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# Study on the Impact of Soil Site Classes on Bridge Construction Costs on the Probolinggo-Banyuwangi Toll Road Project Section 3

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**Keywords**
soil site class, construction costs, bridge

**Abstract**
The construction of the Probolinggo–Banyuwangi Section 3 toll road requires an in-depth analysis of the impact of soil site class on bridge construction costs. This study aims to evaluate the relationship between soil site class and bridge construction costs using a quantitative approach with a comparative analysis method. Data were obtained through geotechnical investigations and borehole analysis using N-SPT values. The results indicate changes in soil site class at several locations, such as Pier 1, which shifted from medium to soft soil. This impacted the need for redesigning foundations and increased implementation costs by up to 345.40%. These findings highlight the importance of evaluating soil site class in infrastructure planning to optimize structural stability and cost efficiency.



## Introduction

The development of toll road infrastructure is one of the main priorities in the national development plan to support economic growth and improve connectivity between regions (Adhy Muhtar et al., 2021; Arganata & Swasto, 2022; Elisha et al., 2020; Fauzan et al., 2023; Nugraha, 2023; Nusriadi et al., 2021). The Probolinggo–Banyuwangi Toll Road is one of the strategic projects that aims to improve transportation efficiency in the eastern region of Java Island. In Section 3 of this project, the existence of bridges is an important element in overcoming geographical obstacles such as rivers and valleys. However, the geotechnical characteristics of the soil along this path are a major challenge affecting the design, construction, and construction costs of the bridge (Bagheri & Rezania, 2021; Qader et al., 2023; Turan et al., 2022).

The geotechnical condition of the soil, especially the *kelas tanah situs* (soil site class), is a crucial factor in determining the stability and safety of the bridge structure. The *kelas tanah situs* reflects the mechanical and dynamic properties of the soil, such as bearing capacity, deformation, and liquefaction potential (Juwono et al., 2020; Kabeta et al., 2020; Scheepers & Malan, 2022; Shabarov & Kuranov, 2023). This factor has a significant effect on foundation design, material selection, and construction methods. Previous research has shown that soil site classes with low bearing capacity, such as soft soils or sandy soils with liquefaction risks, require deeper foundations and the use of reinforcement materials, which ultimately increase construction costs .

On the other hand, soils with better site grades allow for savings on structural elements without compromising safety aspects . However, in the Probolinggo–Banyuwangi Toll Road Section 3 project, the geographical location includes various types of soil, ranging from *lempung lunak* (soft clay soil) to *pasir vulkanik* (volcanic sand), requiring an in-depth analysis of the influence of soil conditions on the cost of bridge construction. Moreover, the East Java region is included in the earthquake-prone zone due to the activity of the Indo-Australian and Eurasian plates, so it requires a structural design that is resistant to dynamic loads .

Previous research has provided a relevant view of the relationship between geotechnical conditions and construction costs. A study by Halimatusadiyah et al. shows that soft soils with liquefaction potential require additional reinforcement, which can increase costs by up to 40%. In addition, another study by Pranata identified that the variability of *kelas tanah situs* can affect the design of foundations and structural elements, especially in infrastructure projects in areas with high earthquake risk. Meanwhile, research on *perbaikan tanah dasar* (basic soil improvement) in the Probolinggo–Banyuwangi Toll Road Section 3 project highlights the importance of selecting efficient soil improvement methods to reduce the risk of deformation and construction costs .

Although there have been many studies that examine the influence of soil conditions on construction costs, specific studies that link the *kelas tanah situs* to the cost of building bridges on the Probolinggo–Banyuwangi Toll Road project are still limited. This study aims to fill this gap by analyzing in depth the relationship between *kelas tanah situs* and bridge construction cost elements. This analysis is expected to provide practical guidance in the planning, design, and budget management of similar infrastructure projects in the future.

## 2 Materials and Methods

The research stage begins with a review of related literature to formulate and study relevant theories as the basis for the research to be carried out. Furthermore, a data collection and data analysis process is carried out, which includes examining the influence of changes in *site classes* and the amount of additional construction costs.

### Research Location

The location of the research is in the Probolinggo–Banyuwangi Toll Road Construction Project Section 3. The exact location is at the *STA 44 + 575 Sungai Deluwang* bridge (Deluwang River bridge), which is indicated to have undergone a change in the *kelas tanah situs* (soil site class) based on the results of geotechnical investigation through the measurement of the *N-SPT* value from the *bore hole* data obtained. The next stage is to analyze soil parameters to evaluate their influence on the design and performance of the bridge structure.

**Research Design**

This study uses a quantitative approach with a comparative analysis method. The focus of the study is to identify the relationship between *kelas tanah situs* (soil site class) and bridge construction costs, as well as evaluate the impact of site class changes on key cost elements.

**Data Collection**

The primary data used in this study was obtained from the results of soil investigation through the *borehole* method equipped with *Standard Penetration Test* (SPT) testing, which had been carried out by the contractor during the construction preparation stage. Technical planning documents, including details of foundation, abutment, and superstructure designs, as well as the *Rencana Anggaran Biaya* (RAB or Cost Budget Plan) of the project, were also utilized. Secondary data consisted of literature studies related to the geotechnical conditions of the region, especially along the Probolinggo–Banyuwangi Toll Road, as well as scientific documents and publications on the influence of *kelas tanah situs* on construction structures and costs.

**Data Analysis Techniques**

The analysis is carried out in several stages:

a) *Soil Site Class Classification*
   Based on *N-SPT* data from *borehole* testing, the soil is classified according to geotechnical standards (*SNI 2833:2016*). The parameters used include soil bearing capacity, liquefaction potential, and dynamic deformation .

b) *Earthquake Load Calculation*
   Spectral response analysis is performed based on the predetermined *kelas tanah situs*. This analysis is carried out with the help of Midas Civil software.

c) *Estimated Construction Costs*
   The cost of building a bridge is calculated based on a design that is adjusted to the results of soil classification. This analysis includes the elements of the foundation, abutment, and superstructure of the bridge.

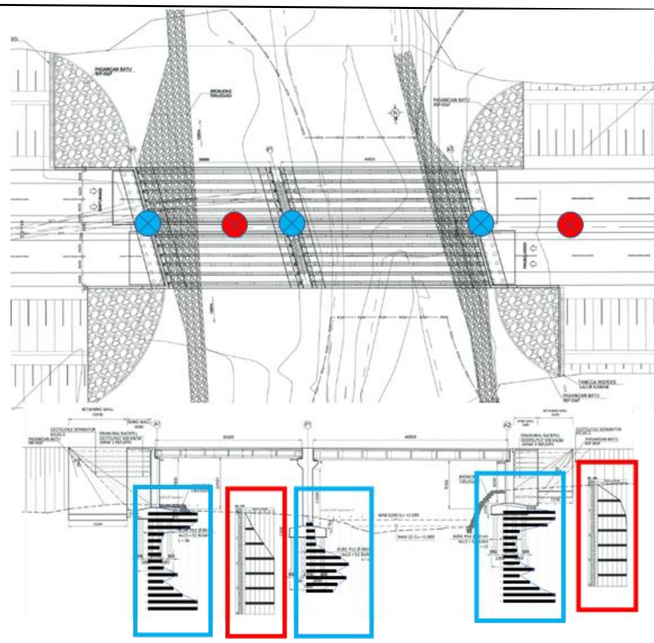

**Figure 1. Layout of Soil Research Location**

Land investigation by Planning Consultant

Soil research by Contractor

## 3 Results and Discussions

The analysis was carried out to evaluate the influence of soil site class changes on the foundation structure, abutment, and bridge pillars, including the calculation of the bearing capacity and foundation subsidence. Structure modeling uses finite element method-based software, such as Midas Civil, to analyze the internal forces acting on the structure due to dead loads, additional loads, seismic loads, and lateral ground pressures.(Pangestu & Indianto, 2021)

### N-SPT Sfoil Research Data

The full soil survey data can be seen in the following table:

**Table 1. Land Data N-SPT Abutment 1**

| No. | Depth | N-SPT | Soil Type |
|---|---|---|---|
| 1 | 0.00 | 0.00 | Silt Brown Sand Boulder Inserts |
| 2 | 2.00 | 60.00 | Silt Brown Sand Boulder Inserts |
| 3 | 4.00 | 60.00 | Brown Boulder Insert Loose Sand |
| 4 | 6.00 | 51.00 | Sand Loose Black Pebble Inserts |
| 5 | 8.00 | 19.00 | Black Loose Sand |
| 6 | 10.00 | 16.00 | Black Clay Sand |
| 7 | 12.00 | 14.00 | Black Clay Sand |
| 8 | 14.00 | 16.00 | Black Clay Sand |
| 9 | 16.00 | 17.00 | Black Clay Sand |
| 10 | 18.00 | 19.00 | Sand Grey Clam Inserts |

| No. | Depth | N-SPT | Soil Type |
|---|---|---|---|
| 11 | 20.00 | 36.00 | Sand Grey Clam Inserts |
| 12 | 22.00 | 19.00 | Gray Loose Sand |
| 13 | 24.00 | 31.00 | Black Loose Sand |
| 14 | 26.00 | 42.00 | Black Gravel Insert Sand |
| 15 | 28.00 | 60.00 | Black Boulder Insert Sand |
| 16 | 30.00 | 60.00 | Black Boulder Insert Sand |

**Table 2. Land Data N-SPT Pillar 1**

| No. | Depth | N-SPT | Soil Type |
|---|---|---|---|
| 1 | 0.00 | 0.00 km | Black Fine Sand |
| 2 | 2.00 | 6.00 | Black Fine Sand |
| 3 | 4.00 | 8.00 | Black Clay Sand |
| 4 | 6.00 | 8.00 | Black Clay Sand |
| 5 | 8.00 | 9.00 | Black Clay Sand |
| 6 | 10.00 | 17.00 | Fine Sand Scallop Inserts |
| 7 | 12.00 | 31.00 | Fine Black Loose Sand |
| 8 | 14.00 | 38.00 | Sand off Black Clam Inserts |
| 9 | 16.00 | 27.00 | Black Clay Sand |
| 10 | 18.00 | 36.00 | Black Sand |
| 11 | 20.00 | 28.00 | Black Sand |
| 12 | 22.00 | 24.00 | Brown Sand Silt |

**Table 3. Land Data N-SPT Abutment 2**

| No. | Depth | N-SPT | Soil Type |
|---|---|---|---|
| 1 | 0.00 | 0.00 | Silt Brown Sand Boulder Inserts |
| 2 | 2.00 | 60.00 | Silt Brown Sand Boulder Inserts |
| 3 | 4.00 | 60.00 | Brown Boulder Insert Loose Sand |
| 4 | 6.00 | 51.00 | Sand Loose Black Pebble Inserts |
| 5 | 8.00 | 19.00 | Black Loose Sand |
| 6 | 10.00 | 16.00 | Black Clay Sand |
| 7 | 12.00 | 14.00 | Black Clay Sand |
| 8 | 14.00 | 16.00 | Black Clay Sand |
| 9 | 16.00 | 17.00 | Black Clay Sand |
| 10 | 18.00 | 19.00 | Sand Grey Clam Inserts |
| 11 | 20.00 | 36.00 | Sand Grey Clam Inserts |
| 12 | 22.00 | 19.00 | Gray Loose Sand |
| 13 | 24.00 | 31.00 | Black Loose Sand |
| 14 | 26.00 | 42.00 | Black Gravel Insert Sand |
| 15 | 28.00 | 60.00 | Black Boulder Insert Sand |
| 16 | 30.00 | 60.00 | Black Boulder Insert Sand |

## Calculation of Soil Site Class

Based on SNI 2833 2016, the soil site class can be determined based on the results of the N-SPT soil survey data, the calculation of the soil site class is calculated using equation (1)(Badan Standardisasi Nasional, 2016)

$$\overline{N} = \frac{\sum_{i=1}^{m} t_i}{\sum_{i=1}^{m}\left(\frac{t_i}{N}\right)} \qquad (1)$$

There are 2 (two) N-SPT land survey data conducted by Planning Consultants and Contractors.

**Table 4. Calculation of Land Abutment Site Class 1 (N-SPT Land Survey Data by Planning Consultant)**

| No. | Depth (m) | | N-SPT (Ni) | Ti/Ni |
|---|---|---|---|---|
| | Cumulative | It | | |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 3.00 | 3.00 | 17.00 | 0.18 |
| 3 | 6.00 | 3.00 | 38.00 | 0.08 |
| 4 | 9.00 | 3.00 | 60.00 | 0.05 |
| 5 | 12.00 | 3.00 | 60.00 | 0.05 |
| 6 | 15.00 | 3.00 | 60.00 | 0.05 |
| 7 | 18.00 | 3.00 | 60.00 | 0.05 |
| 8 | 21.00 | 3.00 | 60.00 | 0.05 |
| **Total** | | **21.00** | | **0.15** |
| **Value $\overline{N}$** | | | **□ti/Ni** | **41.55** |
| **15 > 41.55 < 50 = Medium Soil Site Class (SD)** | | | | |

So based on the calculation table above, it is concluded that the location point belongs to the Medium Soil (SD) site class.

**Table 5. Calculation of Land Abutment Site Class 1 (N-SPT Land Survey Data by the Contractor)**

| No. | Depth (m) | | N-SPT (Ni) | Ti/Ni |
|---|---|---|---|---|
| | Cumulative | It | | |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 2.00 | 2.00 | 60.00 | 0.03 |
| 3 | 4.00 | 2.00 | 60.00 | 0.03 |
| 4 | 6.00 | 2.00 | 51.00 | 0.04 |
| 5 | 8.00 | 2.00 | 19.00 | 0.11 |
| 6 | 10.00 | 2.00 | 16.00 | 0.13 |
| 7 | 12.00 | 2.00 | 14.00 | 0.14 |
| 8 | 14.00 | 2.00 | 16.00 | 0.13 |
| 9 | 16.00 | 2.00 | 17.00 | 0.12 |

| No. | Depth (m) | | N-SPT (Ni) | Ti/Ni |
|---|---|---|---|---|
| | Cumulative | It | | |
| 10 | 18.00 | 2.00 | 19.00 | 0.11 |
| 11 | 20.00 | 2.00 | 36.00 | 0.06 |
| 12 | 22.00 | 2.00 | 19.00 | 0.11 |
| 13 | 24.00 | 2.00 | 31.00 | 0.06 |
| 14 | 26.00 | 2.00 | 42.00 | 0.05 |
| 15 | 28.00 | 2.00 | 60.00 | 0.03 |
| 16 | 30.00 | 2.00 | 60.00 | 0.03 |
| **Total** | | **30.00** | | **1.17** |
| **Value $\bar{N}$** | | | **□ti/Ni** | **25.72** |
| **15 > 25.72 < 50 = Medium Soil Site Class (SD)** | | | | |

So based on the calculation table above, it is concluded that the location point belongs to the Medium Soil (SD) site class. From the two tables above, it shows that in Abutment 1 there is no change in the site class of the land product survey conducted by the Planning Consultant or the Contractor.

**Table 6. Calculation of Pillar 1 Soil Site Class (N-SPT Land Survey Data by Contractor**

| No. | Depth (m) | | N-SPT (Ni) | Ti/Ni |
|---|---|---|---|---|
| | Cumulative | It | | |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 2.00 | 2.00 | 6.00 | 0.33 |
| 3 | 4.00 | 2.00 | 8.00 | 0.25 |
| 4 | 6.00 | 2.00 | 8.00 | 0.25 |
| 5 | 8.00 | 2.00 | 9.00 | 0.22 |
| 6 | 10.00 | 2.00 | 17.00 | 0.12 |
| 7 | 12.00 | 2.00 | 31.00 | 0.06 |
| 8 | 14.00 | 2.00 | 38.00 | 0.05 |
| 9 | 16.00 | 2.00 | 27.00 | 0.07 |
| 10 | 18.00 | 2.00 | 36.00 | 0.06 |
| 11 | 20.00 | 2.00 | 28.00 | 0.07 |
| 12 | 22.00 | 2.00 | 24.00 | 0.08 |
| **Total** | | **22.00** | | **1.57** |
| **Value $\bar{N}$** | | | **□ti/Ni** | **13.97** |
| **13.97 < 15 = Soft Soil Site Class (SE)** | | | | |

So based on the calculation table above, it is concluded that the point belongs to the Soft Land (SE) site class. From the two tables above, it shows that in Pillar 1 there is a change in the site class of the land survey conducted by the Planning Consultant and Contractor.

**Table 7. Calculation of Land Site Class Abutment 2 (N-SPT Land Survey Data by Planning Consultant)**

| No. | Depth (m) | | N-SPT (Ni) | Ti/Ni |
|---|---|---|---|---|
| | Cumulative | It | | |
| 1 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2 | 3.00 | 3.00 | 47.00 | 0.06 |
| 3 | 6.00 | 3.00 | 60.00 | 0.05 |
| 4 | 9.00 | 3.00 | 60.00 | 0.05 |
| 5 | 12.00 | 3.00 | 60.00 | 0.05 |
| 6 | 15.00 | 3.00 | 60.00 | 0.05 |
| 7 | 18.00 | 3.00 | 60.00 | 0.05 |
| 8 | 21.00 | 3.00 | 60.00 | 0.05 |
| **Total** | | **21.00** | | **0.36** |
| **Value $\bar{N}$** | | **□ti/Ni** | | **57.72** |
| **57.72 > 50 = Hard Soil Site Class (SC)** | | | | |

From the calculation above, it can be concluded that the location is a Hard Land (SC) site class. From the two tables above, it shows that in *Abutment* 2 there is a change in the site class of the land survey conducted by the Planning Consultant and Contractor. Based on the results of the calculation of the soil site class above, the soil site class matrix is obtained as follows.

**Table 8. Site-Class Matrix**

| No. | Location Points | Site Class | | Information |
|---|---|---|---|---|
| | | Planning Consultant | Contractor | |
| 1. | *Abutment* 1 | Medium Soil | Medium Soil | Remain |
| 2. | Pillar 1 | Medium Soil | Soft Soil | Change |
| 3. | *Abutment* 2 | Hard Soil | Soft Soil | Change |

So based on the matrix of the soil site class, it can be concluded that Abutment 1 of the soil site class does not change so there is no need for further evaluation.

**Calculation and Evaluation of Foundation Carrying Capacity**

**a. Pillar 1**

The maximum axial force of a single pole that occurs in the combination of lays is 125.98 tons and the combination of earthquakes is 695.82 tons. Meanwhile, based on the Detail *Engineering Design (DED) drawing*, the length *of the planned Bored Pile* on Pillar 1 is 12 meters, from the results of the calculation of the carrying capacity of a single pole with a length of 12 meters, namely at a depth of 16 meters, the carrying capacity of a single pole permit is 103.34 tons in service conditions and 161.46 tons in earthquake conditions as stated in the following figure:

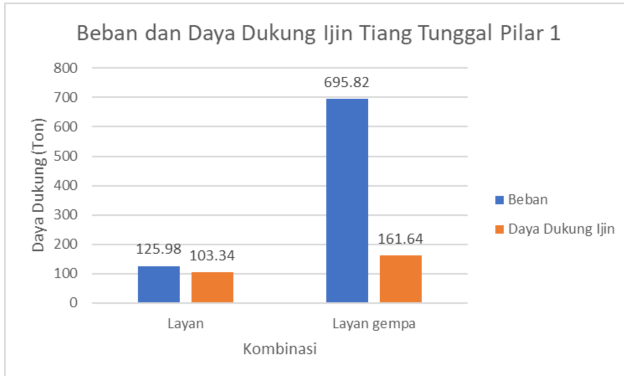


**Figure 2. Graph of Load and Carrying Capacity of Single Pillar Pole Permit 1 Based on Calculation Results**

So it can be concluded that the *Bored Pile* foundation with a length of 12 meters is not able to withstand the axial force of the earthquake conditions that occur, so *the Bored Pile* must be enlarged to a diameter of 1.20 meters and extended to a depth of 18 meters or with a pile length of 14 meters so that it has a single pile carrying capacity of 292.04 tons in service conditions and 456.32 tons in earthquake conditions with a total of 6 x 15 pieces.

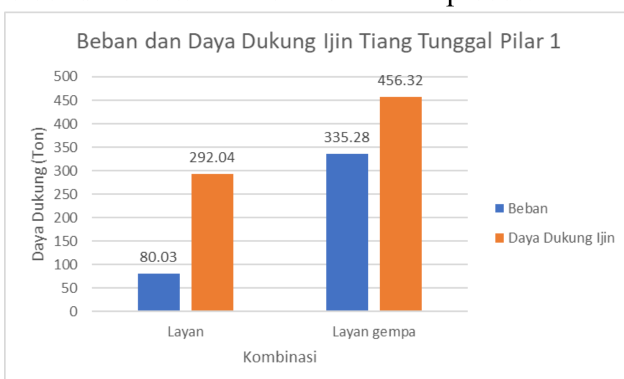


**Figure 3. Graph of Load and Carrying Capacity of Single Pillar Pole Permit 1 Based on Calculation Results**

In addition to single poles, it is also necessary to review the maximum axial force in the pile group, the maximum axial force of the pile group that occurs in the laying combination of 6547.37 tons and the combination of the earthquake laying of 5691.76 tons. From the carrying capacity of a single pile, the carrying capacity of the pile group is calculated based on *The Bridge Specifications of AASHTO* which suggests to estimate the efficiency value of the pile group adopted from the proposal made by *Converse-Labarre* (Bowles, 1988).

Based on the results of the calculation of the carrying capacity of a single pile and the carrying capacity of the pile group, it can be concluded that, *the Bored Pile* Pillar 1 foundation with a diameter of 1.20 meters can support the load on it at a depth of 18 meters with a total of 6 x 15 pieces.

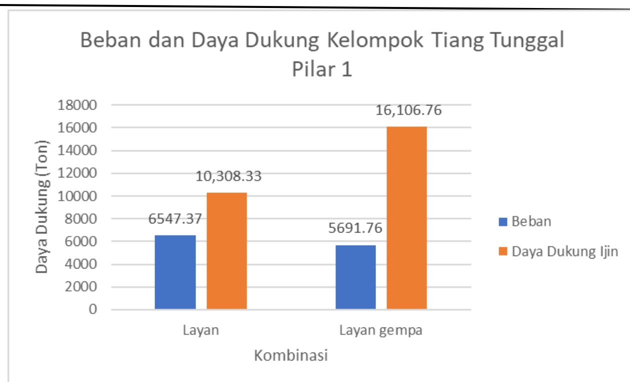


**Figure 4. Graph of Load and Carrying Capacity of Pillar Group Pillar Group 1 Based on the Results of Calculations**

## a. Abutment 2

Based on the modeling results using Midas Civil software and with loading according to the load calculation above, the maximum axial force of a single pole that occurs in the combination of the service is 179.22 tons and the combination of the earthquake service is 216.35 tons. Based on the Detail *Engineering Design* (*DED*) drawings, the length of *the Bored Pile* planned in *Abutment* 2 is 15 meters or equivalent to a depth of 20 meters, from the results of the calculation of the carrying capacity of a single pole at a depth of 20 meters, the carrying capacity of a single pole permit is 153.48 tons in service conditions and 239.81 tons in earthquake conditions as shown in the graph below.

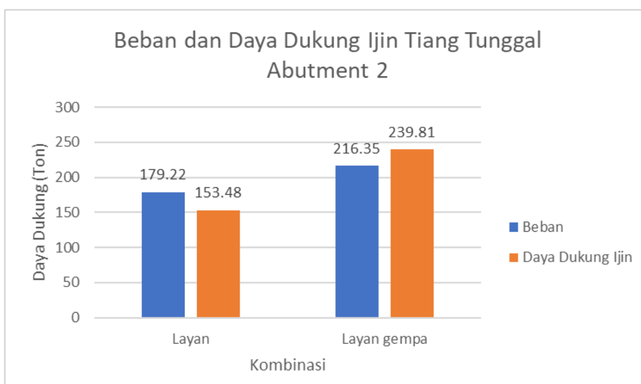


**Figure 5. Load and Bearing Capacity Chart of Single Pole Abutment 2 Based on DED**

So it can be concluded that the *Bored Pile* foundation with a length of 15 meters, namely at a depth of 20 meters, is not able to withstand the axial force that occurs, so *the Bored Pile* must be extended to a depth of 24 meters with a *Bored pile length* of 18 meters which has a single pole carrying capacity of 187.32 tons in service conditions and 292.69 tons in earthquake conditions with a total of 4 x 13 piles.

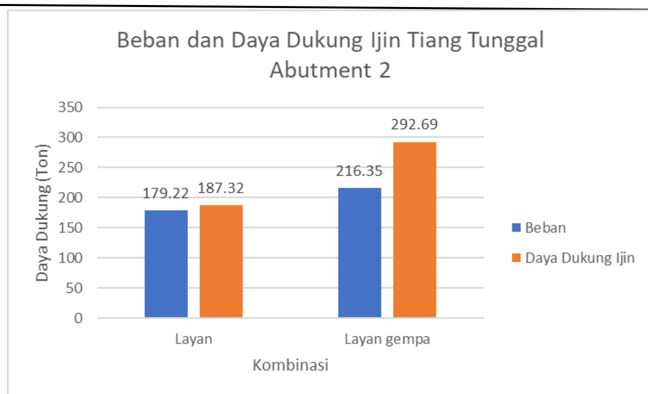


**Figure 6. Graph of Load and Carrying Capacity of Single Pole Abutment 2 Based on Calculation Results**

In addition to single poles, it is also necessary to review the maximum axial force in the pile group, the maximum axial force of the pile group that occurs in the combination of lays of 5667.83 tons and the combination of earthquakes of 5211.95 tons. From the carrying capacity of a single pile, the carrying capacity of the pile group is calculated based on *The Bridge Specifications of AASHTO* which suggests to estimate the efficiency value of the pile group adopted from the proposal made by *Converse-Labarre* (Bowles, 1988).

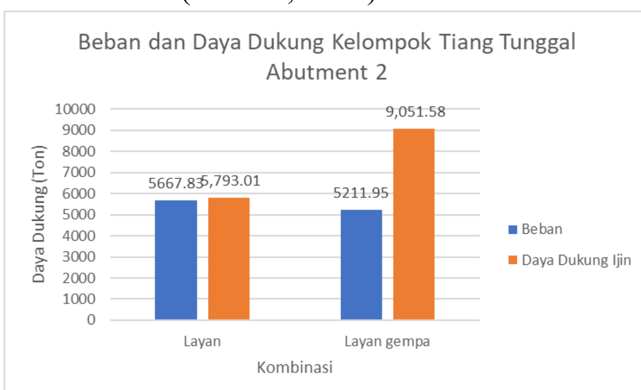


**Figure 7. Graph of Load and Carrying Capacity of Abutment Pole Group 2 Based on the Calculation Results**

## Calculation of Additional Implementation Costs

### a. Pillar 1

The additional implementation cost for *bored pile* work is Rp. 15,105,536,100.00 or an increase of 345.40%. More details can be seen in the chart below.

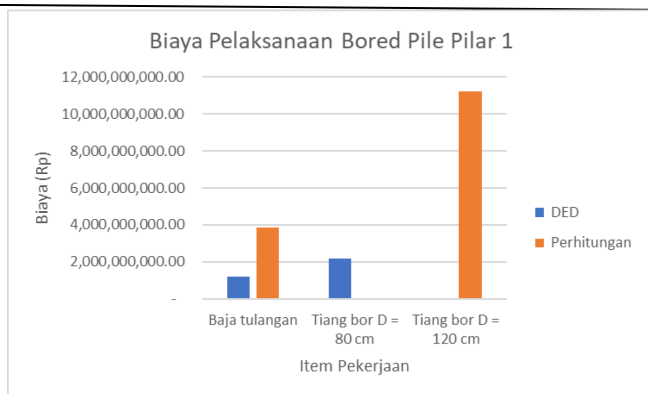


**Figure 8. Chart of Bored Pile Pillar 1 Work Implementation Cost**

From the value of the implementation cost, there was an increase in the implementation cost of 69.60% or Rp. 1,386,822,663.42. So it can be seen as shown in **Figure 9.** next:

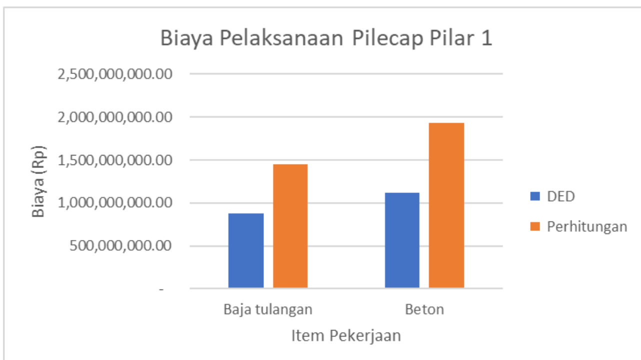


**Figure 9. Pile Cap Pillar 1 Implementation Cost Chart**

Meanwhile, the implementation cost based on the calculation has increased by 41.99% or equivalent to Rp. 2,327,293,140.25 as seen in **Figure 10** below.

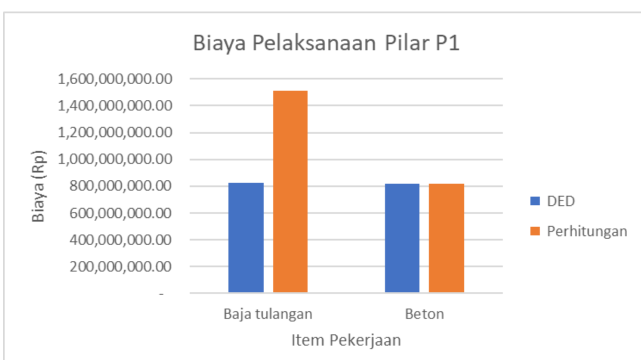


**Figure 10. P1 Pillar Implementation Cost Chart**

Meanwhile, the implementation cost from the calculation results increased by Rp. 144,503,784.03 or by 13.87%. More details can be seen in **Figure 11** below

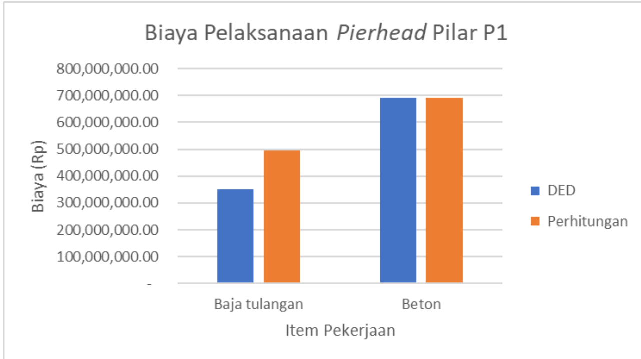


**Figure 11. Pierhead Pillar 1 Work Implementation Cost Chart**

## a. Abutment 2

The additional implementation cost for *bored pile* work is Rp. 815,677,577.43 or an increase of 19.85% so that the following graph is obtained:

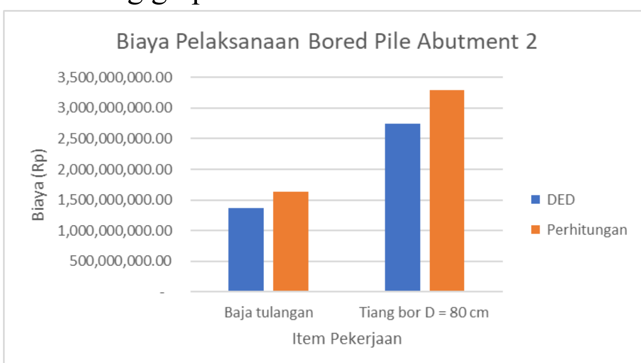


**Figure 12. Bored Pile Abutment Work Implementation Cost Chart 2**

Meanwhile, the implementation cost from the calculation results increased by Rp. 394,250,967.96 or by 25.95%. More details can be seen in **Figure 13**.

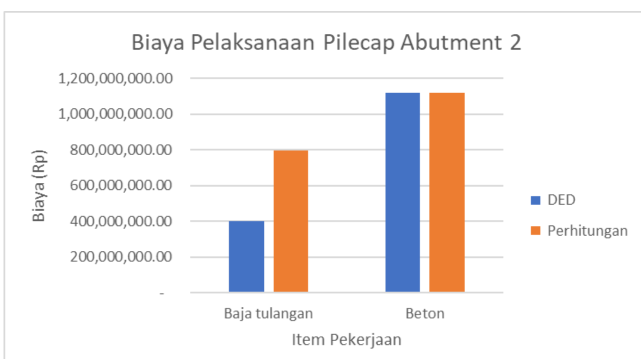


**Figure 13. Chart of Pilecap Abutment Work Execution Cost 2**

Meanwhile, the implementation cost based on the calculation has increased by 1.86% or equivalent to Rp. 36,740,126.25 as seen in **Figure 14.** below.

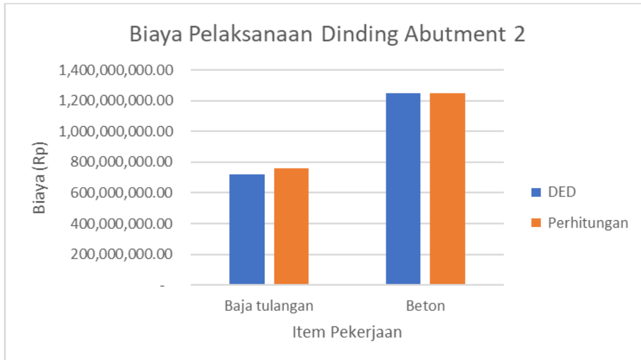


**Figure 14. Abutment Wall Work Execution Cost Chart 2**

## Conclusion

This study investigates the impact of *kelas tanah situs* (soil site class) on bridge construction costs for the Probolinggo–Banyuwangi Section 3 toll road, focusing on the relationship between soil type and the financial implications for bridge foundation design. The results revealed significant variations in *kelas tanah situs*, such as at *Pier 1*, where the soil shifted from medium to soft, requiring a foundation redesign. This led to a 345.40% increase in implementation costs for *bored pile* work at *Pilar P1* (Rp. 11,714,051,147.25), a 19.85% increase at *Abutment 2* (Rp. 815,677,577.43), and other cost increases in *pilecap* and *pilar* work. These findings underscore the necessity of considering *kelas tanah situs* in early infrastructure planning to ensure structural stability and optimize project costs. The implications of this study suggest that accurate soil assessments are crucial for effective budgeting and project execution in large-scale infrastructure projects, potentially saving costs in the long term by addressing soil-related issues early in the design phase. To mitigate cost increases, further studies should focus on optimizing *soil treatment* techniques and adjusting project planning to account for variations in soil conditions.

## 5. References

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