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# ANALYSIS OF SUBGRADE STRUCTURE SETTLEMENT ON THE JAKARTA BANDUNG HIGH-SPEED RAILWAY PROJECT

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**ABSTRACT:** The construction of the Jakarta-Bandung high-speed railway in Indonesia faces significant challenges due to high settlement rates. Geodetic studies conducted by the Bandung Institute of Technology (ITB) reveal that Bandung experiences some of the fastest and most extensive land subsidence globally, with rates varying from 8 to 23 cm per year across the region. These substantial subsidence rates critically affect the stability of subgrade structures along the railway route, necessitating a comprehensive analysis of foundation performance to predict settlement during construction and operational phases. This study employs PLAXIS software to simulate settlement under three foundation scenarios: CFG pile foundation, spun pile foundation, and without foundation. Settlement results are also compared against abutment construction using a bored pile foundation. The analysis indicates that the spun pile foundation achieves the lowest settlement rate and total settlement. These findings provide a valuable reference for mitigating structural subsidence and optimizing foundation design in high-subsidence areas.

*Keywords: Settlement, Bandung Region, PLAXIS Software, Soil and Ground Treatment, Consolidation*

## 1. INTRODUCTION

The Jakarta-Bandung high-speed railway spans 141 km and comprises two primary structural types: bridges and subgrades. To accelerate bridge construction, girder erection is facilitated using specialized erector and transporter equipment, which transfers girders from production facilities to erection sites. These routes traverse both bridge and subgrade structures, potentially causing structural subsidence. It is imperative to assess this subsidence to identify and mitigate significant variations that could compromise the integrity and safety of the railway system.

The Jakarta-Bandung High-Speed Railway (HSR) adheres to stringent construction standards and technical requirements. Track smoothness is a critical determinant of operational speed, passenger comfort, and safety, all of which are essential for the project's success. Excessive settlement following track installation can disrupt the smoothness, leading to noncompliance with technical specifications and incurring repair costs that are often prohibitive or impractical. Consequently, analyzing and predicting settlement behavior during construction and operational phases is essential, necessitating a systematic evaluation of settlement and deformation prior to project implementation.

This study focuses on the geotechnical evaluation of subgrade #54, a section experiencing severe land subsidence located between STA 129+667 and STA 130+967. This section employs a spun pile foundation. The analysis also includes the abutment at STA 131+000, supported by a bored pile foundation. The bearing capacity evaluation relies on detailed engineering designs and soil investigation data to inform the analysis and ensure the structural integrity of the railway.

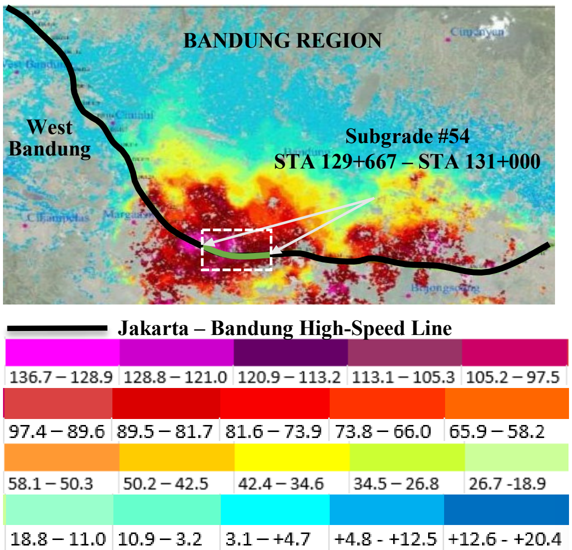



Fig.1 Settlement Map Monitored by InSAR (October 2014 – April 2017)

This study employs PLAXIS software to simulate soil conditions and properties using the E50 modulus approach, derived from soil investigation data detailing the characteristics and stratification of each analyzed section. The loading analysis includes calculations of dead loads exerted by structural components, beginning with the retaining walls, soil layers, and aggregates, and extending to simulations of the erector load and the operational load of the rail and locomotive. Simulations are conducted for each cross-sectional area following the determination of relevant soil parameters.

The structural response is evaluated under loading conditions during both construction and operational phases, incorporating three different foundation scenarios. Comparative settlement analyses are performed across cross-sections to identify differential settlement values. The foundation option yielding the lowest settlement magnitude and rate is deemed optimal. These findings inform the selection of a foundation type that effectively minimizes settlement while ensuring structural integrity.

## 2. RESEARCH SIGNIFICANCE

This study serves as a reference for determining foundation structure models based on the geographical soil conditions characterized by extremely high settlement levels. This concern arises from the significant potential for differential settlement spanning STA 129+667 to STA 131+000. Given the maximum train speed of 350 km/h, differential settlement of the high-speed rail structure poses substantial risks. The primary objective of this study is to predict the rate and total settlement up to the operational period, which can be utilized as an early warning system and a basis for future remedial actions.

## 3. RESEARCH METHODOLOGY

### 3.1 Soil Classification

This study examines subgrade #54, located between STA 129+786 and STA 130+967, along with the abutment at STA 131+000. Soil testing points are strategically distributed at 100-meter intervals within the construction area to provide comprehensive geotechnical data, ensuring a thorough understanding of the soil's properties and behavior across the project site. Transition modeling for the abutment at STA 131+000 is informed by test results from STA 130+969, ensuring accuracy in the analysis and helping to predict potential settlement behavior in the transition zone.

Settlement analysis uses PLAXIS 2D V.20 software, utilizing parameters derived from laboratory-calculated N-SPT (Standard Penetration Test) values. To streamline the PLAXIS soil structure modeling process, the original N-SPT data is simplified by consolidating similar soil types into single layers with uniform properties. Additionally, soil layers with a thickness of less than 1 meter are integrated into adjacent layers, as their impact on settlement is deemed negligible. This approach significantly enhances the efficiency and accuracy of the settlement predictions, thereby facilitating better decision-making during the design and construction phases.

### 3.2 Load Classification

The loading analysis is based on the dimensions of the girder transporter (erector), which is used to transport girders with a length of 32.7 meters during the erection phase. The loading process is divided into two stages: construction and operation. The construction stage represents the load applied to the subgrade and Spun Pile foundations during the building phase.

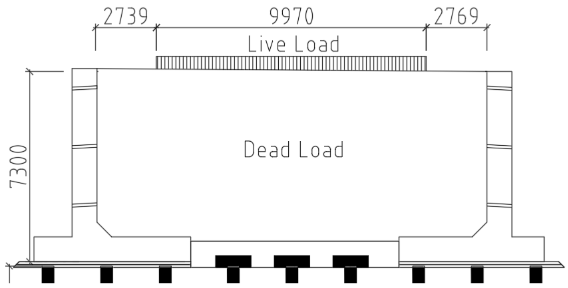



Fig.2 Force diagram of train live load

### 3.3 Operational Structural Requirements for High-Speed Railway

Ensuring safety aspects is important during operations, including structural degradation, both in general and differential settlement. Below are the requirements for the settlement of high-speed railway structures.

Table 1. Criteria on control over the post-construction settlement of ballasted track subgrade

| Design speed (km/h) | General section (mm) | Transition section (mm) | Settlement rate (mm/y) |
|---|---|---|---|
| 200 | ≤150 | ≤80 | ≤40 |
| 250 | ≤100 | ≤50 | ≤30 |
| 300, 350 | ≤50 | ≤30 | ≤20 |

*Source: B 10001-2016 Code for Design of Earthworks and Track Bed for Railway.*

Table 2. Criteria on control over post-construction settlement of bridge pier (abutment) foundation

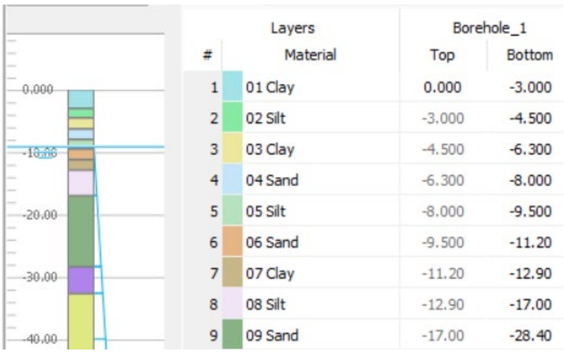
| Design speed (km/h) | Ballasted track (mm) | | Ballast less track (mm) |
|---|---|---|---|
| | 200km/h | 250-250km/h | |
| Uniform settlement of pier (abutment) | ≤50 | ≤30 | ≤20 |
| Differential settlement between adjacent piers (abutments) | ≤20 | ≤15 | ≤5 |

*Source: B 10001-2016 Code for Design of Earthworks and Track Bed for Railway.*

## 4 RESEARCH PROCEDURE

### 4.1 Soil Formation and PLAXIS Parameters

The soil layers and groundwater levels obtained from laboratory results are simplified and arranged in sequence according to their respective depths.



| # | Layers Material | Borehole_1 Top | Bottom |
|---|---|---|---|
| 1 | 01 Clay | 0.000 | -3.000 |
| 2 | 02 Silt | -3.000 | -4.500 |
| 3 | 03 Clay | -4.500 | -6.300 |
| 4 | 04 Sand | -6.300 | -8.000 |
| 5 | 05 Silt | -8.000 | -9.500 |
| 6 | 06 Sand | -9.500 | -11.20 |
| 7 | 07 Clay | -11.20 | -12.90 |
| 8 | 08 Silt | -12.90 | -17.00 |
| 9 | 09 Sand | -17.00 | -28.40 |

Fig.3 The soil formation and groundwater table STA 130+980

Meanwhile, the soil parameter used is Eref50, which is calculated from the N-SPT values using the following equation:

$$E_{oed} = E_{oed}^{ref}\left(\frac{c\cot\varphi+\sigma_1}{c\cot\varphi+p^{ref}}\right)^m \quad (1)$$

$$E_{50} = E_{50}^{ref}\left(\frac{c\cos(\varphi)-\sigma_3\sin(\varphi)}{c\cos(\varphi)-p^{ref}\sin(\varphi)}\right)^m \quad (2)$$

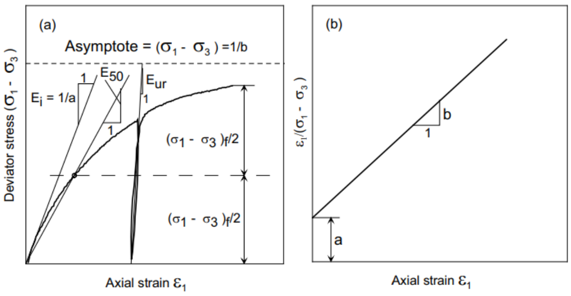



Fig.4 (a) Hyperbolic Stress-Strain Curve and (b) transformed hyperbolic stress-strain curve
(Source: Hans-Georg Kempfert and Berhane Gebreselassie "Excavation and Foundation in Soft Soils")

### 4.2 Structure and Loading

After modeling the soil formation and defining the parameters, the next step is to consider the structural components, such as Cement-Fly Ash Gravel (CFG) piles, spun piles, and pile caps, for soil reinforcement. The CFG pile utilizes a material with a compressive strength (fc') of 40 MPa, with a diameter of 40 cm and a length adjusted to the required design depth. The spun pile also has a 40 cm diameter, with a standard length of 8 meters. For design depths exceeding 8 meters, the spun piles are connected by welding to achieve the necessary depth.

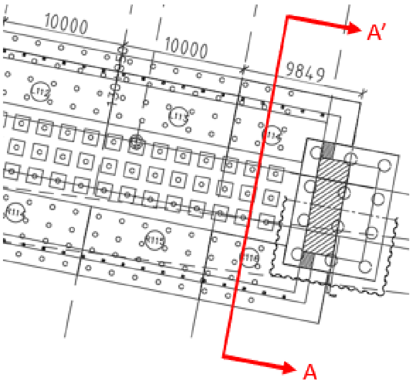



Fig.5 The Arrangement of Spun Piles and Pile Caps for Subgrade #54 at STA 130+962

Figure 5 shows a spun pile formation layout from the general drawing of the subgrade at STA 130+900 - STA 130+967 (Abutment). A cross-sectional image (A-A') is made at the intersection between the subgrade and the abutment as follows.

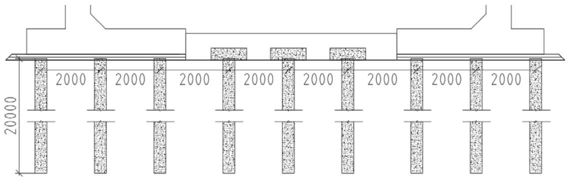



Fig.6 Cross Section A – A' 20 meters depth of the Spun Pile or CFG Pile with a spacing of 2 m

Table 3. Spun pile specifications

| Specifications | |
|---|---|
| Size (mm) | 400 |
| Thickness (mm) | 75 |
| Cross Section (cm$^2$) | 765.76 |
| Unit Weight (kg/m) | 191 |
| Class | A2 |
| Crack* (ton.m) | 5.50 |
| Break (ton.m) | 8.25 |
| Allowable Compression (ton) | 121.10 |
| Decompression Tension (ton) | 38.62 |
| Length of Pile (m) | 6 – 14 |

(*Source: Spun pile WIKA Beton catalogue*)

The end bearing and side friction resistance of the Spun Pile are calculated by using the following table, which incorporates soil properties and pile dimensions.

Table 4. End Bearing Capacity Calculations of Spun Pile

| End Bearing Capacity | |
|---|---|
| fc' (MPa) | 52 |
| E (kN/m$^2$) | 4700 (fc')1/2 |
| | 33892181.99 |
| D (m) | 0.4 |
| Fmax (kN) | 1187.991 |

Table 5. Axial Skin Resistant Parameter Spun Pile

| Axial Skin Resistant Myerhoff (1976) | |
|---|---|
| Pa | (qc x Ap)/ SF1 + Σi (li x fi x Ast)/SF2 |
| qc (N) | End bearing resistance |
| Ap (m) | Cross-sectional perimeter |
| li (m) | Length of the segment |
| fi (t/m) | Shear force on the pile |

Table 6. Parameter of qc, fi, safety factor 1 and 2

| | Sand | Clay |
|---|---|---|
| qc (N) | 40 | 25 |
| fi (t/m) | 10 | 12 |
| SF 1 | 3 | |
| SF 2 | 5 | |

Meanwhile, the CFG Pile's end-bearing capacity is calculated using the following table.

Table 7. End Bearing Capacity of CFG Pile Calculations

| End Bearing Capacity of CFG Pile | | |
|---|---|---|
| fc' | 40 | MPa |
| E | 4700 (fc')1/2 | MPa |
| | 29725.41001 | MPa |
| | 29725410.01 | kN/m$^2$ |
| d | 0.4 | m |
| Fmax | 902.52 | kN |

The pile cap on the subgrade has the exact dimensions, 1.2 m x 1.2 m, with a thickness of 0.4 m at each end of the Spun Pile. There are connectors between the ends of the Spun Pile and the pile cap to ensure that the structure can withstand longitudinal loads during train operation. The calculation of bending stiffness (EI) and axial stiffness (EA) can be calculated in the following table.

Table 8. Flexural Stiffness and Normal Stiffness Calculations of Spun Pile.

| EI and EA of Spun Pile | | |
|---|---|---|
| c | 25 | MPa |
| E | 23500000 | kN/m$^2$ |
| h | 0.4 | m |
| b | 1.2 | m |
| EI | E x (h3 x b) / 12 | |
| | 150400 | |
| EA | ; E x h x b | |
| | 11280000 | |

The abutment structure comprises bored piles, pile caps, abutment bodies, and girders. It features a bored pile foundation with a diameter of 100 cm and a depth of 35.5 meters. The pile cap supporting the abutment is 10.4 meters by 7.4 meters and 2 meters thick. It is supported by 10 bored piles spaced at 2.8-meter intervals.

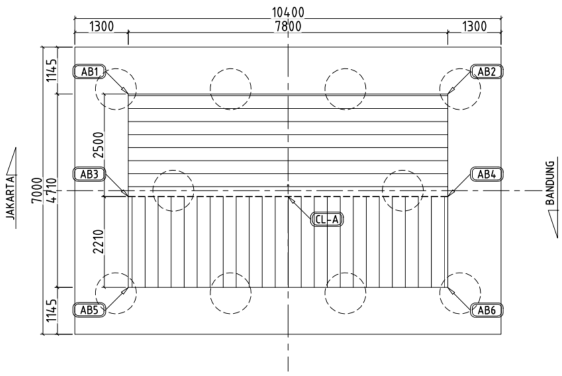



Fig.7 Layout Design for Abutment STA 131+000 (*Source: General drawing of bridge and abutment structure)*

Due to the lack of axial side resistance in bored piles, only the bored pile's end-bearing resistance (cone resistance) is calculated.

Table 9. End Bearing Capacity of Bored Pile Calculations

| End Bearing Capacity of Bored Pile | | |
|---|---|---|
| fc' | 40 | MPa |
| E | 4700 (fc')1/2 | |
| | 29725.41 | MPa |
| | 29725410 | kN/m$^2$ |
| d | 1 | m |
| Fmax | 8605.41 | kN |

Table 10. Flexural Stiffness and Normal Stiffness Calculations of Pile Cap

| EI and EA of Pile Cap | | |
|---|---|---|
| fc' | 45 | MPa |
| E | 3.20E+07 | kN/m$^2$ |
| h | 2 | m |
| b | 10.4 | m |
| EI | E x (h3 x b) / 12 | |
| | 2.20E+08 | |
| EA | E x h x b | |
| | 6.60E+08 | |

### 4.3 Loading

In PLAXIS, the loading calculation is modeled based on the structure supported by the foundation and subgrade. For the abutment, the model includes the pile cap, abutment body, girder, track, and train. Conversely, the subgrade consists of the pile cap, retaining wall, filling materials (soil types A, B, and C), graded crushed stone, track, ballast, and train. During the construction phase, the dead load comprises all structural components above the subgrade, excluding the track and train. The live load during construction includes the erector and the girder being transported.

During the operational phase, the dead load is augmented by the track and ballast, which contribute 20.53 kN/m². The live load during operation consists of the train load, which is 4 x 250 kN.

### 4.4 Stagged Construction

The calculation process is carried out in 4 phases: existing conditions, CFG Pile or spun pile, and pile cap installation; the construction period for the erection process lasts 180 days, and the last is operational loading.

## 5 RESEARCH DISCUSSION

### 5.1 PLAXIS Parameters

The determination of PLAXIS parameters requires calculations to obtain $E^{ref}_{50}$ using the following equation:

Table 11. PLAXIS parameters

| Soil | SPT | CPT |
|---|---|---|
| Sand (normally consolidated) | Es = 500(N+15) | Es = (2-4)qu |
| | 7000 √N | 8000 √qu |
| | 6000N | |
| Clayey sand | Es = 320(N+15) | |
| N55 = | 70/55 x N70 | |
| N70 = | N x µ1 x µ2 x µ3 x µ4 | |
| µ1 = | Average Energy Ratio (Er) | |
| µ2 = | Rod Length Correction | |
| µ3 = | Sampler Correction | |
| µ4 = | Borehole Diameter Correction | |
| Es = | 500 (N55 +15) | |
| q = | e1 x Es | |
| | 0.001 x Es | |

$$-q_f = (c\cot(\varphi) - \varphi_3)\frac{2\sin(\varphi)}{1-\sin(\varphi)}$$

$$q_a = \frac{q_f}{R_f}$$

$$-\varepsilon_1 = \frac{1}{E_i}\frac{q}{1-q/qa}\ for:\ q < q_r$$

$$E_i = \frac{2E_{50}}{2-R_f}$$

$q_f$ = Ultimate Deviatoric Stress
$q_a$ = Asymptotic Value of The Shear Strength
$R_f$ = Failure Ratio qf/qa (default $R_f$ = 0.9)

The calculation results show the parameters for the soil segments at STA 129+786, STA 129+886, and STA 130+769.

Table 12. Soil parameter of STA 129+786

| Depth (m) | General section (mm) | E (Kpa) Undrained | E (Kpa) Drained |
|---|---|---|---|
| 0 – 17.5 | Clay | 8207 | |
| 17.5 – 18.7 | Sand | | 19968 |
| 18.7 – 25 | Clay | 9036 | |
| 25 – 25.9 | Sand | | 16978 |
| 25.9 – 33.4 | Clay | 5574 | |
| 33.4 – 54.8 | Sand | | 10384 |
| 54.8 – 60.4 | Clay | 8818 | |

Table 13. Soil parameter of STA 129+886

| Depth (m) | General section (mm) | E (Kpa) Undrained | E (Kpa) Drained |
|---|---|---|---|
| 0 – 5.4 | Clay | 6262 | |
| 5.4 – 7.5 | Sand | | 15598 |
| 7.5 – 16.9 | Clay | 8523 | |
| 16.9 – 20 | Sand | | 19641 |
| 20 – 21.6 | Clay | 8050 | |
| 21.6 – 22.5 | Sand | | 16025 |
| 22.5 – 23.9 | Clay | 8374 | |
| 23.9 - 25 | Sand | | 17316 |
| 25 – 33.9 | Clay | 17669 | |
| 33.9 - 45 | Sand | | 12586 |

Table 14. Soil parameter of STA 130+967

| Depth (m) | General section (mm) | E (Kpa) Undrained | E (Kpa) Drained |
|---|---|---|---|
| 0 – 3 | Clay | 6458 | |
| 3 – 4.5 | Silt | 11491 | |
| 4.5 – 6.3 | Clay | 6063 | |
| 6.3 – 8 | Sand | | 17216 |
| 8 – 9.5 | Silt | 8506 | |
| 9.5 – 11.2 | Sand | | 27742 |
| 11.2 – 12.9 | Clay | 6694 | |
| 12.9 - 17 | Silt | 8309 | |
| 17 – 28.4 | Sand | | 11494 |
| 28.4 – 32.7 | Silt | | |
| 32.7 – 46.9 | Sand | | 9712 |
| 46.9 – 48 | Clay | 4062 | |
| 48 – 52.5 | Silt | 6532 | |
| 52.5 – 61.4 | Clay | 5968 | |
| 61.4 – 76.2 | Sand | | 8145 |
| 76.2 – 80.45 | Clay | 3627 | |

**5.2 Load Calculation**

The structure's loading calculation is based on its volume and density. In PLAXIS, loads are represented as pressure (kN/m²), meaning the load applied to the foundation is distributed over its area. For the subgrade, the area is determined based on the dimensions of the erector (19 m x 32.7 m), while for the abutment, the area is calculated based on the dimensions of the pile cap (10.7 m x 7 m).

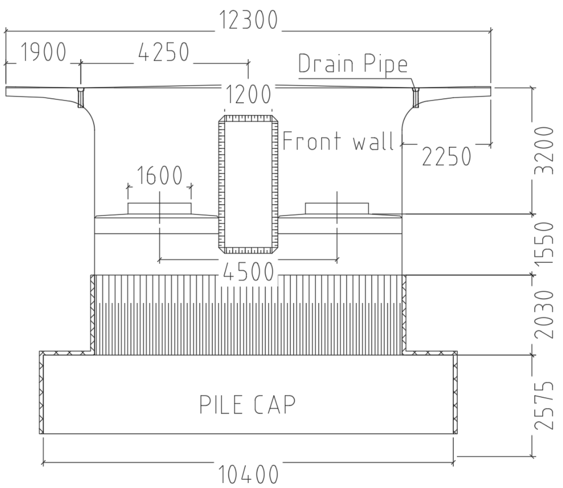



Fig.8 Front View of Abutment STA 131+000

Figure 8 shows the front view of the abutment structure. The calculation of the abutment dead load is based on the density and volumetric mass and the components contained in the abutment, such as piping, embedded stairs, and settlement monitoring. Figure 9 shows the side view of the abutment.

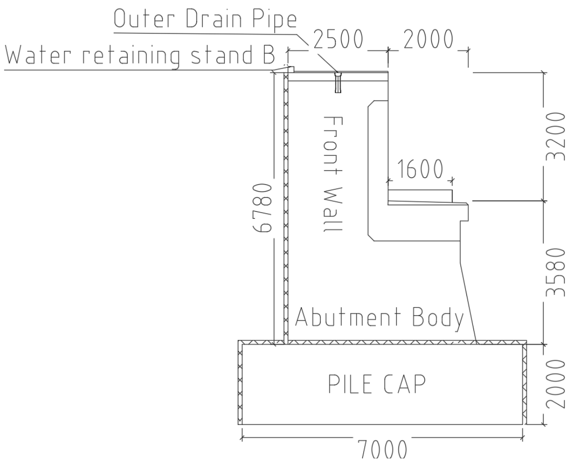



Fig.9 Side View of Abutment STA 131+000

Table 15. calculation of the load received by the abutment by the transporter and girder

| Abutment Calculations | | |
|---|---|---|
| Concrete Density | 2548.42 | kg/m³ |
| Pile cap | | |
| T | 2 | m |
| L | 10.18 | m |
| W | 7 | m |
| Volume | 142.52 | m³ |
| Body | | |
| Area | 21.5286 | m² |
| L | 7.8 | m |
| Volume | 167.9231 | m³ |
| Volume total | 310.4431 | m³ |
| Weight Abutment | 791139.3 | kg |
| Girder | 1027.46 | kg |
| W total | 792166.8 | kg |
| Area | 36.738 | m² |
| Load | 211.5291 | kN/m² |
| Track | 20.5 | kN/m² |
| DL | 232 | kN/m² |
| Transporter | 900 | ton |
| Girder | 1027.46 | ton |
| | 963.73 | ton |
| Area | 32.448 | m² |
| LL | 291.4 | kN/m² |
| ϒ /sat | 17 | kN/m³ |
| ϒ concrete | 25 | kN/m³ |
| w | 16 | kN/m³ |
| v | 0.15 | |

Table 16. Calculation of the load received by the subgrade section per 32.7 m by the transporter and girder

| Subgrade Calculations | | |
|---|---|---|
| Concrete Density | 2400 | $kg/m^3$ |
| Gravel Density | 1920 | $kg/m^3$ |
| Cantilever Wall Area | 18.73 | $m^2$ |
| Cantilever Length | 32.7 | m |
| Concrete Weight | 1469.9304 | ton |
| ϒ /sat | 17 | $kN/m^3$ |
| ϒ concrete | 24 | $kN/m^3$ |
| w | 2.8 | $kN/m^3$ |
| Cantilever Wall | 1469.93 | ton |
| Pilecap | 70.5 | ton |
| Group A, B, C | 2526.62 | ton |
| Group A, B | 1771 | ton |
| Graded Crushed Stone | 572.78 | ton |
| | 6410.83 | ton |
| Transporter | 900 | ton |
| Girder | 967.62 | ton |
| | 1867.62 | ton |
| Area | 618.03 | m2 |
| DL | 101.76 | $kN/m^2$ |
| LL | 29.64 | $kN/m^2$ |

Thus, the dead load value at section STA 129+780 is 101.76 $kN/m^2$, and the live load during construction is 29.64 $kN/m^2$. By using the formulas and equations provided, the results for each cross-section are as follows:

Table 17. Loading for each section

| Load ($kN/m^2$) | STA 129+780 | STA 129+880 | STA 130+960 | STA 131+000 |
|---|---|---|---|---|
| Dead Load | 101.76 | 85.78 | 130.10 | 232.0 |
| Live Load | 29.64 | 30.53 | 28.43 | 291.4 |

*Source: Code for Design of Earthworks and Track Bed for Railway, National Railway Administration, Beijing. 2016*

### 5.3 Spun Pile Bearing Capacity

The characteristics and soil structure in the Bandung area necessitate soil reinforcement through the use of spun piles and pile caps. The spun piles employed have a diameter of 40 cm, with a design length ranging from 8 to 20 meters. This variation in length depends on the load the piles are designed to support, as well as the soil's end-bearing capacity and frictional resistance. These reinforcement measures are critical to ensuring the stability and performance of the structures in the region.

Table 18. The axial skin resistance (ASR) of the spun pile at STA 129+780

| Depth (m) | Soil Classification | N-SPT | Pa (ton) | ASR (kN/m) |
|---|---|---|---|---|
| 0 – 2.4 | Clay | 125 | 7.17 | 70.36 |
| 2.4 – 5.4 | Clay | 400 | 11.72 | 114.98 |
| 5.4 – 7.5 | Sand | 525 | 15.89 | 155.92 |
| 7.5 – 10 | Clay | 745 | 24.38 | 239.17 |
| 10 – 11 | Clay | 650 | 25.71 | 252.18 |
| 11 – 16.9 | Clay | 792 | 41.67 | 406.79 |

Table 19. The ASR of the spun pile in each section

| Section | Depth (m) | ASR (kN/m) |
|---|---|---|
| STA 129+760 | 0 - 3.1 | 95.16 |
| | 3.1 - 4 | 127.44 |
| | 4 - 6.7 | 224.27 |
| | 6.7 - 11.4 | 305.82 |
| | 11.4 - 13.5 | 362.19 |
| | 14.9 | 472.76 |
| STA 129+880 | 0 - 2.4 | 70.36 |
| | 2.4 - 5.4 | 114.98 |
| | 5.4 - 7.5 | 155.92 |
| | 7.5 - 10 | 239.17 |
| | 10 - 11 | 252.18 |
| | 11 - 16.9 | 406.79 |
| STA 130+960 | 0 - 3 | 92.8 |
| | 3 - 4.5 | 200.2 |
| | 4.5 - 6.3 | 173.3 |
| | 6.3 - 8 | 292.6 |
| | 8 - 9.5 | 286.3 |
| | 9.5 - 11.2 | 472.1 |
| | 11.2 - 12.9 | 334.7 |
| | 12.9 - 17 | 467.3 |

### 5.4 Settlement Calculation

The structure's settlement is calculated and compared with and without soil reinforcement, including spun piles or CFG piles and pile caps in the subgrade structure. Significant settlement is observed when foundation reinforcement and pile caps are not used, leading to considerable elevation differences and potential long-term instability in the foundation. This results in dangerous differential settlement at the transition points, which can affect the overall performance of the structure. The maximum settlement and the variations in settlement across the structure are presented in the table below, offering crucial insights for further analysis and decision-making in the design process.

Table 21. The Value of Settlement for Each Section

| Settlement Condition (mm) | STA 129+760 | STA 129+860 | STA 130+960 | STA 131+000 |
|---|---|---|---|---|
| Without Foundation | 125.2 | 62.38 | 293.5 | |
| CFG Pile | 53.12 | 30.5 | 123 | |
| Spun Pile | 42.37 | 26.41 | 95.12 | |
| Bored Pile | | | | 133.5 |

Table 22. The Value of Differential Settlement for All Sections

| Differential Settlement (mm) | STA 129+760 – STA 129+860 | STA 130+960 – Abutment STA 131+000 |
|---|---|---|
| Without Foundation | 62.82 | 160 |
| CFG Pile | 22.62 | 10.15 |
| Spun Pile | 15.96 | 38.38 |

## 6 CONCLUSION

Based on the settlement results simulated by PLAXIS, it is concluded that the settlement values are drastic and highly variable when no foundation reinforcement, such as spun piles or pile caps, is applied to the subgrade structure. This leads to substantial differential settlement, with values exceeding the maximum allowable limit of 80 mm according to the standards for high-speed trains, posing significant risks during train operations. Therefore, soil reinforcement using Spun Piles or CFG Piles is essential. The lowest settlement value is observed with the use of Spun Piles. Consequently, Spun Pile foundations are selected for the subgrade structure to reduce drastic settlement and significant elevation differences in the transition structure (abutment), ultimately minimizing the risk of future repairs during operations.

## 7 REFERENCES


[1] Bowles, Joseph E., Foundation Analysis and Design, Third Edition, Mc. Graw-Hill Companies, Inc, New York, 1982, pp.39-43.

[2] Kempfert, Hans-Georg dan Gebreselassie, Berhane., Excavations and Foundations in Soft Soils, Springer-Verlag Berlin Heidelberg, 2006, pp.89-99.

[3] Mundrey, J.S., Railway Track Engineering Fourth Edition, 4th ed., McGraw-Hill Education, New York, 2010, pp.491-495.

[4] China Railway First Survey and Design Institute Group Co. Ltd, Code for Design of Earthworks and Track Bed for Railway, National Railway Administration, Beijing, 2016.

[5] Pratama, Ganjar Asandi Putra., Amornfa, Kamol., Soralump, Suttisak., Investigation of Differential Settlement of Pagoda Foundation Using 3D Finite Element Method, International Journal of GEOMATE, Jan., 2024 Vol.26, Issue 113, pp.10-18.

[6] Hamdhan, Indra Noer., Anugrah, R. Fitri Virliani., Nurhaliza, Sharah., The Effect of Soil Improvement Patterns Using Deep Cement Mixing (DCM) on Soft Soil Settlement, International Journal of GEOMATE, July, 2024 Vol.27, Issue 119, pp.120-126.

[7] Thach, Pham Ngoc., Comparing The Dynamic Response of Layered Ground to Different Trainloads, International Journal of GEOMATE, Sep., 2024 Vol.27, Issue 121, pp.33-40

[8] Nguyen, Ngoc Thang., Controlling The Settlement of The Low Embankment On Soft Ground By Surcharge Preloading Method, International Journal of GEOMATE, Aug. 2023, Vol. 25, Issue 108, pp.1-10.

[9] Campos, J., and de Rus., G. Some stylized facts about high-speed rail: A review of HSR experiences around the world, J. of Transport Policy, Vol. 16, No. 1, 2009, pp. 19-28.

[10] Purba, Aleksander, The Challenge of Developing High-Speed Rail Projects: Recent Evidence From Developing Countries, International Journal of GEOMATE, June, 2020, Vol.18, Issue 70, pp. 99 – 105.