20.5 | 78.3 | 23.3 | 42.2 | 1.10 | 0.58 |
| | 24.3 – 25.0 | 81.8 | 24.2 | 25.0 | 0.70 | - |

*Source : Final Report of Geotechnical Investigation for AB Link Road and Lembak Bridge Bengalon*

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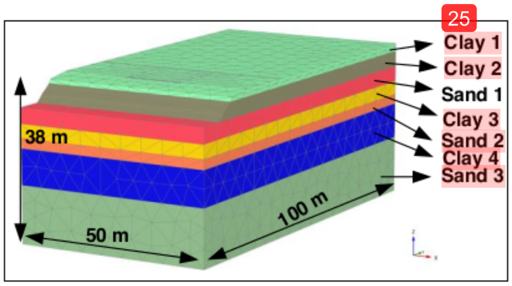
### 4.5 Model and Analysis Parameters

The geometrical model of the embankment and soil stratigraphy used in PLAXIS 3D analysis can be found in **Figure 7.** A medium-density mesh was used for this model. The node used for element analysis is 10-nodes, which are the basic element from 3D FEM.

Based on the soil investigation, lab test result, and other correlation, the parameter used for the case study is listed in **Table 4.**




*Source : Thesis on Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge*

**Figure 7.** Modeling PLAXIS 3D

**Table 4.** Soil Parameter

| Material | E (kPa) | ν | γ (kN/m$^3$) | Kx,kz (m/day) | Ky (m/day) | $c_u$ (kPa) | ϕ (°) |
|---|---|---|---|---|---|---|---|
| Clay 1 | 10000 | 0.33 | 16 | 1.38 E-06 | 2.76 E-06 | 28 | 0 |
| Clay 2 | 6720 | 0.33 | 15 | 4.54 E-06 | 9.08 E-06 | 16 | 0 |
| Clay 3 | 5760 | 0.33 | 17 | 8.42 E-05 | 1.68 E-04 | 24 | 0 |
| Clay 4 | 24000 | 0.33 | 15 | 1.00 E-04 | 2.01 E-04 | 36 | 0 |
| Sand 1 | 15600 | 0.3 | 17 | 1.37 E-01 | 2.74 E-01 | 1 | 31 |
| Sand 2 | 24000 | 0.3 | 17 | 2.71 E-01 | 5.41 E-01 | 1 | 35 |
| Sand 3 | 24000 | 0.3 | 17 | 2.71 E-01 | 5.41 E-01 | 1 | 32 |
| Soil Cement | 40000 | 0.33 | 15 | 1.52 E-08 | 3.00 E-07 | 240 | 0 |
| Fill Material | 14000 | 0.33 | 16 | 0.0372 | 0.06 | 70 | 0 |

*Source : Final Report of Geotechnical Investigation for AB Link Road and Lembak Bridge Bengalon*

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**Table 5** shows the parameter used for the piles and geotextile used in the PLAXIS 3D analysis. The pile modulus used in the analysis is similar to that is used in the field. On the input of embedded pile, a base resistance value is inputted to the model, where the value of the base resistance itself is obtained from the following formula:

$$Q_p = 40 \times N_{design} \times A_p \quad (1)$$

Where :

$N_{design}$ = ½ (N1+N2)

N1 = $N_{SPT}$ average to 10 x D (Pile diameter) measured from the bottom tip upward

N2 = $N_{SPT}$ average to 4 x D (Pile diameter) measured from the bottom tip downward

**Table 5.** Pile and Geotextille Parameter

| Parameter | Unit | Spun Pile | Geotextile |
|---|---|---|---|
| Material type | [ - ] | Elastic | Elastic |
| EA | [kN/m] | 3.30E+06 | 50 |
| EI | [kN/m$^2$/m] | 2.10 E+7 | - |
| A | [m$^2$] | 0.157 | - |
| γ | [kN/m$^3$] | 24 | - |
| $F_{max}$ | [ kN ] | 1265 | - |

*Source : Thesis on Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge*

## 4.3 Analysis Result

The focus of observation in this section is divided into two sections: the observation for the ground settlement and the driven pile's movement during the embankment loading. 2 nos. Inclinometers (AB-1 and AB-2) and 2 nos. Settlement plates (SP-9 and SP-10) were installed on the case study location as presented in **Figure 8.**

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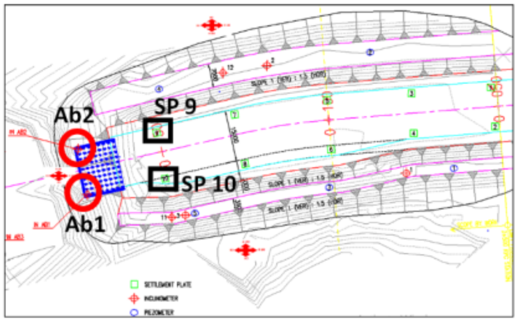


**Figure 8.** Instrumentation Layout

The ground settlement analysis using the PLAXIS 3D yields results close to the actual settlement plate measurement obtained from the field. The analysis result is plotted to the settlement vs. time curve as shown in **Figure 9.** The field's measurement indicates 490 mm ground settlement, and PLAXIS 3D analysis yields similar results for ground settlement estimation of 490 mm. Used the result of the ground settlement analysis was as a parameter for methods A and B.

**Figure 10.** shows the PLAXIS 3D model for Pile AB-1 and AB-2, where the inclinometer was installed, which was used to compare the pile deflection obtained from analysis from Method A and B to actual inclinometer reading.

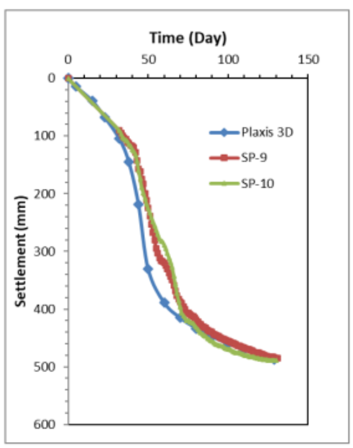


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**Figure 9.** Plaxis 3D output vs Field Measurement

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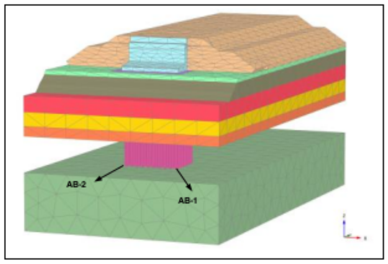


*Source : Thesis on Pile Behavior Toward Abutment Construction using PLAXIS 3D: Case Study on Lembak Bridge*

**Figure 10.** Pile with inclinometer installed

From PLAXIS 3D analysis, Method A shows a significantly larger deflection with the actual measurement in the field. On the contrary, Method B shows where deflection is closer to the actual measurement obtained from the field.

**Figure 11 (a)** shows the pile deflection on AB-1 on Method A is 81.7 mm and Method B is 30.6 mm, while the measured deflection is 19 mm. Method B yields 1.6 times larger deflection than the actual inclinometer reading, while Method A is 4.2 times larger than the actual measurement.

**Figure 11 (b)** shows deflection on AB-2, where Method A yields 6.4 times larger deflection than the actual inclinometer reading, while Method B is 2.4 times larger than the actual measurement. The pile deflection on AB-2 on Method A is 81.9 mm and Method B is 30.9 mm, while the measured deflection is 12.7 mm.

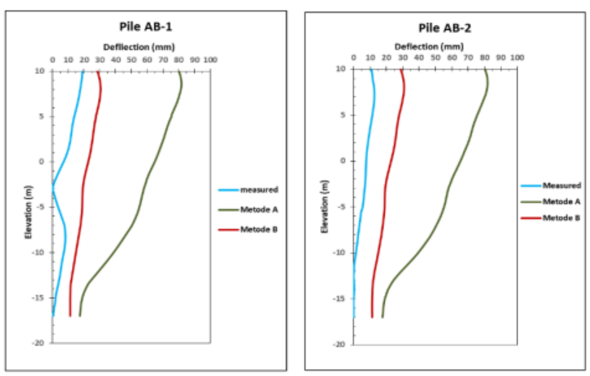


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**Figure 11.** Data Comparison Chart (a). Pile AB-1 Actual vs. Method A vs. Method B

(b). Pile AB-2 Actual vs. Method A vs. Method B

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# 5. Conclusion and Suggestion

## 5.1 Conclusion

Based on the research result, several conclusions were made and summarised as follows:

1. Embankment Ground Consolidation Analysis using PLAXIS 3D with the Mohr-Coulomb material model yields similar results with ground settlement measured from 2 nos. Settlement plate (SP-9 and SP-10) of 490 mm in 129 days.
2. Method A analysis, in which the abutment is constructed beforehand without embankment, produces a much larger pile deflection on Pile AB-1 and AB-2 with a magnitude of 81 mm.
3. Method B analysis, in which constructed preloading embankment was before abutment construction, produces a deflection of 30 mm on Pile AB-1 and AB-2.
4. Comparison between analysis result to the actual inclinometer measurement yields 4-6 times larger deflection on Method A and 1.6 – 2.4 times larger on Method B
5. Construction sequence plays a significant role in the structure built, especially on the river bridge abutment construction and will affect the pile deflection. The correct sequence will reduce the deflection of the pile foundation.

## 5.1 Suggestion

Further analysis is recommended where the material is modeled with other material models other than Mohr-Coulomb, such as Soil Hardening Model (HS) and Soft Soil Model, which may produce a different result.

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